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How Do We Help Students Build Beliefs That Allow Them to Avoid Critical Learning Barriers and Develop A Deep Understanding of Geology?

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Students hold a surprising number of ideas about the Earth's structure and process. This paper begins with a discussion on the nature of understanding in the conceptually confined domain of geosciences. There then follows a report on a study of the ideas about a range of concepts relating to "crystals", "volcanoes", "rocks", and the "Earth", held by eighth-grade students (13-14 years) in one middle school. Such patterns, described here as "alternative frameworks", can be used to inform our understanding of students' learning in earth science. If these alternative frameworks are not taken into consideration, they can represent "critical barriers" to learning in this domain in addition to other barriers identified in this research. The aim of this paper is to relate the students' alternative frameworks, the "critical barriers" that have been spotted and the possibilities of overcoming them. Several different recruitment strategies were used to collect data in order to get to know the students' alternative frameworks. The methodology of this study is based on two researches: a test of the Q-Sort and a paper–pencil test. Based on the results, some suggestions to help teachers and students avoid critical barriers that may be difficult to overcome later in their geological education are presented.

Keywords: Geosciences, Teaching, Learning, Barriers to Learning

INTRODUCTION

At the middle school level, the French National Science Education Standards require children to develop a scientific understanding of the Earth's materials and, logically therefore, of the Earth's structure that provides the context for such an understanding, and emphasize the importance of applying teaching methods that meaningfully engage students in earth sciences learning (B.O.E.N, 2005). 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. However, rather than address such ideas in isolation, research has suggested that a focus on the underlying frameworks or structures within which such ideas are embedded may prove more productive (Vosniadou & Brewer, 1992).

The goal of this study was to argue that children's ideas about concepts such as "crystal", "volcano", "rock", and "Earth", reveal broader patterns of understanding that provide a more informative guide for teachers to address than the consideration of such ideas in isolation. To do this, teachers would need to know not only what constitutes understanding in earth science, but also, if they are to employ a constructivist model of teaching and learning, how such underlying patterns of understanding can be identified and used to target strategies that better facilitate learning in this domain.

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STUDENTS' UNDERSTANDING OF GEOLOGICAL CONCEPTS

For the last three decades, there has been an increasing awareness of the importance of the variation among the ways students conceptualize and think about the phenomena they encounter in either science classes or in daily life (Gilbert & Watts, 1983; Driver et al. 1985; Osborne & Freyberg, 1985). Researchers in many countries have tried to respond to many important questions related to students' existing ideas, what the source of these ideas might be, how extensive they are, why they are so resistant to instruction, and what teachers can do to facilitate conceptual change (Astolfi, 1985; Driver & Bell, 1986; DeVecchi, 1994). Although extensive efforts have been made in physics, biology, and chemistry to identify students' existing ideas, research of existing ideas in the earth sciences has been more limited.

Understanding of the geological aspect of earth science is complex, not only because of the abstract nature of a number of its key foundation concepts (Ault, 1984), but also because it is multi-dimensional and hierarchical. In addition to understanding specific concepts such as "rock", "volcano", "magma", "crystal" or "Earth", it is also necessary to understand three different groups (structure, materials and processes) within which relevant individual concepts are embedded. For instance, a knowledge of the concept group relating to the Earth's structure would incorporate a knowledge of specific concepts such as "rock" and "bedrock", whereas a knowledge of the concept group processes would include knowledge of specific concepts such as "rock formation". This is essential for an understanding of the relationship among the three concept groups, which provides a holistic view of how the earth functions as a dynamics system: a process–product view of rocks described and classified on the basis of their origin within the rock cycle (Duff, 1993). Moreover, there are many kinds of understandings. One may provide the basis for a description of an event, whereas another does more and enables an explanation (Giordan & DeVecchi, 1987; Astolfi & Peterfalvi, 1993). Both descriptive and explanatory understanding come together in earth science to provide knowledge of essential attributes and link concepts with each other to structure scientific perception: a descriptive understanding of how these elements interact as part of a process-product-based system. In planning to support children's understanding in earth science, it is important for teachers to be informed not only of the content of children's prior knowledge, but also of the kinds of understanding such knowledge represents.

Research in Europe and the US has given us a detailed picture of children's understanding of the geological aspects of earth science:

- 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, and geological time (Bezzi & Happs 1994; Sharp et al. 1995; Russell et al. 1993)
- Geological time (Hume, 1978; Ault, 1982; Trend, 1998).

These studies confirm that children develop their own, mostly non-scientific, understanding of earth science 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 Earth's structure, processes and materials 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):

- Geological time;
- Large scale patterns in the environment and the physical changes they represent;
- Bedrock: its existence, scale and layering.

Research of children's existing ideas arises from a constructivist view of science learning (Driver & Bell, 1986; Vosniadou, & Brewer, 1992; Vosniadou, 1994). This view of knowledge posits that learning is a complex process in which instructional experiences interact with the learner's existing beliefs, experiences, and knowledge. Student learning always depends on what students bring to the classroom as well as the experiences they have there. If learners already have theories of how the world works, instruction must be structured to acknowledge and challenge these children's existing ideas (Osborne & Wittrock, 1985). Among a number of researchers (Vosniadou & Brewer, 1992; Vosniadou, 1994; Schnotz et al. 1999) there appears to be a general consensus over a number of important characteristics relating to these existing ideas, in that they are:

- Based on the individual's prior knowledge and experience of the world around them, which develops from birth;
- Personally-constructed views about the physical world which act as personal theoretical lenses and, as such, determine what, for us, counts as observation and what counts as inference;

- Different from the accepted scientific view of the same concept; and
- Resistant to change.

Opinion differs, however, as to whether these various scientific conceptions constructed in students' minds are to be referred to as "misconceptions", "preconceptions", "alternative frameworks", "children's science", or "preconceived notions" (Westerback et al. 1985; Marques & Thompson, 1997; Kusnick, 2002). If these terms are examined for similarities, they have almost the same meaning. In a comprehensive view of the field, Schnotz et al. (1999) defines alternative frameworks, which represent the transformation of students' ideas into knowledge structures or scaffolds determined by researchers. Consistent with this usage, in this paper, the term "alternative frameworks" is used to describe children's ideas about specific earth science concepts such as "crystal", "volcano", "rock", and "Earth", which is different from or inconsistent with the accepted scientific definition.

PURPOSE OF THE RESEARCH

Previous studies have tented to focus more on the investigation of single (or small clusters of) concepts such as rock, mountains or underground held by large numbers of children, rather than on the simultaneous consideration of a range of ideas about the Earth held by individual children and whether these reveal broader underlying patterns of understanding. This paper reports on a study that investigated the children's ideas about the concepts groups (structure and processes) such as "crystal", "volcano", "rock", and "Earth", held by individual children from eighth grade in one middle school in north-west France.

The research was constructed around the following three basic research questions:

- What are the students' alternative frameworks of these four concepts?
- By what means do they create critical barriers to learning?
- Under what conditions could these critical barriers be overcome?

Volcano, rock and the Earth are designated objects commonly studied in the eighth-grade curriculum and are explained in detail. The concept of crystal, on the other hand, is not presented in the same way and is seldom defined in the textbooks currently used in French middle schools. However, the crystal concept must be introduced at the same time as the study of the origin of rocks; if not, this study risks being reduced to a mere presentation of facts (Happs, 1982).

METHOD

The sample

The sample consisted of 120 eighth-grade students. A total of 120 students (13-14 years), of mixed ability and gender from a non-selective "fringe" inner-city middle school in north-west France were involved in the study.

Students' alternative frameworks were collected in the middle of the first term after the introductory lessons to geology and the study of the origin of a sedimentary rock observed during a field trip. The students had not yet studied the themes relative to the internal activity of the Earth (volcanism, seism …).

Instruments and data-collection procedure

In this study, several different recruitment strategies were used to collect data in order to learn about the students' alternative frameworks. The methodology of the study comprises two research: a Q-Sort test and a paper–pencil test.

The Q-Sort test was based on the format developed by Vérin and Peterfalvi (1985), which uses words to be put in relation with three concepts: Crystal, Volcano, Earth (see Appendix A). These words were chosen from a list of words collectively prepared with the geosciences educators in the middle school where the research was done. As these educators indicated during our inquiry, the chosen words had been frequently used by students in their previous assessments.

The paper-pencil test was used to provide more in-depth understanding of particular aspects of the Earth's structure and the Earth's functions. The paper–pencil test included three sections, which comprised drawings and open–ended questions (see Appendix B). These sections consisted of:

- A section on the students' advanced explanation concerning the release or the end of an eruption and the manner in which they portray a volcano (above-ground portion and underground portion);
- A question on the manner of portraying the interior of a crystal and a question asking the students to define a crystal;
- A question concerning the schematization of the relationships between volcanoes and the structure of the Earth. The children were asked to explain the global spread of volcanoes on the surface of the Earth and, in doing this, to represent the latter in cross- section. To ensure that the children understood this task and were able to conceptualise what a cross-sectional drawing

represented, an analogy with the inside of a pear was used. A pear was cut in half, and the children were asked to discuss, and then draw, a cross-section through the pear, labelling the parts.

The questions were selected from previous studies by different researchers (e.g., Bezzi & Happs 1994; Lillo 1994; Ford, 2005) and then adapted to a French context. The questions were phrased in such a way that they could be easily understood by the respondents. In addition, the questions were given to a group of eighth-grade students and teachers for comments on their readability. This process could better suit the question to the context.

A group consisting of geosciences educators was established to examine the validity and readability of the test. The group agreed that the questions could be used for the study's purpose. The group also commented that the question topics were within the range of the topics in the curriculum. In addition, the test questions selected from the related literature were validated in those studies. To examine how students visualise these concepts, we asked them to make drawings to explain their answers. 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 triangulated with information from other probes to provide a more complete "picture" of a child's understanding. This kind of instrument has been used by many researchers in the related literature (e.g., Happs, 1982, 1985; Lillo 1994; Blake, 2005).

The test was administered to one sample (120 students from Grade 8) over a period of two school days. Each section was completed in 30 minutes. The sample group were encouraged to respond to all questions to the best of their ability because their written explanations were very important to identify alternative frameworks.

Some researchers such as Kusnick (2002), Blake (2005), Ford (2005), preferred using numerical scores in their assessment and analysis procedure for statistical purposes. However, making a statistical analysis was not our aim. Rather, bearing in mind that students' errors do not consist of simple aberrations (Schnotz et al. 1999), we wanted to pinpoint the variety of students' identified alternative frameworks that represented "critical barriers" to children developing a scientific understanding in this domain. We defined and discussed in detail the most prevalent key "critical barriers" and made suggestions as to the origin of same in order to help teachers and students avoid these "critical barriers".

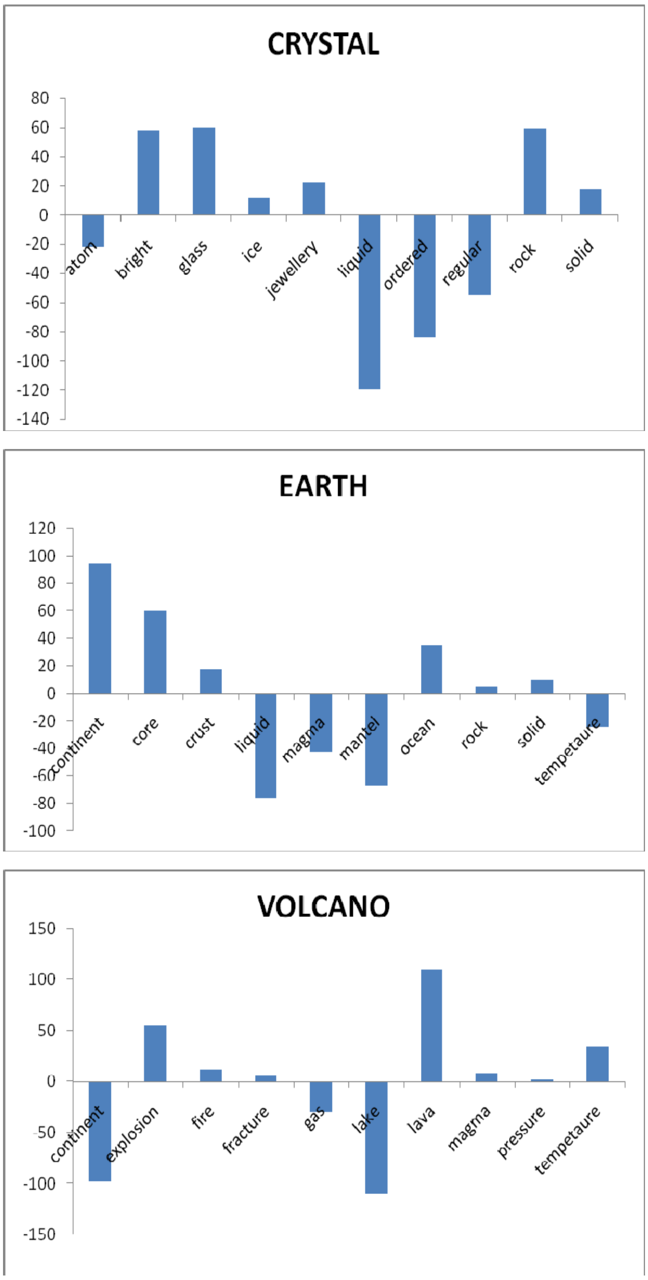

Figure 1. The answers given to of the Q-Sort test by 120 students.

RESULTS

Result from the application of the Q Sort test

In Figure 1 the values appear in an ordinate representation that corresponds to the strength of the agreement or rejection. These values were calculated in the following manner: a coefficient of "+2", "+1", "-1", and "-2" was given to each word and corresponded to "strongly associated", "roughly associated", "roughly rejected", or "strongly rejected", respectively. If they were neither specially associated nor rejected, the coefficient used was "0".

The advantage of such a presentation with positive and negative values is to be able to facilitate the visualisation of the distinctions between the words that are in agreement with the students' ideas and those that are rejected.The data are presented by concept.
These results call for the following comments:

Crystal

The "crystal" concept reminds many students of "jewellery" or of the idea of something "shiny", even "glass" (but then again, who has not seen or heard people talk about crystal glasses?). The same student approaches have also been found in a number of similar studies (Happs, 1982; Russell, 1993; Blake, 2005). The crystal-"rock" association is also frequent; this can be explained by the fact that this test was taken after the study of different crystalline rocks in the context of an introduction to geology. The crystal concept has sometimes been used as a replacement for the "grains" concept. "Solidity" is another characteristic that students associate with crystal (Happs, 1982; Vérin & Peterfalvi, 1985).

On the other hand, four words are strongly rejected; namely, "liquid", "regular", "atom" and "order". Similar to Happ's (1982), Vérin and Peterfalvi (1985) and Westerback et al. (1985, 1991) analysis in their articles, the rejection of the word liquid is apparently linked to the fact that the known examples of crystals are in a solid state. The rejection of the word "atom" is apparently linked to the fact that this word is not well known by students of this level, as they do not study it in physical science in the eighth-grade, and the cultural context of these students does not allow them to study this word. In short as eighth-grade students have rarely observed crystals, at this point in the year; how could they detect any regularity? Finally the idea of order, has no other echo than one of classifying without any connection to the idea of a particular organisational pattern.

Volcano

Regarding the idea of a "volcano", it is principally linked to the idea of "lava", "heat" and "explosion". This is similar to findings by Bezzi and Happs (1994), Sharp et al. (1995) and Marques and Thompson (1997). These associations occur without any commentary. It's the phenomenological aspect that is retained. Even though this test was given before any film presentation on volcanism, as many eighth-grade students had already seen short films on the subject on television, would this be due only to televised documentaries? A volcano is a mountain that gives off heat, produces explosions and throws out lava. The volcano-"fire" association is also quite frequent. It shows the impact of certain images in the description. Therefore, when we later asked the students to indicate the words that they immediately associated with the images seen after viewing a short film on a lava flow, they indicated the word embers as a characteristic key word for volcano. This association can also be obvious in the speeches of certain scientific popularisers under the title of metaphor (see Tazieff & Willemin (1994) in the program, The Fire of the Earth – 3rd episode). It is reinforced by the colour of the lava; the flames that we see as trees and dwellings burn on contact with a lava flow.

Similar to findings by Lillo (1994) and Sharp et al. (1995), the idea of "magma" is rarely linked to that of a volcano but this non-association is very unequal in the students' minds. Certain students confirm that they do not know this word. In contrast, other students remarked the presence of magma as the principal constituent of the globe by pointing out that they had heard of it in geography lessons. An inquiry with the teachers of this subject in the middle school where we did our research indicated that the word was generally cited in their classes. This signifies that the word magma was not integrated and remained at an anecdotal level.

On the contrary, the idea of "gas" and, to a lesser extent, that of "pressure" is hardly ever associated with that of a volcano. This is probably due to the absence of questioning on the mechanism of volcanic eruptions (Bezzi & Happs, 1994; Sharp et al. 1995), and for two related reasons:

- Gas and pressure are two concepts that will be broached later on in schooling;
- At this period in the school year, the concept of gas evokes a substance contained in a recipient (candy, candy box for example) and not a state of the material (Stavy, 1988); the concept of pressure is more in relation with pneumatics or meteorology than with the idea of movement (Abraham et al. 1994).

The apparent rejection of the words "lake" and "continent", is maybe due to the fact that these two words are less related to the eruptive aspect of volcanoes; hence, their lesser attraction.

The Earth

The results concerning the ideas related to the concept of the "Earth" indicate that this concept designates an entity difficult to specify: a globe formed of oceans and continents, with a core in its centre (an image of a cherry or a peach). Similar to Vosniadou and Brewer (1992), Lillo (1994), Marques and Thompson (1997) and Blake (2005), analysis in their articles, students principally make associations with directly-observable elements ("ocean", "continent", "rock"). We can therefore understand that "liquid" is an answer rarely associated with the Earth, even if it appears to contradict the answers of other questions of the paper-pencil test. If the interior of the Globe constitutes a liquid, it is invisible from the exterior; if it is a question of oceans or of seas, many students do not know that they form the largest surface of the globe. On the other hand, students reject "magma" and "mantle", as they are unequally known to them, not as the opposite of the concept of the Earth, but as non-associated answers to this concept.

The intention of such a Q Sort test is to have a rapid image of some associations among three key concepts of the curriculum and the ideas of a student population. However this test presents a few limits:

- The possible associations are limited;
- Certain words were unknown to the students;
- A part of the variation of the results comes from schooling differences. Certain students get a mental block when faced with such a test asking them to engage notions not yet officially broached in lessons; they feel vulnerable. Other students are not affected by this aspect, either because they consider this lack of knowledge natural, or because their past schooling has taught them not to be ashamed of their gaps (Vérin & Peterfalvi, 1985);
- Certain students do not understand the function of the test. They reject certain unknown words, not because they do not associate them with the key concept, but because they do not know them.

RESULTS FROM THE PAPER–PENCIL TEST

The first section: From lava to rock or the liquid-solid passage

From a valve-volcano to an inactive dry-volcano

The first two questions (see Appendix B) allow us to find out the way in which students imagine the interior of the Earth underneath the volcanoes, and could be subtitled: "Where do the lava (and the other products rejected by the volcano) come from?" The resultant representations are outlined below:

1. The drawings of volcanoes in relation with the interior of the Earth (the most numerous); "the interior of the Earth is liquid just as the lava is liquid". Two subsets can be spotted:

a. Similar to findings by Lillo (1994) and Sharp et al. (1995), volcanoes, generally in relation to an immense lake of underground lava (a conception recapturing that which prevailed at the beginning of the 20th Century at a scientific level (Gohau, 1987)): "lava comes from the Earth's magma (drawn just under the ground); it comes from underground rocks; lava is a molten rock coming from a reserve";

b. Similar to findings by Blake (2005), volcanoes in relation to the core (this being, at least a part of it, considered as a liquid, does not give the students any problems): "the lava comes from the core of the Earth that propels it outside; the lava comes from the heart of the Earth".

2. The drawings (very few) of volcanoes possessing a lava lake in the interior of the cone (a volcano like Mount Nyiragongo); whose origin is precise: "the lava comes from the bottom of the volcano" (an arrow indicates the lava lake drawn in the cone). The eruption is therefore just a simple overflow of lava in the manner in which milk overflows in a pan when we forget it on the hob: "lava is a molten rock coming from a volcano that overflows" (associated with a drawing of a cone containing lava).

3. Similar to findings by Happs (1982), a few descriptions of inactive dry volcanoes: they expel rocks that are formed on the walls of the volcano. By anticipating the following paragraph, the students do not ask themselves the question about the solidification of lava because, for them, the volcanic rock already exists.

Hardening or crystallization?

The third question (see Appendix B) was designed to know how the students foresee the liquid-solid passage, as it is, along with others, the object of the eighth-grade lessons. Three types of answers were produced:

1. The rejected basalt comes from the walls of the volcano (to be put in relation with the inactive dry volcanoes). We already mentioned the problem arising from this type of answer.

2. It is the cooling process that causes the solidification of the lava, the term solidification sometimes being replaced by that of hardening. The lava hardens as a mass…: "the rocks are formed with the lava that has cooled down on contact with the air; these rocks are created by the lava that hardens on contact with the air; it is the lava that has solidified". This type of response is similar to those found in other research on children's thinking (e.g., Westerback et al. 1991; Sharp et al. 1995; Ford, 2005).

3. It is by the drying process that the liquid is transformed into a solid: "the red (a volcanic bomb) formed itself by using bits of earth that rolled into the lava and then dried; they (the volcanic rocks) dried on the earth after an eruption; when lava dries it is in a block".

Nevertheless, it must be added that, in the last two types of answers, the phenocrysts of olivine and pyroxene in the rocks are compared to small stones, bits of earth or dust that the lava picked up on the way: "these heavy rocks are full of holes; there are bits of black and yellow stones". The same student responses have also been found in a number of similar studies (Happs, 1982; Russell et al. 1993; Dove, 1998). Therefore, these elements are not directly linked to the formation of volcanic rock: "while forming (the basalt), it picked up small stones on the way, which then integrated themselves into the rock".

The eruption mechanism

Questions 4 and 5 (see Appendix B) should allow us to find out what knowledge is mobilised by the students in their answers.

Similar to findings by Bezzi and Happs (1994), some sample examples are given below:

"The lava comes up because there is an eruption";

"The lava comes up because there is too much lava underground; therefore, not enough room and it overflows (the excess of lava comes from the ground or underground that melts from the heat)";

"The growing heat pushes the lava up";

"The lava is expelled by the gases";

"Two plates separate".

The end of the eruption is often simply the opposite phenomenon of that which caused the lava to rise.

After the questionnaire, similar to findings by Ault (1982), Happs (1982), Westerback et al. (1985), Bezzi and Happs (1994), Sharp et al. (1995), Trend (1998), it will be possible to formulate four types of students' alternative frameworks relative to the formation of volcanic rocks:

1. The transformation of lava into a rock is a simple phenomenon, even passive, we could say, within which the material becomes a block by solidifying, drying, freezing. The crystals do not exist as a result of crystallisation, as those that are visible are considered as dust. Crystal itself is not different from glass, meaning that everything that is solid has a resemblance;
2. A rock has no history because it has always been solid (or at least some of its constituents have);
3. Heat causes the lava to rise;
4. Lava rises because there is an eruption.

The second section: Crystal: A solid constituted of particles packed in a regularly ordered, repeating pattern extending in all three spatial dimensions or a composite object?

After analysis of the students' ideas relative to volcanism, in the second section, the objective was to get an idea of how they portrayed the structure of crystals (see Appendix B).

We must specify that these objects, as well as their chemical composition had already been broached at the beginning of the geology course and the particular structure of the matter had been studied in physics classes. Nevertheless, these notions are complex for eighth-graders, and there is a risk that this question may reinforce false ideas in the students' mind about the notion of a "molecule". On the other hand, the students had no knowledge whatsoever of the crystalline structure of ionic constituents. The principal objective of this question was to find out how they imagined the interior of two different crystals, which would explain the differences of form, and in particular, if they re-employed the idea of molecules (as particles that compose the material), by associating it with a particular disposition.

The analysis of the students' productions shows two principal types of answers (see figure 2).

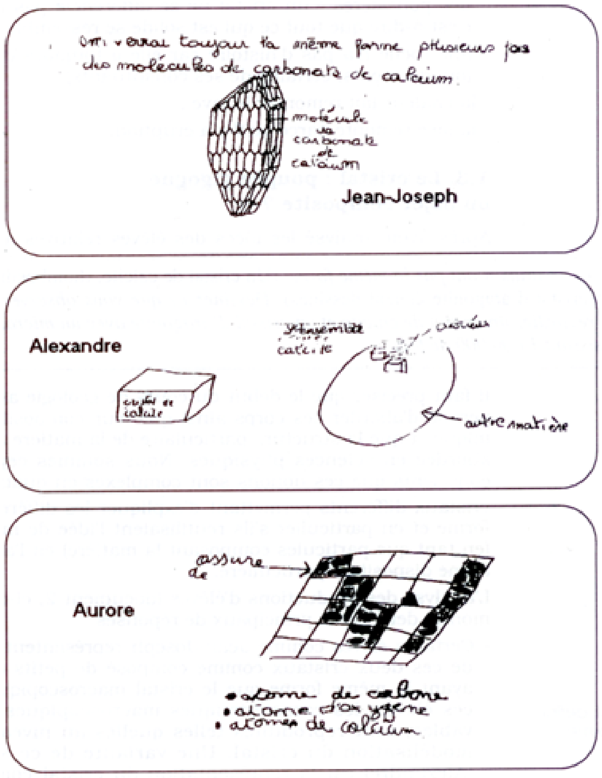

Figure 2. Students' answers indicating the structures of aragonite and calcite crystals.

- Certain students, like Jean, portrayed each crystal as though it were composed of small crystals having the same form as the macroscopic crystal. For these students, the macroscopic characteristics that we can observe are represented through a model of the crystal. A variant of the system (Alexandre) is the representation of the crystal as a whole, made of separate small crystals, sometimes by an intercrystalline material qualified as "another material".
- Other students, like Aurore, re-employ the idea that crystals consist of an assembly of small carbon, oxygen and calcium particles. Each assembly constitutes a motive, and the crystal appears as a regular repetition of motives.

The basic barriers to understanding (Ault, 1982) found are apparently the continuity between the macroscopic and the microscopic (cited as primitive perception in Vérin & Peterfalvi,1985 and Astolfi & Peterfalvi, 1993).

After research of the characteristics of a crystal in the Q-Sort test and previous question, here are a few of the students' answers to the question: "What is a crystal?" (see Appendix B) They show the resistances of preliminary conceptions.

"A crystal is a rock that can be transparent. "A crystal can have many colours". "A crystal is a rock that is usable in commerce";

"A crystal is a shiny material and has a geometric form. It, itself, has a geometric form. As soon as we break it, the pieces that form it still have the same geometric form as in the beginning";

"Crystal has a geometric form. It is shiny; we can see what is in the interior. If we break it, it will still have the same form. It must not be forgotten that crystal is a transparent stone".

There is an obvious juxtaposition of acquired concepts and old ideas (non-scientific, incomplete) that reside and make it difficult to select the characteristic traits of crystal.

The third section: The Earth: a globe with a peach structure

In the Third Section, the children were asked to explain the global spread of volcanoes on the surface of the Earth and, in doing this, to represent the latter in cross-sections (see figure 3).

The graphic representations done by the students are supplemental to the Q-Sort test results. There is an obvious coherence in the "alternative frameworks" raised. As found in previous studies (Lillo, 1994; Marques & Thompson, 1997; Blake, 2005), the terrestrial globe often appears to be composed of three parts: "the crust", "the core", and in between the two, a zone sometimes called "the mantle".

- The core is either a ball of fire (Marianne), or a reserve of lava (Marianne, Didier, Dimitri).
- The liquid mantle either consists of magma or lava, or of water.
- The crust's role is either to "protect" the Earth or to "prevent" the lava from leaking out.

Similar to the findings of Bezzi and Happs (1994), Lillo (1994), Sharp et al. (1995) and Blake (2005), volcanoes are in relation either with the core or with the mantle, the liquid nature of which is preponderant. The model of a "pressure-cooker", proposed by Didier, is interesting in this sense as the idea of a necessary pressure for the eruption is already present.

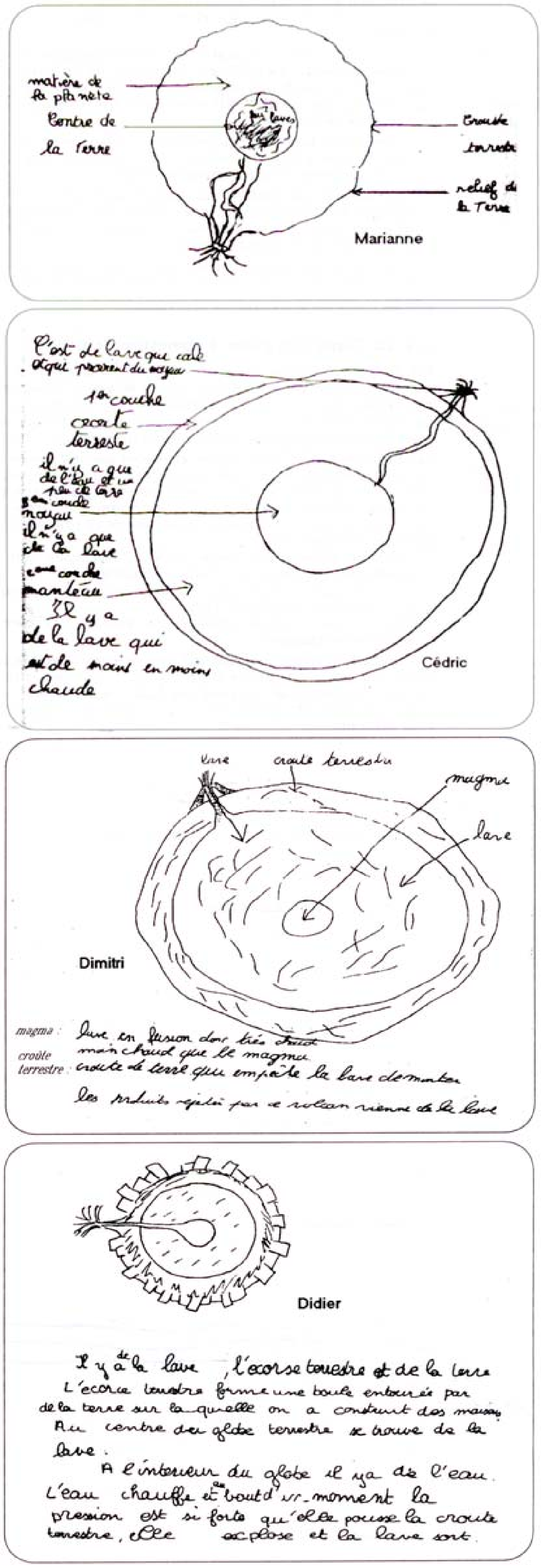

Figure 3. Examples of the students' drawings of the Earth's cross-section.

In addition, he added this commentary under his drawing: "In the interior of the Earth there is water. The water heats up and after a while the pressure is so strong that it pushes the terrestrial crust; it explodes and the lava comes out". This may be explained by the fact that this student has tried to describe volcanoes as a security valve of the Earth (see figure 3).

One of the barriers to learning that appears is the idea of the liquidity of the interior of the Earth, an idea reinforced in all the questionnaires in this study.

DISCUSSION: ANALYSIS OF BARRIERS LINKED TO STUDENTS' ALTERNATIVE FRAMEWORKS

The diverse alternative conceptions may basically be considered in two different ways:

- Either they constitute simple errors, linked to structural or abstract shortcomings, or even a lack of knowledge of basic concepts that we could correct with appropriate exercises (Astolfi & Peterfalvi, 1993; Vosniadou, 1994);
- Or they are critical barriers to learning, as they create ways of thinking that are not adapted to the situation. A change of style with an epistemological rupture is therefore necessary (Ault, 1982; Vosniadou & Brewer, 1992; Trend, 1998).

We must therefore deal with the barrier to learning in a manner that will enable the students to spot the difference between their own explanatory system and the new one, and suit it to their needs. We agree with Schnotz et al. (1999) when he writes "a child can only feel secure if he is certain of having understood what disconcerted him beforehand". To which more general and specific barriers to learning do these students' alternative frameworks correspond?

General barriers

"A student's alternative framework is an explanation or an interpretation, which, by its simplicity, asserts itself as evidence and prevents him from asking himself questions that would speed up the knowledge" (Driver & Bell, 1986). This description reminds us that the students' alternative frameworks are also critical barriers preventing the acquisition of a real motivation to learning. By motivation we mean "cognitive motivation" and not just a mere attraction. As Ault (1982), Astolfi and Peterfalvi (1993), Vosniadou (1994), Trend (1998) have suggested, overcoming identified barriers to learning is "the conceptual issue of learning".

These barriers are rarely isolated but often interact (Astolfi & Peterfalvi, 1993; Vosniadou, 1994; Blake, 2005), which means that they do not correspond to a single type of specific barrier, but to more general barriers. Dealing with such barriers can not be done simply and directly through a single geology lesson, because they are deeply rooted in the student's mind and this narrows the possibilities of eliminating them (Vosniadou & Brewer, 1992; Vosniadou, 1994; Trend, 1998). These barriers must be dealt with on different occasions, not only in biology-geology lessons, but also in other subjects (Astolfi & Peterfalvi, 1993; Vosniadou, 1994). We are therefore far from the very simple idea that a good explanation would permit the student to "rectify" his error.

The general barriers to learning that have been identified are of many natures, namely:

- Tautological barrier: The student is happy to repeat what he has seen, sometimes by integrating an explanatory link-word (because, as…) into his "explanation" (Astolfi & Peterfalvi, 1993): "The lava climbs up because the volcano erupts"; "A rock is a stone"; "A rock, a pebble…"
- Verbal barrier: The student finds it difficult to change the semantic style (Happs, 1982; Vosniadou & Brewer, 1992; Schnotz et al. 1999): "Glass is a fragile material, solid is the opposite of fragile". Because of this, students can not visualize a crystal as being solid.
- Artificial barrier: The student takes in what he observes as a result of man's actions, this then serves as his explanation (Happs, 1982; Kusnick, 2002; Ford, 2005): "The form of crystals (automorphes) is the result of cutting and is not natural"; "A rock is a decorative object"; "A crystal is a jewel".
- Absence of a causality relationship between the phenomena: The student is therefore happy to establish, the best he can, modern-day relationships (Vosniadou & Brewer, 1992; Sharp et al. 1995): "When there is an earthquake the volcano erupts".

Besides these barriers identified there are also those linked to non-adapted ways of thinking. For example; the categorical way of thinking is only a barrier to learning when it prevents the student from progressing (Astolfi, 1985; Driver & Bell, 1986; Schnotz et al. 1999). Just thinking of the material as three criteria classified as "solid", "liquid" or "gas" is not a problem in itself; it only becomes one when the student is not able to overcome these criteria in order to understand the issues relating to a vitreous or crystallised structure.

It is the same thing with primal perception. The students will try to interpret everything from what they see without thinking about changing the style (Happs, 1982; Astolfi, 1985; Schnotz et al. 1999). For these reasons, the following ideas can play the role of a barrier to learning:

"A crystal is composed of microscopic crystals";

"A crystal is a shiny material";

"A rock is a big stone and is coherent (meaning not composed of elements)";

"Crystallisation is a simple mass formation, drying process, i.e. green grains (in basalt) are dust, blocks of rock that the lava picked up on its way";

"A rock exists and has always existed";

"A solid rock can not be deformed";

"The interior of the Earth is a big liquid pocket".

These types of barriers to learning are not particular only to earth sciences, but can also be seen in different forms in other branches of sciences, as well (Gilbert & Watts, 1983; Driver et al. 1985).

Specific barriers: Students' alternative frameworks, a matter of cognitive functioning

For the barrier to learning to be overcome, the student must be ready to leave his ideas behind (Ault, 1982; DeVecchi, 1994; Blake, 2005). It is essential to know what students' alternative frameworks explain and what these alternative frameworks prevent them from understanding, as Astolfi and Peterfalvi (1993), Vosniadou (1994) and Schnotz et al. (1999) proposed. This work was carried out based on a few specific barriers encountered at different moments in this study.

Similar to findings by many researchers in the related literature (e.g., Bezzi & Happs, 1994; Lillo, 1994; Trend, 1998), in this study, the specific barriers to learning emphasised by these few students' productions can be grouped into three main generalisations.

- Crystals do not correspond to a precise organisation of the material;
- A rock does not have a history;
- The Earth has a liquid interior.

These three generalisations appear in one form or another through the lessons. Therefore, during the lesson where basalt was studied (within the context of the first questionnaire of the paper-pencil test on volcanism), the idea that the visible crystals in the rock are dust that the lava picked up on its way corresponds to the first barrier to learning as previously quoted. This enables these students to understand that the rock that they are observing is composed of a homogeneous mixture (the black part of the basalt) within which they see crystals (compared to dust) (Happs, 1982; Westerback et al. 1985; Russell et al. 1993). They therefore explain, in a few words, the way in which basalt is formed without this causing them a problem.

In the school textbooks (e.g., Tavernier, 2004; Périlleux & Thomas, 2005; Salviat & Desbeaux, 2005), a reflection of the teachers' way of functioning, this problem is presented in the form of a question:

- "How can the presence of crystal and glass in the same rock be explained?"
- "How have incandescent lava flows been able to give birth to this rock (basalt)? What are its characteristics?"
- "Do these observations allow for understanding how basalt is formed?"
- "What relationships can be established between the volcanic rock's structure and the two-timed rising of the magma?"

These questions are not real problems that put the students in a research situation, as they already have a solution. Furthermore, even though the description of basalt (black mixture and green dust) is inexact, we cannot say that the flowing lava does not pick up samples of the material present on the ground at that precise moment. This explanation will reinforce the students' alternative frameworks.

Nevertheless, for there to be a scientific problem, the students must realise that their explanatory system no longer functions (Gilbert & Watts, 1983; Astolfi & Peterfalvi, 1993; Vosniadou, 1994). Taking the chosen example, this explanation prevents the understanding that basalt, coming from the cooling down of the lava taken directly from a lava lake, is already composed of two categories of elements. The students' activity will therefore consist of the use of observations or experiments done in class to modify their point of view so as to eventually provoke a rupture with their original way of thinking (Westerback et al. 1985; DeVecchi, 1994; Vosniadou, 1994) and come to the idea that the crystals are formed by the slow cooling process of the lava. It will therefore be possible to put this in relation with the ordered structure of the particles. The advantage will be to finalise class work in relation to preliminary ideas.

This progress will require supplementary knowledge of the structure of the material and knowledge of crystal's properties in comparison with those of glass, for example.

Table 1 demonstrates the examples of an analysis of various barriers to learning by specifying the students' alternative frameworks, what the students' alternative frameworks help explain, what these alternative frameworks prevent the students from understanding, and the final idea that the teacher is seeking to teach.

The Concept: A conceptual level evolved in comparison to the student's alternative frameworks

Students always retain their first alternative frameworks regardless of what follows, and this is why they should learn how to use the right style at the right moment (Gilbert & Watts, 1983). Based on this supposition, finding the location of pertinent clues within the situation will therefore enable the student to correctly explain and anticipate the rest of the problem (Astolfi, 1985).

Table 1. Examples of an analysis of various barriers to learning

The students' alternative frameworks	*What the students' alternative frameworks help explain*	*What the students' alternative frameworks prevent them from understanding*	*The final idea that the teacher is seeking to teach.*
	The crystals do not correspond to a precise organisation of the material		
A (volcanic) rock is formed by drying up.	• The presence of crystals (considered as dust) is separated by glass	• A volcanic rock can be formed on the ocean bed as well.	• A volcanic rock might be formed at two stages: gradual cooling then rapid cooling.
Crystals are formed from small crystals with the same appearance from a macroscopic aspect.	• Different crystals have different structures. • Crystals have various planes. • Many crystals have a cleavage plane.	• Certain crystals have no cleavage.	• Crystals are made up of organized particles: this arrangement gives them their form.
Lava takes the form of a block as it cools. This is a passive phenomenon.	• Lava integrates the dust and small grains that it collects on its route within its fluid structure.	• Cooled liquid sulphur turns into crystal or glass. • There is crystal and glass in the rock which is formed upon the cooling of lava deep underground.	• The new structure of the lava that has become a rock by cooling occurs by the reorganization of particles.
	A rock does not have a history		
Rocks have existed forever.	• There are rocks dating back to ancient times. • Rocks have been used throughout history. • Rocks are inert objects.	• Not all the rocks have the same relative or absolute age.	• A rock belongs to history.
	The Earth has a liquid interior		
Lava comes from underground lakes forming the bedrock of the crust or Inside the Earth is a large pocket of magma.	• The materials ejected out of a volcano are liquid. • Continents drift independent of one another. • Plates change positions.	• In time, different lava combinations might be formed within the same volcano. • Different lava combinations might exist in volcanoes in different parts of the globe.	• Underground magma reservoirs exist independent of one another.
Lava comes from the core of the Earth.	• The core is liquid.	• Although the core is made up of iron nickel, volcanic rocks are composed of silicate.	• The formation of lava coming from magma starts from the crust or mantle.
Solid matter is not fluid.	• Rocks do not float on the surface of the Earth.	• The shapes of glaciers are distorted by the force of gravity. • The shape of glass may be changed without melting it. • Wax may change form without passing through a liquid phase.	• Under certain temperature and pressure conditions, rocks can change form without turning into a liquid state.
Matter is either solid, liquid or gas.	• Different types of matter can be classified according to their external appearances.	• Not all solid matter has a specific identity. • Although glass becomes liquid only after going through a phase of paste viscosity, crystals can directly become liquid without such an intermediary phase.	• Matter can be classified as having a crystallized and an amorphous structure.

Taking the example of the confusion "glass = amorphous structure in glass = window" (a confusion within which the choice of the semantic style used is wrong as the student has not thought about the structure of the material, but about the exterior aspect of the material). When the student must piece together the way a rock containing glass is formed in a conscientious manner or not, he must use another semantic style as noticing the process of glass being transformed into a window will not permit him to assemble this formation.

The student should verify what has changed in relation to what he was thinking (Vosniadou, 1994). This would mean, for the example above that he should be aware of the creation of a new style for the term "glass" and the necessity of using it when asked to think within the realms of geology.

We previously indicated that many eighth-grade students considered the olivine crystals, observed in basalt, to be "grains" coming from the wall of a volcano or picked up off the floor during the lava flow. The standard conceptual level which the teacher wants the student to grasp could be the following: "Macro-crystals are formed in the magmatic chamber" "Glass, which is a result of the lava quickly cooling down at the surface, then imprisons them". We can find such a conceptual level in many school textbooks (e.g., Tavernier, 2004; Périlleux & Thomas, 2005; Salviat & Desbeaux, 2005). This implies that these "grains" are expelled with the lava.

Yet the student runs the risk of not being able to differentiate between his original thought (that "olivine crystals are dust") and the superior conceptual level (expressed above). He will understand what he thinks is identical, knowing the presence of solid elements coming from the interior of the volcano, without seeing that, within his idea these elements have always existed, and therefore within the second conception they have a point of origin. The student is at a non-scientific level of the conception's structure (which would be a primitive stage of the concept) in comparison to the level of conception's structure envisaged by the teacher (which would be an evolved stage).

What relationships are possible between the critical barriers to learning and the geological objectives in the eighth grade?

A reminder of some of the aspects of the national curricula for France (B.O.E.N, 2005) related to magmatic rocks and the structure of the Earth:
"- A demonstration of the Earth's activity: the volcanism. Placement, structure of the rock, origin of the lava. Formation of the oceanic crust.

- The other manifestations of activity of the Globe: seism, deformation of the rocks.
- Continents, oceans, global structure.
- Global tectonics.
- The circulation of matter in the Globe: origin of metamorphic and magmatic rocks.
- Three rocks of a metamorphic series (layer, structure).
- A granite rock (layer, structure)".

If we situate the preceding analysis in relation to the titles above, the teacher's objective, in the eighth grade, could be to evolve the alternative frameworks of the students in relation to the three main types of barriers to learning that we have defined above:

- The crystals do not correspond to a precise structure of matter;
- A rock does not have a history;
- The Earth has a liquid interior.

Crystals do not correspond to a precise structure of matter

Students are often at a level that we have qualified as non-scientific. Crystals are not an object of geological study for them. They are a result of Man's work (shape, mould) (Happs, 1985; Dove, 1998); they are beautiful (shiny); and we find them in caves (Russell, 1993). It is the same thing with glass, which is nothing more than an industrial product, transparent, and used to fill windows while letting light in. It is necessary to remove this artificial idea from the student's mind.

Which conceptual level of glass does the teacher envisage? "A crystal is a solid formed by the slow cooling of a liquid or by precipitation from a solution". "Glass is a solid obtained by the rapid cooling of a liquid". A large margin separates the students' alternative frameworks from the conceptual level envisaged by the teacher. It seems difficult to make up for the gap, a difficulty so great that three barriers to learning interact amongst themselves:

- The difficulty of considering these two materials as different on a molecular scale;
- The difficulty of thinking that one same material (for example, liquid) can become crystal or glass by the cooling process;
- The difficulty of considering crystals as a class of objects with well-defined criteria.

The teacher's objective is therefore to remove these barriers to learning. The first barrier, based on the students' non-scientific level is the absence of questioning relative to crystals. It is reinforced by the idea that these objects are not part of an identifiable class by common characteristics (Vérin & Peterfalvi, 1985 and Westerback et al. 1985). We have stated the different persistent ideas on crystals and, unless these ideas are modified, the student will still continue to explain the presence of crystals in an artificial manner. One way to overcome this barrier could be to teach the student how to list the specific characteristics of crystals and those that distinguish them from other non-crystallised materials (glass; liquid; living beings). At an eighth-grade level these characteristics would be*:* "solid", "limited by the plane faces", "possessing planes of cleavage", "breaking while giving fragments of identical forms".

The difficulty of considering these two materials as different is reinforced by the fact that crystal and glass (hyaline quartz and windows, for example) can have the same appearance due to the verbal confusion between the two terms. In the expression glass in crystal, glass designates the object, and crystal designates the material. On the other hand, we have seen that by not distinguishing between the two concepts, the student is not able to explain the difference between breaking crystal (which generally gives identical geometric forms) and breaking glass (which results in irregular breaking). The teacher's objective regarding this barrier could therefore be to help the student become capable of explaining the difference between obtained forms. At this level, the conceptual level of the concept could be the following: "The form of crystals corresponds to a regular arrangement of particles of which it is composed (molecules in the eighth grade). The absence of form from the fragments of glass's characteristics corresponds to a disorderly arrangement of these particles". To be able to understand this, the student must know that material is formed from particles, that crystals are solids generally limited by plane faces, and often, contrary to glass, have planes of cleavage.

The difficulty of thinking that one same liquid can give either glass or crystal is reinforced by the idea that students regularly study these materials independently, one by one. They therefore don't get the chance to confront their origins. Also, this reinforces their ideas that they are different substances. During their schooling and everyday lives they have never had the opportunity to pay attention to this distinction. Overcoming this barrier supposes that the student has understood: that the structure of these two states of solid materials is linked to the precise organisation of the particles; and that we find the same particles in both liquids and solids, having observed examples of liquids, depending on the duration of the cooling process, giving the two types of structure. The visualised concept could be formed as following: **"**Crystals are a result of the slow cooling of a liquid that would result in glass if cooled rapidly".

A rock has no history

As before we once again come across a student's conceptual level that we could qualify as non-scientific: "rocks are a part of the landscape, just like rivers, trees, houses…" Students do not ask themselves questions about these inert objects that surround them. We can associate the following answers from students with this conceptual level:

- "We find rocks in fields";
- "A rock is a pebble, a stone, a boulder";
- "Mountains are made of rocks, and they are used for building houses and as a hiding place for animals".

This perceptive aspect that dominates is an aspect that does not provoke questions in the student's mind. It is *natural* and, so, "normal" for him to just see rocks around him (Happs, 1982; Dove, 1998, Ford, 2005).

Yet, what does the geology teacher want to accomplish? What the teacher wants to plant in the student's mind is the following idea: "Rocks have a structure and a precise layering that reflect the conditions in which the rock was formed". This conceptual level is then reviewed in the light of further rock studies (rocks from magmatic, sedimentary or metamorphic origin). If it is a rock from magmatic origin, we associate it with a cooling process separated into two sections of magma to the microlotic structure. If it's a rock from a sedimentary, crystallised origin, the precipitation and the deposit are from an over-saturated solution.

How do we advance from this non-scientific level, which often corresponds to the thought process of a student entering the eighth grade, to the conceptual level envisaged?

We have noticed two barriers to learning that are in opposition with this conceptual change, one of which has something in common with the previous study:

- The difficulty of considering rocks as a class of objects;
- The difficulty of considering rocks as the result of physical (change of state, deformation, precipitation) or chemical transformations, and the difficulty of considering the surface of the Earth, at an earlier period, as different from the one that we actually know.

The difficulty of considering rocks as a class of objects is reinforced by the current observations that echo the students' answers. Similar to findings by Happs (1982), Westerback et al. (1985), Blake (2005), also, many rocks are classed according to their construction material quality. On starting eighth-grade lessons, we notice that rocks are often considered on this bias. A way to overcome this stage would be to avoid focusing on the qualities or defects of the construction material, and instead offer an explanation of these properties from the structure of used rocks (Happs, 1982). Otherwise, we will remain on the side of the barrier that we thought had been overcome, meaning that the student has not progressed in relation to the idea that rocks are a "class of objects". At the eighth-grade level, the specific characteristics of the objects of this class could be the following:

- "Solids";
- "Non-living objects";
- "Constitute the Earth's underground";
- "Composed of various elements (grains, homogeneous mixture, fossils)";
- "Have a specific way of depositing (massif, layers…)".

The second barrier to learning is reinforced by the fact that rocks are solid, and it is therefore difficult to imagine them in another form (Dove, 1998; Kusnick, 2002; Ford, 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 rocks are the consequence of slow processes (Ault, 1982, Happs, 1982; Blake, 2005)

The Earth is a globe that contains an enormous reserve of magma

Similar to findings by Lillo (1994), Sharp et al. (1995), Marques and Thompson (1997) and Blake (2005), we have seen that this idea could be represented in two ways: magma occupies the entire interior of the Earth or magma occupies only the Earth's core. The conceptual level intended by the teacher is: "Magma is created in certain places within the mantle or the crust".

The difference between the two conceptual levels, i.e., that of the student and that of the teacher, is that, in the first case, magma already exists and the student does not therefore question the formation process, while, in the second case, the geologist demonstrates the relationship between the formation of the magma and certain phenomena connected to global tectonics (such as zone of divergence or of convergence of lithospheric plates, or hot points).

The History of Science has showed us that the idea of a solid Earth (with the exception of the external core), accepted by geologists, is very recent: it dates from this century. Even more symptomatic yet is the fact that geophysicists admitted it well before the geologists, as a result of the analysis of seismic wave propagation. Certain geophysicists, under the influence of Jeffreys, have even opposed Wegener's theory, as they considered that the Earth was more rigid than steel (Stanleys, 2005).

Three barriers to learning are evident:

The first barrier is outlined by the difficulty of coming out of a cycle of phenomena, which, as their name indicates, "circle" in the fashion of a computer program within which we would forget to insert an instruction allowing us to get out of the process. It's the research of the "correct form", as quoted by Astolfi and Peterfalvi (1993). In effect, similar to findings by Lillo (1994) and Marques and Thompson (1997) for these students, the centre of the Earth is assimilated by a fire (perhaps without a flame) that heats the core and liquefies its constituents. These constituents rise, turning into lava, or they heat the rest of the Earth's rocks, which melt, forming lava which itself rises to the surface. Everything is very coherent in this system.

The resistance to the conceptual change is reinforced by the idea of transmutation, a phenomenon well anchored in the student's mind, which enables the transformation of a substance composed of nickel and iron into other substances composed of silica, aluminium and other cations. Furthermore, it is reinforced by long-held knowledge (they know that worldwide there are many volcanoes that reject lava, which corresponds to a liquid interior) or facts that have recently been discovered (the analysis of seismic S waves indicate the presence of a liquid zone 2900 km deep). Finally, the movement of plates, the convection currants of the mantle, that assume, in their eyes, a substratum fluid, once again accentuating the idea of a liquid Earth, sometimes reinforced by what we read in certain textbooks (e.g., Tavernier, 2004; Périlleux & Thomas, 2005; Salviat & Desbeaux, 2005): "the plates float on the asthenosphere".

To overcome this barrier the students must acquire the idea that atoms cannot transform into other atoms. Is this possible in the eighth grade? Nothing is less sure as everything depends on the order within which teachers of physical science teach the chemistry syllabus. Nevertheless, it can be possible to construct an alternative model with the students, which does not refute the latter, and is also comfortable from an intellectual point of view. For example, it's the formation of magma from a solid material which composes the crust or the mantle. There will obviously be conflict for some time between these two explanations.

The second barrier to learning in the conceptual evolution is apparently the difficulty of differentiating between the long and short-term behaviour of materials (Trend, 1998). The primate of perception reinforces this barrier and is therefore in relation to the first barrier. It is also reinforced by the exclusive use of the coupled terms "solid/liquid". Obviously, these terms oppose the continents and the water of the oceans, lava and rocks, but are also often used to qualify the lithosphere and the asthenosphere, even though some differences exist. In school textbooks (e.g., Tavernier, 2004; Périlleux & Thomas, 2005; Salviat & Desbeaux, 2005), the lithosphere is often qualified as a solid in comparison to the asthenosphere which is considered to be either viscous or mostly solid with a very small proportion of liquid (1 to 2% according to the textbooks). This last term generally attracts students' attention as they find an explanation to the fluid's behaviour. Must we not therefore create a rupture in the way of envisaging the problem and of describing the lithosphere and the asthenosphere in terms of breaking/ductile behaviour? This latter could be considered as liquid behaviour on the geological time scale (Trend, 1998). The obtained conceptual level for opposing the two zones of the globe would be that: “the movement of the lithosphere is provoked by the deformation of the ductile asthenosphere”. This change can be possible if the student is used to manipulating objects like wax, which can be deformed under the action of weak forces, but which will break under the action of strong forces applied in a short time frame. Another option is to study the deformation of materials under various temperature conditions because it can show the necessity of changing the criteria for qualifying solid materials.

A third barrier to learning is that, in the student’s minds, only the heating process is capable of transforming the mantle or the crust into liquid (Lillo, 1994; Marques & Thompson, 1997). It is the model of everyday life: the idea is reinforced by the fact that the heating process produces practically all fusions. On the other hand, it does not allow the understanding of liquefaction or vaporisation at a constant temperature, for example, changing the state of butane from a liquid to a gas. The change in thinking that needs to be introduced is that: “fusion can be produced by heating and/or by decompression”.

We are well aware of the fact that eighth-grade students still do not have the precise relative knowledge of the concept of pressure because they will not study it until the ninth grade. The representation that they have of this concept is generally the following: “It is an action (sometimes a substance in movement), which packs the material down (which does not indicate whether the student thinks of molecules or atoms)”. It is also how some of them explain the liquid state of butane in a lighter or a bottle. By enriching the spectrum of the conditions within which a change of state can be produced, we can bring the students to reconsider their initial explanation of fusion. They will then see that fusion is possible without a variation of temperature but with a reduction of pressure. The example of the lighter within which we observe butane in a liquid state become gas when we open the valve is an example of a possible demonstration. This conceptual level permits the explanation of the change of state that is produced in the asthenosphere on a level of divergence zones.

IMPLICATIONS: POSSIBLE DEVELOPMENT LEVELS OF ANALYZED STUDENTS’ ALTERNATIVE FRAMEWORKS IN THE EIGHTH-GRADE

The knowledge that has been gradually acquired by the scientific community during the development of science, shall be referred to herein as “Reference Knowledge” (Giordan & DeVecchi, 1987). Analysing the Reference Knowledge in order to construct a teaching sequence can be done not only by using university textbooks, but also by putting these books, as well as Official Instruction texts, in relation to the students’ alternative frameworks and the barriers to learning that they bring about. This is what De Vecchi (1994) clarifies: “To our knowledge, the conceptual levels should be constructed from a precise analysis of the concept (Reference Knowledge), of the use of which it has made for itself, and the barriers to learning that the students come head-to-head with in building their own knowledge”. In one year, the level of understanding of a concept such as that of “crystal”, “rock” or “volcano”, “Earth”, is enriched in the light of the barriers to learning overcome.

Figure 4 proposes a concept map showing the different levels of development of a same concept in the eighth grade. These different conceptual developments were arranged in the context of which the edges are rectilinear. The students’ alternative conceptions given are in a box with a bold background. The arrows carry out the conceptual change from one level to another. An arrow generally crosses a framework-conception, thus showing that this conception must be overcome. The concept map as a whole forms a network as often many concepts or sub-concepts intervene in the construction of the envisaged concepts. It is the case, for example, concerning the concept of the rock which supposes only at a moment that the students have constructed the concept of crystal. These different conceptual developments have been written under an operative form that permits the explanation of geological phenomena considered in class.

If we take the case of the rock concept, we find the different attributes that we previously quoted. They could be broached together, or separately, depending on the established progress. One of the proposed conceptual levels could be that “the rock is an underground constituent” (level 1). The superior level would be that “a rock is constituted of grains” (level 2). It is no longer the hardness or the coherence that matters, it is the fact that it is composed of distinctive elements. The fact that “the rock has a history” could be the following objective.

These proposed conceptual levels are the result of class activities in the context of different lessons and are therefore operative. The rock concept is not studied under the form of a monograph, but constitutes one of the conducting threads of the geology sequences. The overlapping of one level onto another does not always make progress. It can be done by integrating new knowledge. We therefore advance from the level wherein “the rock is constituted of grains” (joined together or not) to the level wherein “the rock is composed of crystals and/or glass”. This is done after having constructed the crystal concept, which always corresponds to the second level previously defined.

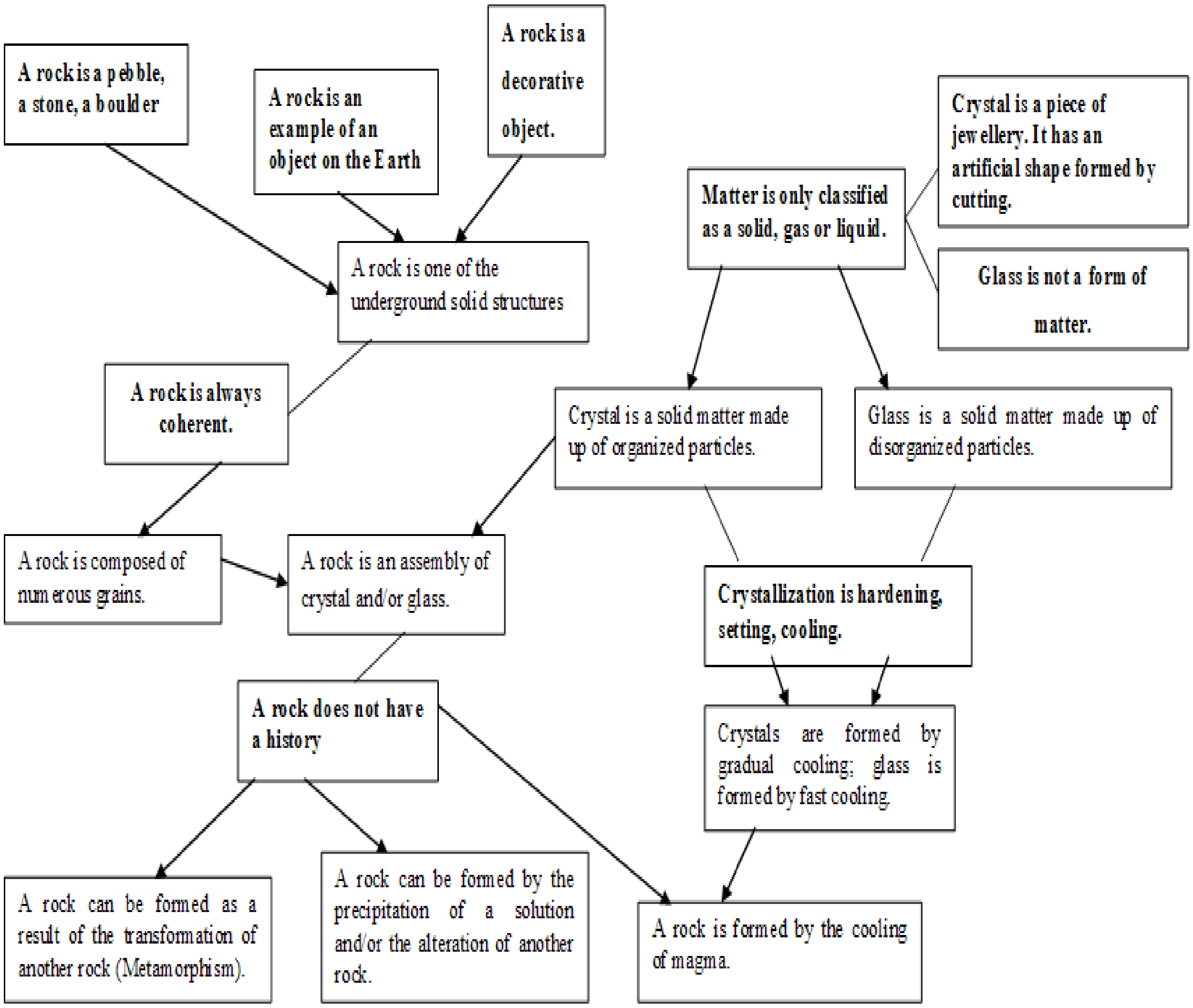

Figure 4. The different conceptual levels: Rock – Crystal – Glass - Students' alternative frameworks defined in bold.

On the other hand, these conceptual developments have been put into the perspective of the students' alternative frameworks. The change of level is done by the modification of initial knowledge, such as:

To go from the idea that "a rock is a gathering of crystals" to the idea that "a rock is the result of the cooling process of magma" presupposes that the student has overcome the learning barrier constituted by "a rock (inert material) has no history". Students can progress from the idea that "a crystal and a glass are two identical solids" to the idea that "a crystal is composed of ordered particles" (even though a glass is composed of particles dispersed without an precise order), if they have overcome the stage of categorical thinking that leads them to consider that all the substances that belong to the class of solids have the same structure.

Accordingly, scientific knowledge is developed in relation to what the student thinks or does not think in the absolute. These conclusions are supported by Schnotz et al. (1999) in the quotation: "a concept is a denomination and a definition, otherwise said as a name laden full of sense, capable of fulfilling a discriminate function in the interpretation of certain observations". This signifies that it does not only consist of an accompanied word in its definition.

CONCLUSION

The results show that children's alternative frameworks vary in terms of their differentiation; organisation and vocabulary, suggestive of different levels of understanding that facilitate their categorisation as alternative frameworks.

In addition, this study highlights the possibility that within a conceptually-confined area like geosciences, students' understanding of closely related concept groups tends to be uneven, creating a "critical barrier" (Ault, 1984), preventing the long term development of a Scientific, holistic understanding of how the Earth functions as a dynamic, integrated system. As pointed out above, this necessitates a Scientific, descriptive understanding of each concept group as well as a casual understanding of the relationship between them.

This study revealed the alternative frameworks of the students in relation to the following three main types of barriers to learning emphasised by these all students' productions are grouped.

- Crystals do not correspond to a precise organisation of the material;
- A rock does not have a history;
- The Earth has a liquid interior.

In considering the function of alternative frameworks on children's understandings of earth science concepts, it may be that they operate in a analogous way to the possible sub-conscious intuitive theories of naïve physics held by children, with structure their knowledge acquisition of physical phenomena (Vosniadou & Brewer, 1992, Vosniadou, 1994). Although such comparisons cannot be taken too far and would merit further investigation, it is suggested that children's existing alternative frameworks may influence the way knowledge is interpreted and understood in this domain, particularly evident when the appropriate alternative framework is absent.

The results from this study can be used to inform Earth science instruction in this area and at this grade level. It is suggested that in order to avoid these grouped critical barriers and develop a deep understanding of geology, a concept map showing the different levels of development of a same concept in the eighth grade are proposed.

Identifying critical barriers to learning linked to alternative frameworks, and preparing the concept maps not only help to develop teaching strategies, but also provide a first step for future research, which should address the effects of developing guide materials and teaching strategies, as well as organizing workshops for teacher training.

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Appendix A

The Q-Sort test was presented in the following manner:
Dear student,

In the first three questions you are asked to associate, by classifying, a key concept (in bold) to ten words of everyday vocabulary (classed by alphabetic order in each list). To do this, you transfer, on the answer sheet, the number of words in the boxes that correspond to the question. At the top, you will indicate the word which, in your opinion, is closest to the key concept and, at the bottom, those with the least association. The boxes in the middle correspond to words that are neither close nor far from the key concept.

1. Crystal: 1.atom; 2.glass; 3.ice; 4.jewellery; 5.liquid; 6.order; 7.regular; 8.rock; 9.solid; 10.shiny

2. Earth: 1.continent; 2.core; 3.crust; 4.heat; 5.liquid; 6.magma; 7.mantle; 8.ocean; 9.rock; 10.solid

3. Volcano: 1.continent; 2.explosion; 3.fire; 4.fracture; 5.gas; 6.heat; 7.lake; 8.lava; 9.magma; 10.pressure

Appendix B

The Survey Questions:

The First section

The students were asked the following questions:

Dear Student,

The video document has shown a few eruptions of a volcano, Mount Etna.

1. Draw a volcano as you imagine it and replace the products that are rejected.
2. On the drawing, show precisely where the products (gas, lavas, and different-sized rocks) could come from.
3. Pieces of rocks coming from volcanoes (solidified lavas, solid projections) are arranged on your table. Using the information brought to you by the film, explain how these different rocks could be formed.
4. After a certain amount of time (a few weeks or a few months) the eruption stops. For which reasons?
5. Mount Etna erupts on a regular basis. What makes the lava rise and expel the rocks?

The second section

The students were asked the following questions:

Dear Student,

1. Calcite and aragonite are both composed of carbon and calcium molecules (a combination of carbon, oxygen and calcium atoms). Nevertheless, these crystals do not have the same form (a calcite crystal, a rhombohedra crystal and an aragonite crystal were drawn). Draw what you would observe if you looked at a calcite crystal and an aragonite crystal with a microscope that enlarges them a million times.

2. Please explain, what is a crystal?

The third section

The students were asked the following questions:

Dear Student,

1. Please explain the global spread of volcanoes on the surface of the Earth and in doing this, represent the latter in cross-sections.