Geomorphological analysis of the interaction between glaciation and the Tartaret volcano in the late quaternary in the Lac Chambon region, France

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Preface

This report is the result of my MSc thesis for the master program Earth and Environment at Wageningen University. This thesis was supervised and examined by dr Jeroen Schoorl. This MSc thesis was supported by two BSc thesisses, executed at the same time by Evelien Castrop and Marte Hofsteenge. I hope you enjoy reading this thesis.

Before going to the actual thesis, there are a few people I would really like to thank, without whom I would not have managed to complete this. Firstly, I would like to thank Jeroen Schoorl, who has taken the time to advise and help me throughout the whole process, come up with solutions when I did not see them, and staying enthusiastic about the topic from start to finish, which really helped me keep my drive as well. Secondly, I would like to thank Tony Reimann, for acting as external advisor, putting a lot of thought, enthusiasm and effort into dating my samples, but also in explaining me the principles of luminescence. Along the same line, I greatly thank Alice Versendaal and Erna Voskuilen, for taking me (temporarily) into their lab with open arms, being patient with me and my tricky samples, sharing their knowledge with me and also a very good laugh from time to time. From the HWM chair group, I would like to thank Roel Dijksma and Ton Hoitink, for taking time to think about my topic and possible solutions without being related to it in the first place. I am also grateful to the people at the geodesk, who've helped me out twice, at very crucial moments, saving my work. Also a big shout out to all my fellow MSc student friends who have helped me in many ways with my thesis, whether it was solving an equation, proofreading some of my writing, or simply being someone to talk to about the thesis during lunch break walks: thank you all, you know who you are. And last, but definitely not least, I would like to thank Evelien Castrop and Marte Hofsteenge, for being amazing field- and thesis buddies. Without them the field work would have been a lot more difficult, maybe even impossible in this form. So thank you for navigating, carrying soil drills, being a reference point for measuring slopes, and participating in late night brainstorm sessions. But mostly thank you for being the social company on this journey.

Abstract

The geomorphology of the Lac Chambon area, Massif Central, France, has always been under debate amongst geomorphologists. Lac Chambon is situated just at the end of a U-shaped valley, and blocked in the east by the Tartaret volcano. The combination of three processes, glaciation, volcanic activity and a related extreme flood, make it a complicated area. Due to the absence of the 1:50.000 geological map, the area is unexplained up till now. The aim was to explain the geomorphology of the area downstream of Lac Chambon. In order to obtain this, fieldwork was executed. At 250 points landforms were observed and described considering shape, size, parent material, position in the landscape, land use, slope and aspect.

A geomorphological interpretation map was created out of the field data using the image editor program Gimp. This map shows the interpretation of an eruption with a lava flow of the Tartaret volcano reaching to the town of Neschers (20km downstream), a glacier build up afterwards, and eventually a glacial outburst flood, followed by another lava flow and the formation of secondary scoria cones.

Since this geochronology contradicts with literature (13ka at Neschers, 28 ka in Murol close to the cone), and because the origin and extent of a flood event remained unclear, additional modelling was done using Arc GIS. The volume of an old phase of Lac Chambon (the so called Tartaret lake), the glacier, and a possible marginal glacier lake were estimated. Using Chézy's formula, different scenarios were created, calculating at two locations in the study area how long it would take for each volumes to completely flow through. In order to explain certain flood features in the area, it was thought that the minimal flow time should be at least a day. Only the glacier seemed to have a sufficient volume to make this requirement. The part of the glacier around Murol is just about enough to explain the flood features in the landscape.

Also, three samples were collected for luminescence dating. The two xenolith samples (granite in basalt from a lava flow) turned out to be unsuitable. A sample of Tartaret scoria was dated, and came to an age of 15.7935 ka ± 2.9527 ka. Since this location is thought to have caused the blockage creating the Tartaret lake in 12.6 ka, the resulting age seems old but has the right range.

In conclusion, it is thought that at least two eruptions, of which one with a lava flow was present from the Tartaret, with indications but no hard prove for a second one, that there was a glacial induced extreme flood present, that a margin lake is not proved but likely, and that the Tartaret lake had no extreme flooding event. However, the geochronology of all these events is still unclear and up for discussion, so additional research is needed.

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1 Introduction

Geomorphology is of great importance of understanding an area, since it explains the types of soils that are present, the water availability, the risk at erosion, etc. Even for natural hazards it is important to understand the role of geomorphology (Alcántara-Ayala, 2002) Different techniques have been developed to investigate the geomorphology of landscapes (Walsh, Butler, & Malanson, 1998), but the landforms still have to be interpreted. Different interpretations amongst geomorphologists and geologists can lead to discussions. One of these areas that has always been up for discussion is the area around Lac Chambon, France. This is due to the number of processes and interactions that took place during the late Pleistocene/beginning Holocene, and the fact that there was never sufficient consensus to produce the final 1:50000 map. The geomorphological processes influenced not only this area but also probably the Allier River, the main river of the Limagne rift valley, to which the study area drains. This research is a case study for the area east of Lac Chambon, France, and much of this introduction will therefore be a description of the study area. The research focusses on the interaction between an alpine glacier and a volcano, which is not a common combination and not widely studied. Therefore, apart from giving more insight into the study area, this research will also give more insight into unknown processes around Alpine glaciers and volcanoes.

1.1 General area

The study area is located in the Massif Central. The Massif Central is part of the Variscan orogenic belt, which is the collision zone between Gondwana and Laurasia(Lardeaux, Ledru, Daniel, & Duchene, 2001). The Massif lies in the western part of the belt and had multiple orogenic events from the late Silurian-early Devonian up to late carboniferous (Lardeaux et al., 2001). Faure, Lardeaux, and Ledru (2009) describes six main tectonic-metamorphic events, of which the first (D0) and third (D2) coeval with respectively the Caledonian and Hercynian orogeny (Burret 1972; Faure, Lardeaux, and Ledru 2009; McKerrow, Mac Niocaill, and Dewey 2000). The majority of the basement rocks of the Massif Central are gneisses and granites. Different gneissic and granitic nappes (structures), are recognized in the area, dating from the mentioned orogenies. (Faure et al., 2009; Turpin, Cuney, Friedrich, Bouchez, & Aubertin, 1990).

The Limagne graben crosses the Massif Central and is a rifting area. There is prove that during tertiary times a mantel plume was present underneath the Massif Central (Granet, Wilson, & Achauer, 1995). This caused uplift of the massif, which is still happening present day, and causes tension over the lithosphere resulting in rifting (Granet et al., 1995). Rifts are elongate depressions beneath which the entire thickness of the lithosphere has ruptured under extension.(Celal Sengör & Burke, 1978). Rifts can occur with or without the drive from a mantle plume. Convection plumes van dome up and crack the lithosphere. (Celal Sengör & Burke, 1978). The presence of a plume enabled the rifts in western Europe to open obliquely to the direction of mantle movement without significant extension in the lithospheric mantle (Zeyen et al., 1997). There are different types of rifts and they can exists isolated, aligned along narrow belts, or even clustered together. (Zeyen et al., 1997). The Limagne rift valley is part of the cenozoic rift system of western and central Europe, which extends from North sea to the Atlantic coast of North Africa. (Ziegler, 1992). The rift system has a length of 1100km and developed during late Eocene to recent times (Ziegler, 1992). The subsidence of the lithosphere (the rifting) happens in step faults: blocks of basement rock subside. This does not always happen continuously: therefore, blocks sticking out can create relief in the landscape.(Boivin et al., 2017) Most rifts have associated volcanism that is mainly basaltic. In continental rifts, the basalt is mainly alkaline (Celal Sengör & Burke, 1978).

The Limagne rift valley is drained by the Allier River, a tributary of the Loire. The Allier has a clear succession of terraces (Veldkamp and Kroonenberg, 1993). Lakes are abundant in the area, since both the effects of volcanic eruptions (maar explosions, formation of calderas, blockage of rivers by scoria cones and lava flows) and mass movements have been causes for lake formation (Macaire, Cocirta, De Luca, Gay, & De Goër De Hervé, 1992).

In the Miocene the volcanism started in the Massif Central. Relevant for our study area is the Mont Dore, the youngest stratovolcano of the Massif Central, which covers an area of 500km^2 a stratovolcano, and was active between 3.1MA and 200ka (Nomade et al., 2014). At the western rim of the Limagne graben, the Chaîne de Puys complex is situated, which is active in the late quaternary and Holocene. This is a N-S trending range of a hundred small scoria-scones, trachyte-domes, maares and basalt flows. The activity of the Chaîne des Puys was from 150 000 till 3500 years ago (Nehlig et al., 2003). The highest peak is the trachyte-dome of the Puy de Dome (1456 m). (Nehlig et al., 2003)

At least during the last two ice ages, the Saalien and Weichselien, the Massif Central, including the Mont-Dore, was glaciated (Buoncristiani & Campy, 2004)(Veyret, 1980). Since the end of the Weichselien, there has been a retreat with two assumed re-advances. (Etlicher & De Goër De Hervé, 1988)

1.2 Specific area

Figure 1: Location of the study area (on the right) in the Massif Central, France

This study focusses on a specific area around Lac Chambon, which can be seen in figure 1. Lac Chambon is located at the end of a U-shaped valley. This valley is thought to be a remnant of the Mont-Dore glaciations. Though morainic material is mentioned (Boivin et al., 2017), distinct end moraines have not been found. (Buoncristiani & Campy, 2004) Therefore, the extent and dating of the glacier remains unclear.

East from Lac Chambon is the Tartaret Volcano, which is part of the Chaîne de Puys complex(Boivin et al., 2017). At several places in situ lava flow can be observed, from Murol all the way up till the town of Neschers (Nowell, Jones, & Pyle, 2006). There are multiple dates mentioned in literature (Miallier et al., 1994; Nowell et al., 2006), but two moments of eruptions come forward: one 28.000 years ago and one 13.000 years ago. The one of 28.000 years ago has been identified by plagioclase dating (Guérin, 1983). The 13.000 years ago was found by dating so called baked sediments (Pilleyre, Montret, Fain, Miallier, & Sanzelle, 1992), as a correction on a dating that first resulted in 27.000 years ago (Raynal et al., 1985). The 13.000 flow is also confirmed by a dating of ashes in peat bogs (Bastin, Gewelt, & Juvigné, 1990).(Miallier et al. (1994) and Raynal et al. (1985) provide a date for the Neschers site between 15.300 to 12.100 BP, as mentioned by (Bello, de Groote, & Delbarre, 2013)

The Tartaret caused one of the two lake formation phases that Lac Chambon has known, between 12.600 BP and 8.500BP (Macaire et al., 1997). This lake is referred to as the Tartaret Lake. The second, current, phase was caused by the collapse and the following landslide blocking by the Dent Du Marais, 2.600BP. (Macaire et al., 1992)

The study area is drained by the Couze du Chambon river, flowing from Lac Chambon through the study area towards the Allier river. The river La Planchette flows from the Massif surrounding the study area, and joins the Couze Chambon from the south just before the town of Les Granges.

1.3 Research gap

Due to the different phases of fluvial, glacial, volcanic and tectonic activity, the area is very dynamic with a difficult geology and geomorphology to explain. A complicating factor is the absence of the 1:50000 geological map. Other maps are present, in appendix 1 two manually drawn maps (including one that was part of the rejected 1:50000 map)and (Boivin et al., 2017; de Goër et al., 1991) from de Chaîne de Puys. However, they do not include the entire study area.

The main question marks are around the number and location of lava flows, the extent of the glacier, and the origin of an extreme flood in the area. As mentioned, there are different observations of in situ lava found with different dates. Therefore, the number and location of lava flows should be investigated, as will be done simultaneously in another research by Marte Hofsteenge. When it comes to the glacier, no end moraines have been exclusively reported or mapped to this point (Buoncristiani & Campy, 2004) (apart from the mention in (Boivin et al., 2017). Possible explanations for this are that the moraines have been destroyed by either a volcanic eruption or washed away by a possible mega flood. One of the possible sources for a mega flood is the abrupt melting of the glacial ice by the eruption of a volcano. This type of mega flood is known as a Jökulhaup.

Events like Jökulhaup are a common phenomenon in Iceland. If a glacier would have been present on or next to the Tartaret during one of the eruptions, this may have caused a Jökulhaup or mega flood of another kind. This could have influenced the catchment and terraces of the nearby Allier River (Veldkamp & Kroonenberg, 1993). At the end of the Late Pleniglacial (though exact dating is still under debate), a strong rise from the river bed level was caused by major sediment fluxes. A possible explanation is the deglaciation on the Mont-Dore and the Cantal, generating extra meltwater over a longer period of time (Veldkamp & Kroonenberg, 1993). However a possible extreme flood could also have caused a major flux in a short amount of time. Rough estimations of the possible water volume for such a flood have been made. (van Orsouw, 2017). If those volumes were actually present have never been checked. Nor has there been any research done on evidence of glaciovulcanism and a coexisting mega flood in this area.

Most of the Jökulhaup literature is on locations in North-America and Iceland (Russell et al., 2006). It mostly involves an ice sheet located near or on a volcano. In general, these ice sheets have well developed outwash plains and other glacial features. A Jökulhaup or even the lava flow itself will therefore barely disturb the glacial structures. Since it involves a smaller, alpine glacier here that was forced into a valley, the scale and landforms are less extensive. Therefore, the change that all glacial landforms are wiped out by an eruption (either by a Jökulhaup or a lava flow) is more likely. Since the combination of an alpine glacier and a volcano is quite rare, little is known about the effects and the landforms to recognize it.

A Jökulhaup is not the only possible source for an extreme flood event. As discussed before, Lac Chambon has had a previous lake phase know as Lac Tartaret (Macaire et al., 1997). However, after 8.500 years BP the lake does not register anymore and has disappeared. Depending on the rate of draining, this could have caused an extreme flood.

Overall, there are still a lot of question marks about the geology and geomorphology of this area. The presence of a glacier is highly certain, but the location and timing are unknown. The eruption of the Tartaret Volcano is a fact, but the number and timing of eruptions, exact presence of a flow(s) and location(s) of a flow(s) are also unknown. The presence of an extreme flood event is expected, but the source and extend also remain unclear.

1.4 Objective

The goal of this research is to investigate the geomorphology of the area, with a specific focus on the glacial influences. Simultaneously, two other researches will be focussing on the volcanics and on the flood processes. Field data is collected and used for modelling. The focus will be on finding glacial, volcanic and flood landforms, and hints to determine the age or geochronology of the three processes.

So far only estimations and assumptions have been made of the volume of the glacier that might have been released during a mega flood. By looking for clues in the landscape that indicate the magnitude of the flood, estimation for the required water volume and its possible origin (glacier or Tartaret lake) can be made. This research will give more insight in geological history of this area, and together with the other two researches answer whether or not a volcano induced mega flood can have occurred.

1.5 Research question and hypothesis

To achieve the aim as described above, the following research question and sub questions have been formulated:

Research question:
How can the geomorphology of the area downstream of Lac Chambon be explained?

Sub questions:
1. Which glacial landforms can be found where?
2. Where are remnants of an extreme flood present?
3. How many lava flows of the Tartaret can be found where?
4. What is the fluvial influence in the landscape?
5. What age / geochronology do the volcanic, glacial, and flood remnants have?

Question 2 and 3 will be mostly answered by two separate researches running simultaneously. The fieldwork for all three researches will be conducted at the same time the results on the researches about the Tartaret and the mega flood will be analysed in those researches, but also in the analysis of this research.

Hypothesis:
The hypothesis is that both the volcanic activity from the Tartaret, glacial activity and an extreme flood event have had a crucial role in the formation of the geomorphology of the Lac Chambon area.

Within this, it is thought that the processes of the volcano and the flood are more recent than the glacier, and will have a more clear impact (at the surface) on the landscape.

For the combination of the processes, it is thought that an eruption does not automatically also result in a lava flow, but it can cause a glacier to melt and create a mega flood. A mega flood only occurs when all water melts at once, which is likely when the glacier is located over the volcano, but not automatically the case.

For each sub question a hypothesis is formed:

Which glacial landforms can be found where?

Complete moraines have never been observed, but this does not mean that there are still moraines, of parts of moraines or morainic material are still present in the landscape. A logical location for an end moraine would be at the end of the glacier, so at the end of a U-shaped valley. so it is expected that they have been removed by other processes. Since it is an alpine glacier, the periglacial zone was most likely not as extensive as for instance with ice sheets in northern America or Iceland where mega floods are more common. An eruption underneath the glacier most likely happened at or around the snout, meaning that all glacial landforms were removed by both the eruption and the following mega flood.

Sinkholes might be possible to be found in the area, since they form from ice that was not melted by a mega flood. This ice is not likely to travel far, so these landforms can be expected close to the expected snout (end moraines). Also glacial till is likely to be present, since it is known that the area has been glaciated. Those are the most likely glacial landforms to be found, but others are not excluded. It can be that glacial landforms (moraines) are present upstream of the Tartaret and lac Chambon, but since the glaciers extend was probably past that, it is more likely to find traces downstream.

Where are remnants of a mega flood present?

Hypothesis: the hypothesis is that in the wider areas (where deposition outweighs erosion) in figure 2 traces of a mega flood can be found. These include large, massive blocks and mega ripples (Judith Maizels, 1997). It is thought that at least one mega flood has occurred, so it is expected to find remnants.

How many lava flows of the Tartaret can be found where?

In figure 2 three possible flow paths from the Tartaret can be seen, so it is likely to find a flow there. There is no reason the Tartaret cannot have erupted more than once during its active period, so multiple lava flows are expected to be found in the landscape.

What is the fluvial influence in the landscape?

Rivers can influence a landscape by incising and eroding. Some materials (sediments) are easier to erode than others (bedrock). If there are different parent materials in the landscape, which could be expected in this area, this will be reflected in the behaviour of the river.

What age / geochronology does lava flow affected materials and glacial remnants have?

This question can be answered in two ways: the first is if there is suitable datable material present to date. It is expected that this will correspond or at least relate to known dates from literature

The second way is to look at clues that indicate a certain geochronology, for instance if one deposit is found on top of another, the one underneath is most likely the oldest. This is for instance the case when looking at flood deposits and lava flows: an eruption underneath a glacier will first cause a water flow, and then a lava flow. So if the sediments are from the same eruption, the lava flow should be on top.

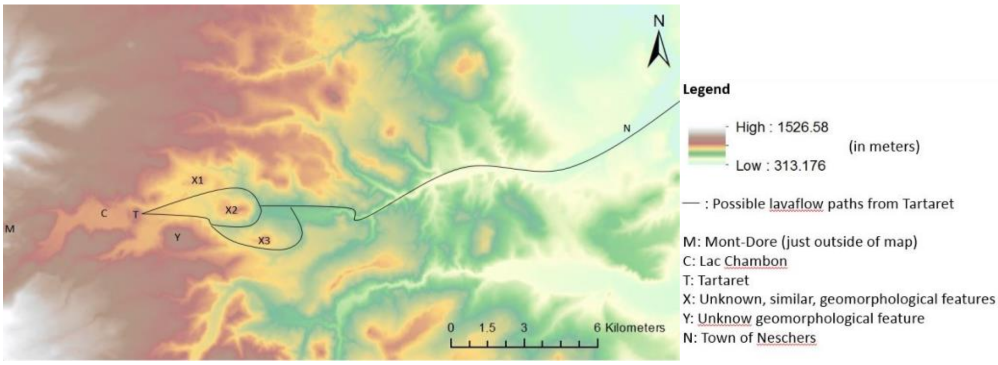


Figure 2: DEM of the study area, indicated are areas of geomorphological interest.

2 Methods

Different methods were used in this research in order to answer the research questions. Figure 3 shows how these methods are linked together. The boxes in this workflow diagram are the methods; the circles are inputs or outputs. The separate methods from the diagram will be discussed in this section.

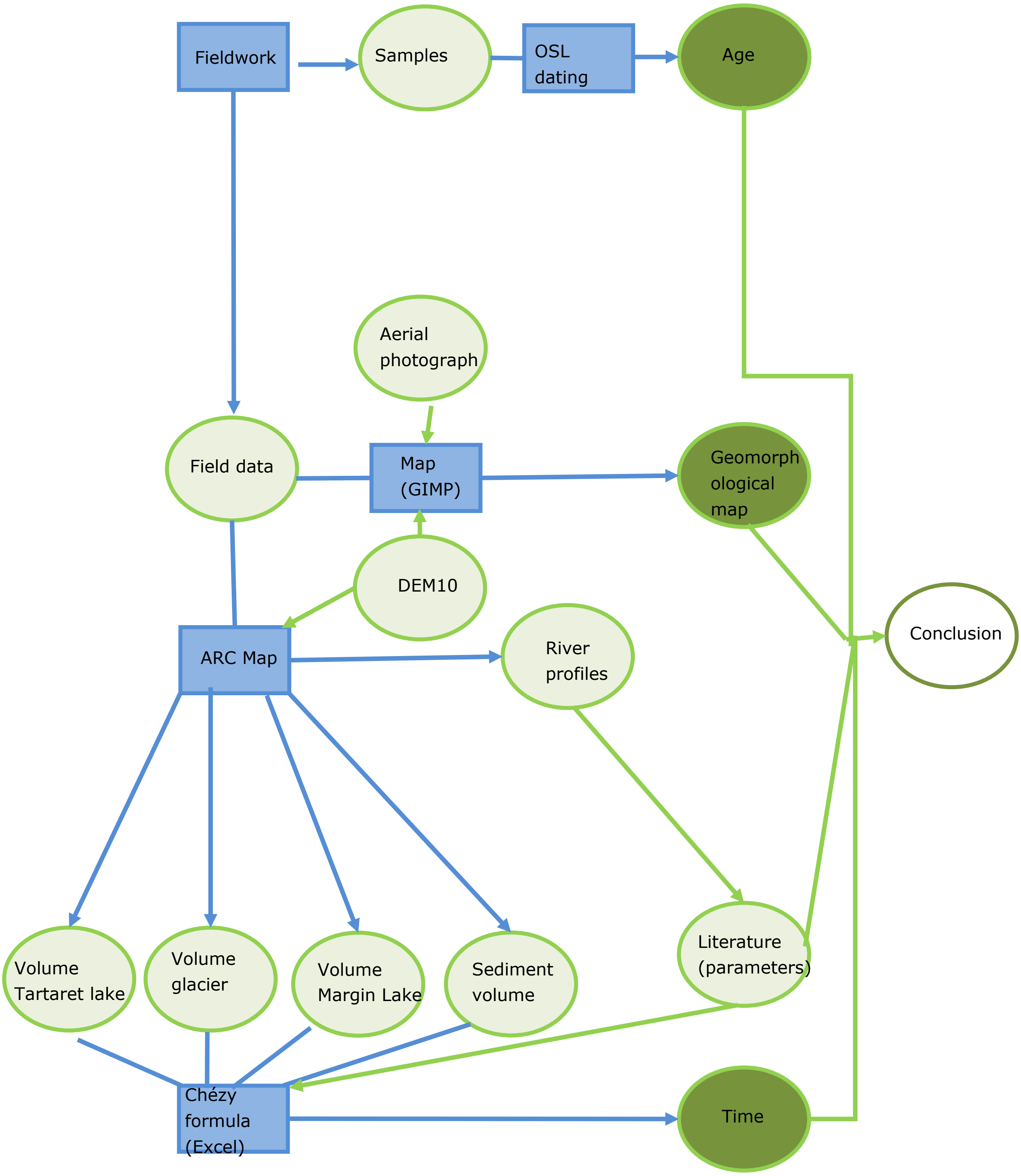


Figure 3: Flow diagram showing the methodology of this research. Blue square = method, green circle = in- or output. Dark green circles are final results. In or outputs connected with blue arrows are created by a method, with green arrows come from elsewhere.

As can be seen in the diagram the field data is used as input in the methods later on in the process. Some methods are in fact largely based on the field data. Therefore in this section there will be sometimes referred to field data which will be discussed later in the results and discussion.

2.1 Fieldwork

The data collection for this research has been done through field work. The fieldwork was done together with two other researches, focusing respectively on the Tartaret volcano lava flows and the mega flood remnants. The fieldwork spanned three weeks. The first week was used to make an inventory of the geomorphology of the area, with a focus on the most clear geomorphological units, as can be seen in figure 2. Those were based on the DEM and literature (The village of Neschers is indicated to be at the end of the Tartaret lava flow (Cullis, Louis, Giraud, Glangeaud, & Marty, 1902)) The second week the area was studied in more detail and also in larger spatial extent, due to the practical reason that a car was available in this week. At the end of the second week a list was made with locations still to be studied to get a full picture of the area, which was visited in the last week.

The sampling focussed on determining the geomorphological identity of the landforms in the area. The selection of the features to identify was mostly done on looking at anomalies: everything that is not expected in the typical geomorphology of the processes. For example, when the Couze Chambon makes an unexpected turn or when the U shaped valley suddenly narrows into a V-shape. At each feature the geomorphology is described by estimating the size, determining the parent material, position in the landscape, land use, and if needed the slope and aspect. Field forms were used as a basis and the form and a filled out example can be found in appendixes 1 and 2. At each location the relevant part of the field form for that location was filled out. Since not all observations could be described in the format of the field form, sometimes separate descriptive notes were taken instead (including the important aspects of the form).

In the field special attention was paid to collecting material for dating. For both the glacial as volcanic traces, dating additional to what is known in literature ((Bastin et al., 1990; Guérin, 1983; Pilleyre et al., 1992)) is desirable. There were a few locations most likely to contain suitable material for dating, which all inform some sort of contact surface, for instance between volcanic or glacial material and the sedimentary parent material. Fluvial stratifications were also of interest for taking samples for dating.
A special case of a contact is a xenolith: the original rock (in this case Hercynian rocks like granite) included in basalt from a lava flow. The lava solidified around the piece of granite to the current basalt. Therefore, the granite has been exposed to an immense heat, thought to be enough to reset any signal in the granite crystals. Ever since, the basalt will have protected the granite from any outside (light)radiation, therefore the signal in the granite minerals will refer to the formation of the basalt (and volcanic eruption). Since it is hard to date basalt this method could be an approximation for the age of the lava flow.

2.2 Map

The observations done in the field were translated into a geomorphological map, which is not an observation but an interpretation map. The field data were used as base, with the addition from the DEM model and aerial photograph (from google earth image) those three sources of information, with addition of literature, were used to interpret the geomorphology of the area. Examples of how the DEM and aerial photograph were used to help convert the field data to a map are: i) extrapolating a certain deposit over the area on the same altitude (using the DEM) and ii) using the aerial photograph to identify landforms that were not sampled to similar landforms (same size and land use). Most decisions and interpretations will be discussed within the results and discussion section. The map was produced with the image manipulation program GIMP, together with the two other researchers (Castrop and Hofsteenge).

2.3 Modelling ARC Map

Modelling in ArcMap is done in order to make quantitative interpretations of the field data. Which calculations are needed depends on the outcomes of the field work. In part 1 of "results and discussion" the outcomes of the field work and the recommendations for the modelling will be discussed in detail. Since the input for modelling is based on field data, the exact inputs will not be discussed here. Instead, general method for hydrological modelling in ARC MAP are described, i.e. creating a flow accumulation map (for river profiles) and obtaining volumes.

2.3.1 Profiles

To get an insight in the hydrology of an area, a flow accumulation map can easily be created in Arc Map, showing which cells in a DEM accumulate most water in the area. This results in a pattern of streams, from which an altitude profile of the river bed can be created using 3D analyst. By comparing the resulting profiles to profiles of similar streams found in literature, anomalies can be pointed out, supplying more information about the geomorphological processes forming the area. Figure 4 shows the model used to produce the flow accumulation map.

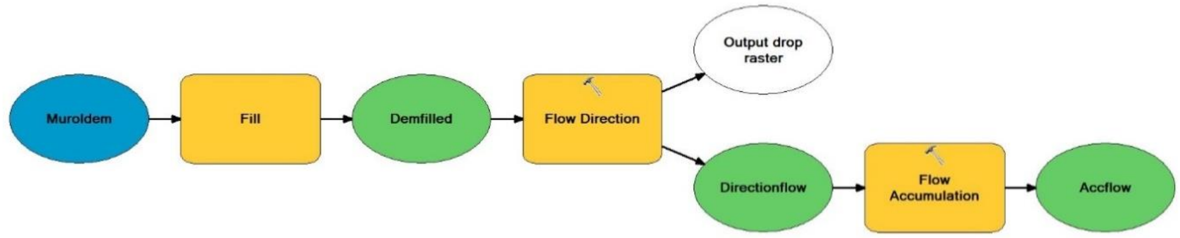


Figure 4: ARC GIS model to calculate flow accumulation, for display of rivers. Squares are modelling tools, blue circles inputs and green circles outputs. Output drop raster was optional.

2.3.2 Volumes

To analyse the effects of geomorphological processes, it can be useful to estimate water or deposit volumes. This is done as follows in ARC Map: first, a polygon is created, following the outlines of the area the volume should be calculated from. Then, the Dem model should be clipped (using "clip"), resulting in the area of the polygon. With the function "surface volume" the volume can be calculated, either from the exact DEM (so the volume of the landforms present), or for instance until or above a certain plain height (e.g. a water table). In figure 5 an example model of this is given.

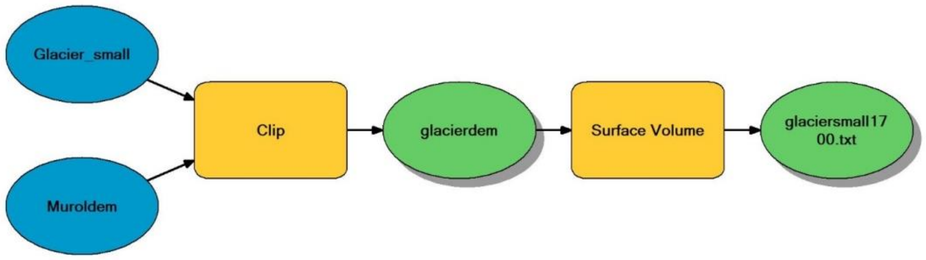


Figure 5: ARC GIS model to calculate volume of a landform (in this case glacier). Squares are modelling tools, blue circles inputs and green circles outputs.

2.4 Chézy (Excel)

Where calculating the water volumes is merely step one, the next step is to link those to the landscape and literature in a way that it can be decided which source or sources would have been most likely to have taken place. Palo floods are often modelled using paleo stage indicators, as in (Bodoque, Eguibar, Díez-Herrero, Gutiérrez-Pérez, & Ruíz-Villanueva, 2011) but those were absent in the field. Large boulders were present, but without any water level indicators it is hard to use these for quantification. Since flowrates and concentration were not known a lot of modelling techniques used in hydrology were unsuitable.

Eventually, it was decided to use Chézy's formula to calculate stream velocity. Needed input is dimensions of the valley it flows through, water depth, roughness coefficient and slope. Slope and dimensions can be taken out of the current DEM, which is an assumption to be representative for the channel present at the time of the flood. Manning's roughness coefficient can be found in literature, and water height can be estimated using field data. Chézy's formula produces a flow velocity (m s^{-1}). It was decided that the easiest way to compare different volumes and their effect was in time (s). Therefore, the outcome of Chézy was translated to time using the discharge. The equations look like this:

$$\upsilon = C * \sqrt{Rh * i} \qquad \textit{(Equation 1)}$$

$$C = \frac{1}{n} * Rh^{\frac{1}{6}} \qquad \textit{(Equation 2)}$$

$$Q = \upsilon * A \qquad \textit{(Equation 3)}$$

$$T = \frac{V}{Q} \qquad \textit{(Equation 4)}$$

In which υ is the flow velocity (m s^{-1}), C is the Chézy constant, Rh is the Hydraulic radius (m), I is the slope (fraction), n is Manning roughness coefficient (-), Q is the discharge (m^3s^{-1}) A is the cross sectional area (m^2), T is time (s) and V is the volume of a possible source (m^3).

Since the inputs and the exact application depends on field data, those will be presented just before the results.

2.5 OSL dating

2.5.1 Field sampling

Three samples were taken in the field; all sampling locations can be seen in figure 6. Two samples were basalt samples containing granite xenolith fragments. Both were found in an in situ lava flow, one being very close to the original Tartaret cone, and the other being in the V-shaped valley around Les Granges. They were carefully taken out with a hammer without damaging the visible granite surface. One of the samples can be seen in figure 7.The third sample was a tube of 33 cm, taken in a quarry at the north side of the Tartaret. It was taken in a scoria wall, which is thought to be a remnant of the wall blocking the former Tartaret lake (Macaire et al., 1997). Since scoria is porous material, it is likely that the scoria was first "clogged" with sand and clay from the lake. The theory is to date that sand and clay using OSL, to get more certainty about the lake presence and a possible (sudden) drainage. The wall that was sampled seemed to be composed of different layers, and it was made sure to insert the tube in one layer that looked like containing a high amount of sand and clay. Both sides of the tube were covered with dark tape to limit light penetration. The sediment was dry upon sampling. Figure 8 and 9 show the sampling of the tube sample. The dating methods will be discussed in a next section.

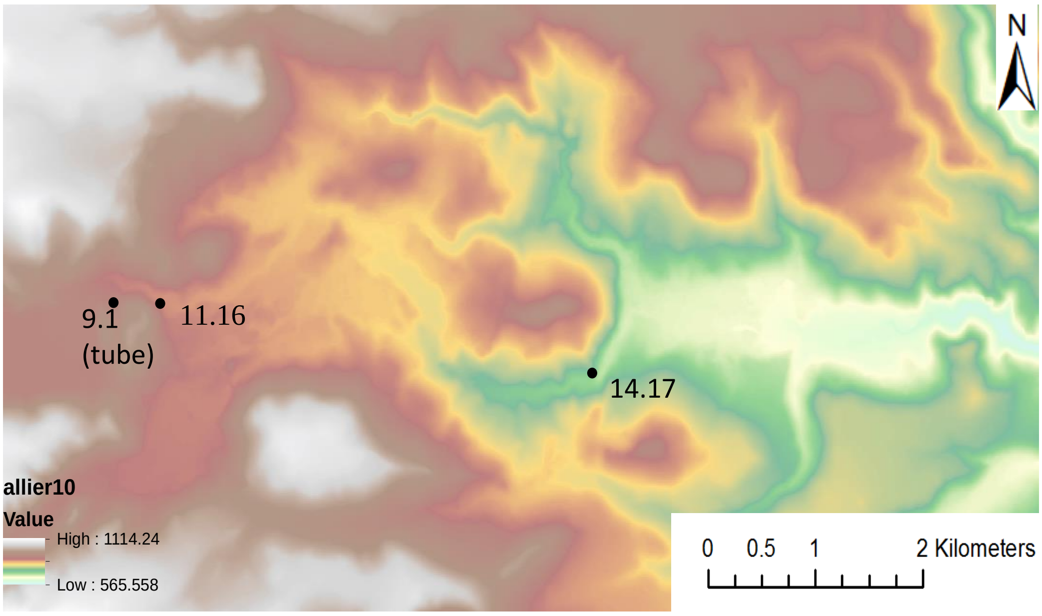


Figure 6: DEM showing the sample locations.

Figure 7: sample from 11.16, showing the granite (xenolith) inside the basalt

Figure 8: Tube inserted in scoria wall for OSL sampling. Hammer for scale

Figure 9: Sample (in red) in scoria wall

2.5.2 Lab preparation

All three samples were taken to the lab to determine the age, by using luminescence dating. Luminescence dating is based on the principle of the build-up of a signal in sediment that has been buried or otherwise shielded from light. The build-up of the signal is caused by natural radiation from the sediment and cosmic radiation. If the dos rate (rate at which the signal accumulates) is known, measuring the signal will tell how long it has been building up, i.e. how old the sediment is. (Preusser et al., 2008).

In order to extract feldspar and quartz from the granite sample, the granite piece had to be taken out of the basalt. Sample 11.16 was cut out by drilling a core, including the entire piece of granite. However, the basalt broke, making it necessary to continue with the water table saw. The resulting core was cut into pieces of 2mm with the water saw. Here it became clear that the piece of granite was less than 7mm thick. The first 4 mm were discarded due to light influence, mm 4-6 were separated, and mm 6-7 mm did not contain enough material for measurements. Due to the shape of the cut out column with granite, the slices were slightly under an angle, meaning that some of the 4-6mm slice was probably less deep and had light influence. Therefore also the 4-6mm was discarded and this sample was not measured.

For the second sample (14.17) the granite was also taken out using the drill. The resulting column was cut into pieces of 2mm thickness with the water saw. Here it became clear that the piece of granite was less than 8mm thick. The first 4 mm were discarded due to light influence, mm 4-6 and 6-8mm were grinded and sieved and 212-250 fraction was separated by a magnetic separator, since quartz and feldspar minerals that contain the targeted luminescence signal are not magnetic. The 6-8 mm did not contain enough material. The 4-6mm however did.

The tube was opened in the lab. At both sides, 5 cm was discarded due to light influence. A colour distinction was observed at 21 cm, after that it was more gradual to darker material. That material was taken, see figure 10 for a schematic representation. The material was sieved, and the 180-250 micrometre fraction was kept and also separated magnetically.

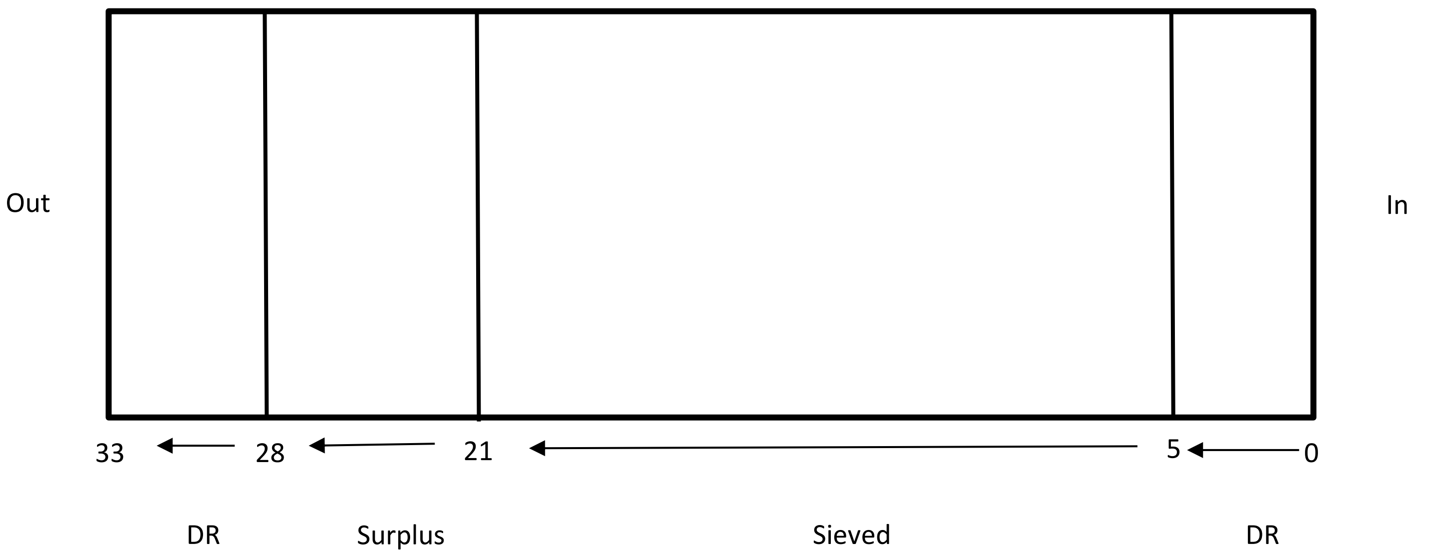


Figure 10: schematic representation of the OSL sample tube, indicating the side that was inserted in the wall (in). A colour distinction (from darker to light material) was observed at 21 cm, the light part was discarded.

2.5.3 First measurement – luminescence pre-testing

A polymineral multiple signal single aliquot measurement was carried (PMS SAR), using the protocol proposed by (Reimann, Notenboom, De Schipper, & Wallinga, 2015) (i) to check for suitable luminescence signals and (ii) sufficient luminescence signal resetting prior to burial (termed bleaching). Six discs were used, three for the rock sample and three for the tube. The rock sample did not contain a sufficient luminescence signal and was therefore excluded from further measurements. The tube, however, did contain did contain a sufficient infra-red stimulated luminescence (IRSL) feldspar signal. Resulting from this pre-test it was decided to focus on the IRSL signal from feldspar for further analysis by applying a dedicated measurement protocol (see below and appendix) to the extracted feldspar minerals.

2.5.4 Second measurement – feldspar luminescence

Before measurement a density separation was done to separate the lighter feldspar fraction from the heavier quartz. In contradiction to the first measurement, only K-feldspar was measured this time to obtain a palaeodose (dose that was received during burial) from the K-feldspar extracts the post infrared IRSL (pIRIR) protocol proposed by(Thomsen, Murray, Jain, & Bøtter-Jensen, 2008) was applied. This protocol uses an elevated post-IR stimulation temperature at 225 °C (short $pIRIR_{225}$) and is characterized by low fading rates. The measurement set-up (detection window, signal integration, rejection criteria etc.) was similar to that of (Kars, Busschers, & Wallinga, 2012). This paper also thoroughly tested the performance of this measurement protocol. Six aliquots were used for this measurement. The exact protocol can be found in appendix 4.

2.5.5 Dose rate

In order to calculate an age, the sample dose rate needs to be established as well. The dose rate describes the radiation causing the luminescence signal built-up consisting of the effective radiation in the sample surrounding, the internal radiation of the K-feldspars and the cosmic radiation. To determine the radiation received from the surrounding hereto surplus material was dried, ashed and mixed with wax to form a 1cm thick puck. Afterwards the radiation was measured for 48 hours on a high-resolution gamma spectrometer, and translated to a dose rate by taking water and organic matter content of the sample into account. For more details of the dose rate determination including internal and cosmic dose rate the reader is referred to Kars et al (2012).

With the following simple equation the age was calculated out of the dose rate and palaeodose:

Luminescence age (a) = Paleo dose (Gy)/Dose Rate (GY a^{-1})

This age was corrected for anomalous fading by applying the fading model of Huntley & Lamothe(2001)using the measured $pIRIR_{225}$ laboratory fading rate of 2.5 ± 0.4 %/decade.

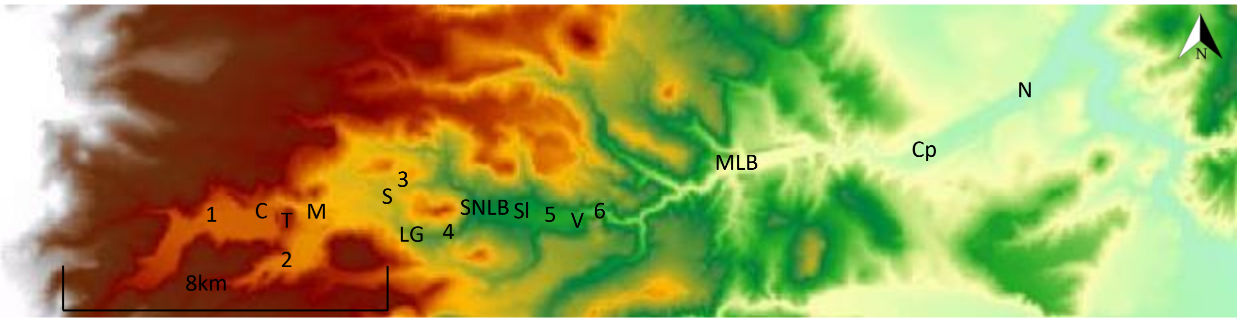
3 Results and discussion

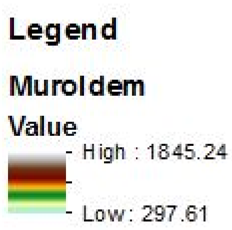
This section will be divided into two parts. Part 1 will contain the results from the fieldwork presented as an interpreted map of the different geomorphological processes. These processes will be discussed, which is partly based on the work of (Hofsteenge, 2017)and (Castrop, 2017). The interpretations made in the map also raise some questions about the processes and their chronology. This will be the start for part two, where it will be attempted to answer those questions and falsify or verify different hypothesis by OSL dating and modelling in ARC map. The outcomes of part one and two will be discussed together, and lead to the conclusion.

3.1 Part 1

The geomorphological map that was created will be discussed per process that as explained in the introduction are thought to have most impact in forming the landscape: volcanic activity, flood events and glacial processes. These processes are represented with different colours in the map. They will be discussed showing different fragments of the geomorphological map. This means that the process is shown that is discussed at that moment, but not necessary also is at the surface at that time. In that case the landform is interpolated, assumed it is present. This is shown by dotted instead of solid lines at the borders. Red colours are used for the volcanic processes, blue for the flood processes and green for glacial processes. Fault lines, indicating the edges of the different blocks in the Limagne rift valley are present as solid black lines over the map, and are based on (Boivin et al., 2017) After the three different processes the entire map (with legend) will be presented and discussed, showing what is at the surface and thereby also presenting the geomorphology.

Figure 11 contains the towns (letters) and valleys (numbers) that will be referred to in this section. The entire map and legend can be found in figure 36 and 37 at the end of part 1.





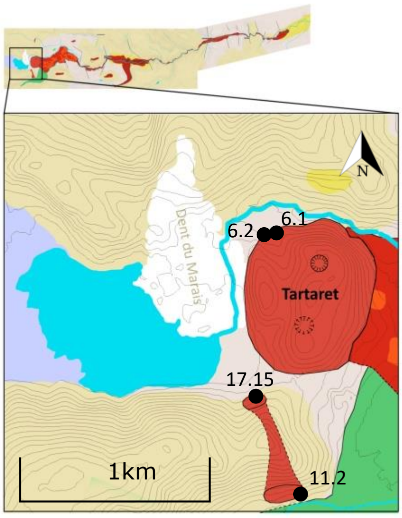
Legend letters (towns/locations):
C: Lac Chambon
T: Tartaret volcano
M: Murol
S: Sapchat
LG: Les Granges
SNLB: Saint-Nectaire les Bas
Sl: Saillant
V: Verrières
MLB: Montaiguit le Bac
Cp: Champeix
N: Neschers

Legend numbers (valleys):
1: U- shaped valley
2: La Planchette valley
3: dry valley
4: V shaped valley (at Les Granges)
5: Valley at Saillant (and Verrières)
6: Narrow valley past Saillant

Figure 11: DEM of the study area, showing the towns/locations (letters) and valleys (numbers) that will de be referred to in the field data discussion.

3.1.1 Volcanic structures

(Hofsteenge, 2017) has conducted a research to find out whether the Tartaret had one or more eruptions accompanied with scoria cone(s) and or different lava flows. The following will be a summary of her work, describing observations and interpretations from west to east.



On the location where the Tartaret is expected, a 100m hill, with red scoria is observed. At the North-East side of the Tartaret in a quarry (point 6.1 and 6.2), two walls of scoria with different directions are seen. One direction of layering points to the present day top part with a depression in the Tartaret hill. However, the other layering direction points to a possible second cone more to the east, which is now not observed anymore. However, there is a mention in literature about a second cone, which is mapped (de Goër et al., 1991). This and the two different directions of scoria layering indicate that at least two cones must have been present, and two cones are mapped in figure 12. In addition, the first one pointing towards the depression on top of the Tartaret hill as just described, is observed above the other one, indicating it is younger.

Figure 12: part of the geomorphological map around the Tartaret volcano. Left of the Tartaret is Lac Chambon and the landslide Dent du Marais. Two cones are shown on the Tartaret, further south some scoria is observed as well (point 11.2 and 17.15).

At the west side of the Tartaret (at points 11.2 and point 17.15) black scoria is found. Black scoria forms further away from the cone (in contradiction to the red) (de Goër et al., 1991), so this might belong to an older, wider cone of the Tartaret, which is presently not observed. The part of the map around the Tartaret can be seen in figure 13.

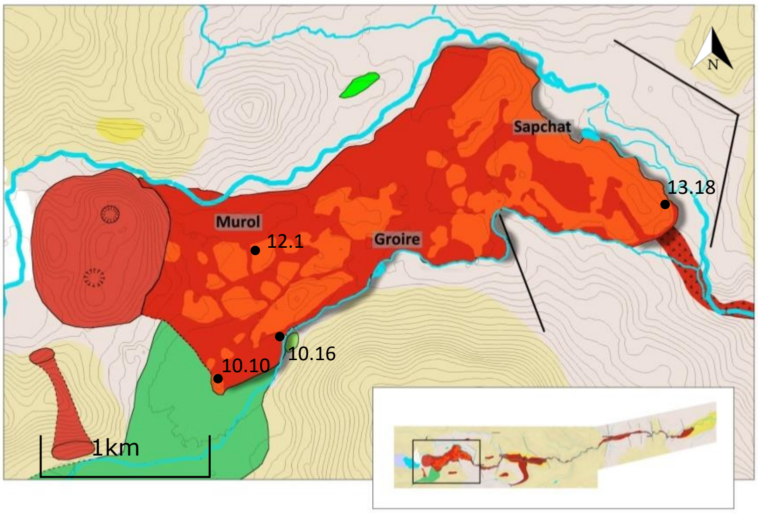


Figure 13: part of the geomorphological map between Murol and Sapchat. On the left side the Tartaret is shown (dark red). The lava flow is shown with bright red colour and secondary cones on the lava flow with orange. The river Couze Chambon flows north of the lava flow and the river La Planchette on the south.

Between Murol and Sapchat a general pattern of flat strips of pastures and small hills are observed, described by (de Goër et al., 1991) as a lava flow with small volcanic structures on top (see Figure 14).

These small hills show big blocks of basalt or scoria material and volcanic bombs (figure 15). The scoria material and volcanic bombs can be explained with the theory of rootless cones (Glangeaud, 1913): small hills that form after secondary eruptions, caused by the interaction of a lava flow with water (for example river valleys, wetlands or a swampy areas), and not from an actual vent as sis the case with normal scoria cones. Some of the hills with the more dense basalt could be seen as tumuli : rootles volcanic structures which form in relatively long lava flows with lava tunnel systems (de Goër et al., 1991). These type of rootless cones are also found in the Myvatn area in Iceland, as described by (Thorarinsson, 1979). However, they are normally not higher than 10m, so the higher hills in the Murol area maybe cannot be explained this way. Other possible theories for these larger hills, could be that they are remnants from a glacial moraine system or that they are the sides of collapsed lava tunnels.

Considering possible moraine structures they seem rather scattered over the whole area. In general. This moraine would not have the typical orientation perpendicular on the valley, and would be located on top of a lava flow. This would suggest a glacial advance after a Tartaret eruption, which gives around 15ka to build up to a sufficient extent in order to produce a jökulhaup, which does seem realistic but might be worth modelling. The theory of collapsed tunnels is more likely because all tunnels normally collapse within 10.000 years, and since the youngest eruption is estimated 13.000 ago that could be a possibility. (Huff & Owen, 2013). However, edges of collapsed tunnels would be expected at the edges of the low, and there are as the map shows also hills present in the middle of the flow. Also, a clear edge in the north is missing. In addition, the collapsed tunnel theory would not explain the presence of scoria. The southern border of the flow is drawn in the map by connecting the most southern small hill (point 10.10), the place where in situ basalt was found in the river La Planchette (10.16) and the Tartaret. The border in the east is drawn on a clear edge as seen on the DEM, where in situ basalt was still observed in the field (point 13.18, figure 16).

Figure 14: Volcanic bomb in scoria on a small hill in Murol, point 12.1 Figure 15: Wall of basalt, expected end of lava flow E of Sapchat(13.18)

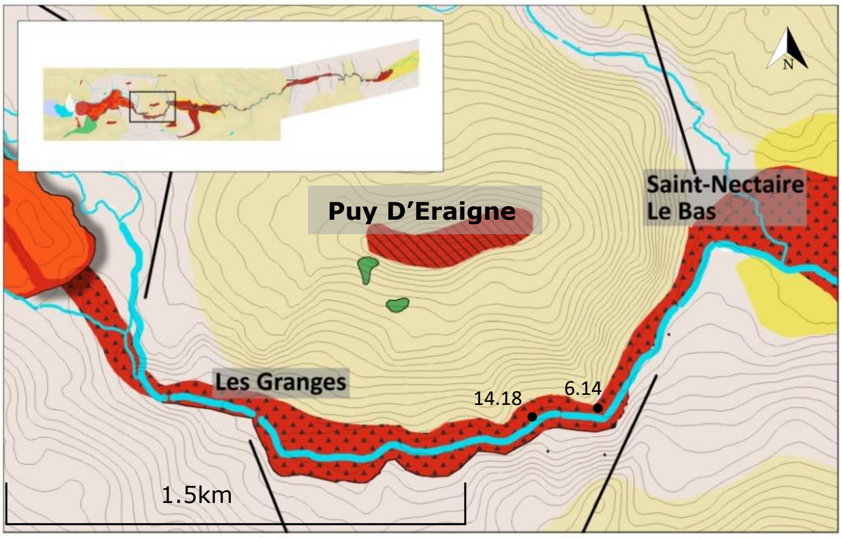


Figure 16: part of the geomorphological map between in the V-shaped valley of Les Granges. The lava flow is observed next to the river Couze Chambon. On Puy d'Eraigne north of Les Granges old Mont Dore lava is found.

In the V-shaped valley between Les granges and Saint-Nectaire le Bas, basalt is observed twice, both close to the river, as well as on the valley slopes. In figure 17 a hill slope basalt section is shown on top of a layer of granite. The height difference between the two observations is 7m. Considering the absolute heights these basalts are found around 700m, this is considerably lower than the older Mont-Dore basalts found elsewhere higher up in the area (around 900m). The basalt found here is therefore thought to be part of the Tartaret. It could be two different flows, but since there are no further specific observations they are mapped as one.

Figure 17: Contact between basalt from a lava flow and granite, approx. 7m above the river, point 6.14

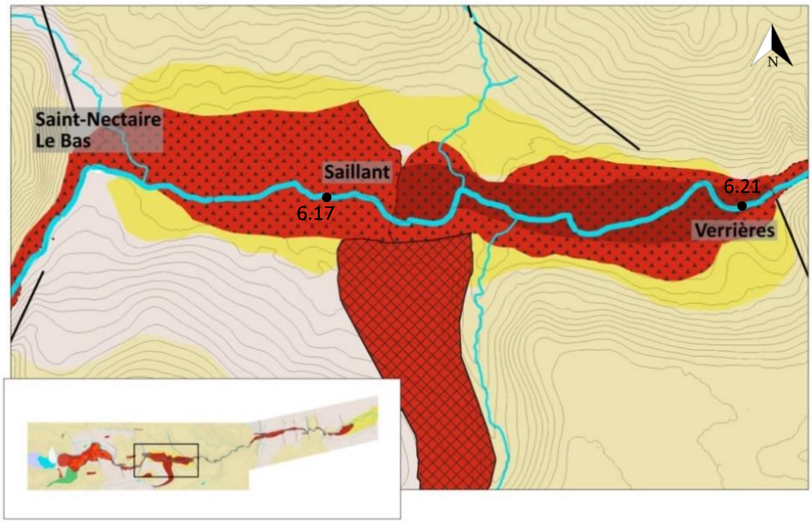


Figure 18: part of the geomorphological map in the valley of Saillant and Verrières. The lava flow is shown in red, with a collapsed tunnel in dark red. Note a lava flow with unknown age is situated in a side valley in the south (red with diamond pattern).

Figure 19: Pinnacle next to the river Couze Chambon in the town of Verrieres

As the valley widens, at the town of Saillant, in situ basalt is observed as well as a waterfall over basalt (point 6.17 see picture in figure 20). Further downstream, basalt with a thickness of 13 m and a basaltic pinnacle of 28.5 m is observed (point 6.12, figure 19). If this remnant pinnacle was part of a Tartaret lava flow (+- 10-30ka) and considering incision rates between 0.5-30cm/ka (Righter, 1997), it is even with maximum incision not likely that the Couze Chambon incised this deep. A possibility is the collapse of a lava tunnel, which also seems to be visible on the DEM (and is mapped in darker red in figure 18), but more remnants would be expected at both sides. The thickness of the flow could be caused by thickening / accumulation of the flow just before the narrowing of the valley. A third option could be that this pinnacle is a remnant from an older flow. Indeed, in a large side valley South of Saillant, in situ basalt is found, at 60 to 100 m above the present day Couze. This seems to be quite low for a Mont-Dore flow but too high for a Tartaret flow and is therefore expected to have an age in between these two known events.

Figure 20: waterfall in the town of Saillant, point 6.17

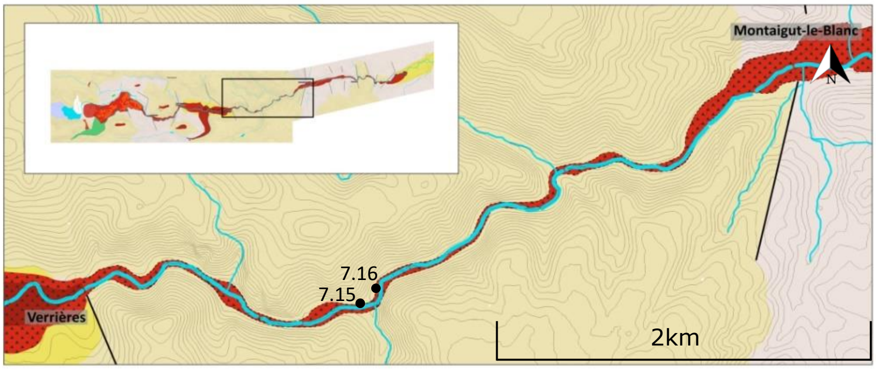


Figure 21: part of the geomorphological map in the narrow valley between Vèrrieres and Montaigut-le-Blanc

Figure 21 shows the narrow valley between Verrières and Montaignut-le-Bac, where a lot of granite and no in situ basalt is observed. The basalt could be eroded away, which is likely because there are no erodible Oligocene deposits present. Another possibility is that the river flows on top of the basalt, which is not likely since there was already incision in Verrières. A third option is that the lava flow did not record at all. Pinkerton and Wilson (1994) state that there are many factors influencing flow length and thickness, on being topography but also viscosity and effusion rate. It is therefore not unimaginable that flows do not record everywhere.

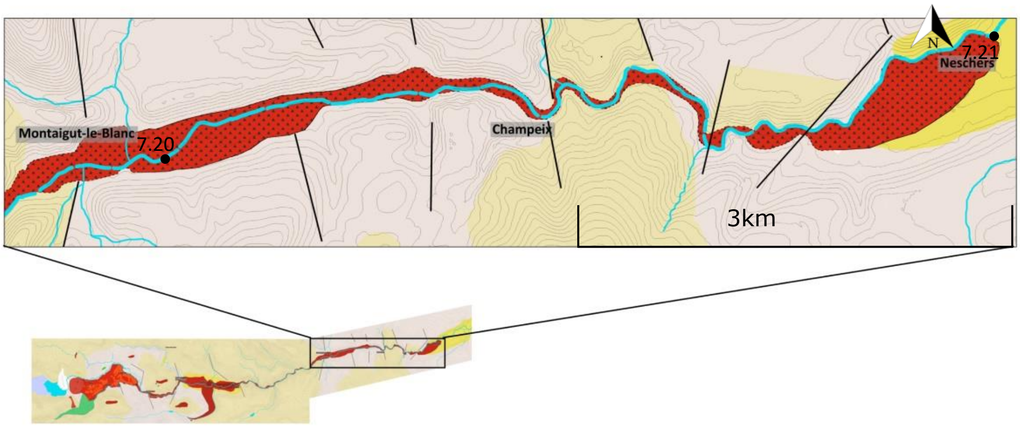


Figure 22: part of the geomorphological map from Montaigut-le-Blanc till Neschers

In the valley of Montaigut-le-Bac until Neschers (which is wider than the previous part of the valley and can be seen in figure 22) in situ columnar basalt is observed. Also in situ basalt is observed at Neschers (figure 23), where the surface level drops clearly, indicating this is the end of the flow. In the narrower part around Champeix no in situ basalt is observed.

Figure 23: In situ basalt at the end of the village of Neschers, point 7.21

Hofsteenge (2017) assumes there are two lava flows, one that reaches to Neschers and one that created the scoria cones close to the Tartaret. The main reason to assume this is that flood deposits were found at the surface downstream of the scoria cones. The scoria cones could not have resisted both a glacier or a large amount of water, the possible causes for the flood deposits. Therefore they must have formed after the flood. Since the flood deposits seem to be on top of a lava flow, two different flows are most likely, the one at Neschers being older than the one close to the Tartaret.

However, the conclusion on ages and chronology is the opposite of what is found in literature. Though both this research and literature suggest two flows, the perspectives on which flow is older than the other one is exactly reversed. This research suggest the Neschers one to be older, though literature says the opposite (Macaire et al., 1997; Pilleyre et al., 1992). However, so far only two dates of literature have been mentioned and discussed.

However, there are 24 mentioned dates in literature, including possible lava flows, tephras, and lake sediments. Some of those are double, referring to the same measurement or original paper. The remaining original datings are 2 C14 dates by Brousse, Maury, and Santoire (1976), 3 dismissed TL dates by Raynal et al. (1985), 2 Feldspar dates by Guérin (1983), 1 possible Tephra by Bastin, Gewelt, and Juvigné (1990), one lake deposit date by Macaire et al. (1992), and 1 to 5 TL dates by Pilleyre et al. (1992) .

The original dates will be discussed below. However, the oldest original papers either still have to be found or are in non-digital thesisses in a library in France (Brousse et al., 1976; Guérin, 1983; Raynal et al., 1985). The mentions of these dates will therefore be discussed. Different authors cite dates differently, and there is also some confusion about the use of the term BP. Furthermore, the methodology and origins of the material differ widely, possibly creating problems with the relevance of a certain date and comparing all the dates.

There are a few C14 dates mentioned. Cited in Nowell, Jones, and Pyle (2006) are a C14 date of 7.75±0.50 ka from a lava flow of the Tartaret in Verrières (Brousse et al., 1976). Also another C14 date is mentioned, again from 7.75±0.50 ka, from the Couze Chambon lava flow in Champeix (Brousse & Lefevre, 1990). In Pilleyre et al. (1992), 2970BP and 6900BP are mentioned as first attempts of dating Tartaret volcanic activity by radiocarbon on black sediments Brousse, Maury, and Santoire (1976).

Apart from carbon dates, there are also TL (thermoluminescence) dates mentioned. Miallier et al. (1994) state two dates from TL on Feldspar grains extracted from the lava flow itself at two locations just near Murol (Guérin, 1983) obtaining 28200 ± 2300 (95%) years and 27200 ± 2700 (95%) years. At first these dates seemed to be confirmed by another TL measurement, on quartz grains from backed sediment under the lava flow at Neschers (Moulin-sous-Chirel site) giving an age of 27000 ± 4000 years (Raynal et al., 1985). However, for this last quartz date the same authors assumed an error and recalculated their date, also changing from the blue signal to the red TL signal, obtaining 13700 ± 1600 (95%) years (Pilleyre et al., 1992).
This apparent confirmation and then recalculation as described by Miallier et al. (1994) is discussed more extensively in (Pilleyre et al., 1992). They mention the 28200 years B1980 date by TL on plagioclases (Guérin, 1983). Then the authors also dated this lava flow using the quartz inclusion technique with a blue filter (BG12 Leitz) (Raynal et al., 1985) and found an age of 27,000 B1980 in good agreement with Guerin's result. However, they repeated and improved the method with the RTL quartz technique and the resulting age was 13,700 ± 800 years (Neschers) However this is a weighted mean of 3 or 5 TL analysis (RTL and BN/BS) on different grain size fractions 15.1 ± 1.1, 16.4 ± 1.2, 13.0 ± 0.5 ka (RTL) and BN/BS (blue filter) leads to 16.4 ± 1.2, 18.2 ± 2.7 ka. A weighted mean does give more information and less errors, but the fact that they are different measurements (different methods) makes it more complicated.
In Nowell, Jones, and Pyle (2006) multiple TL dates are mentioned as well. Again the quartz TL date on a lava flow from the Puy the Tartaret at Neschers, here mentioned as 13.7±0.8 (Pilleyre et al., 1992). Also the TL dates on baked quartz under the Tartaret lava at Neschers (Moulin sous-Chirel) by (Raynal et al., 1985) are mentioned as (28.2±2.3) (27.0±4.0) (27.2±2.7), but also to be dismissed by Pilleyre et al. (1992). And the TL dates of 27.25±2.7 on assumingly feldspar (citing does not state this specifically) at the Couze Chambon at Murol by Guérin (1983) and TL date of 28.25±2.3 on assumingly feldspar at the Couze Chambon south of Sapchat by Guérin (1983) are mentioned. Then Bello, de Groote, and Delbarre (2013) also mention the thermo-luminescence analysis of a sample of sediment found under the Tartaret lava flow, to provide approximate dates for the Neschers site of 15,300 to 12,100 BP (Miallier et al., 1994; Raynal et al., 1985).

Apart from the C14 and TL dates, Maillier et al 1994 mention two other dates. Firstly, the dated Tartaret lake sediments are mentioned as 12450 ± 100 BP (Macaire et al., 1992), which after calibration would lead to 15037-14241 before present. It is not completely clear however how “present” is interpreted here: as BC or as an old C14BP year. The second date is from tephra at (tourbes du Cézallier), which is hypothetically linked to the Tartaret and dates at 10750 ± 230 BP(Bastin et al., 1990). The authors mentioned 2 options for this tephra date: i) yet another younger Tartaret eruption (Clearly different cones at Murol), or ii) this tephra is from another volcano.

This overview from literature shows there are a lot of mentions, which slightly differ, and that there are different methods used on different materials, and different standards in documenting BP for instance. Combined with the findings in this section of Hofsteenge 2017, it can be said with certainty that there was at least one eruption of the Tartaret that produced a lava flow. To be sure of a second flow, irrefutable evidence has to be found in the field which is either an observation in the field of two flows with a clear contact surface, or two clear hard dates from literature on different units. This has not been found, but literature and fieldwork do give clues for a second flow. It does seem logical to have had 2 eruptions, since after an eruption with a flow the cone gets destroyed and a horseshoe shape remains. Since a clear cone is visible in the landscape, another build up face (which happens during an eruption) would have been necessary.

To go back to the conclusion of Hofsteenge, the contradictory findings are either an error in the datings in literature (of which (Pilleyre et al., 1992) is doubted most by Hofsteenge (2017)), or in our interpretations. Since the flood can have other origins than a jökulhaup (as explained by Castrop 2017)), the lava flows could be from the same event. Also, though different steps and other clues for two flows are observed, there is no clear contact between two flows observed. The possibility that the lava flows are the result of one eruption cannot be excluded.

3.1.2 Flood event

Castrop (2017) has conducted a geomorphological analysis for evidence of an extreme flood in the Murol area. The following will be a summary of her work.

The aim of the study was to see if there were geomorphological features in the landscape to support the hypothesis of a flood event. Remnants of a flood could be large boulder erratics, a large amount of displaced sediments or mega-ripples (Judith Maizels, 1997). Geomorphological features indicating large fluvial events have been found in the study area.

The most significant observations for possible flood events were done in the La Planchette valley south of Murol, the dry-valley North of Sapchat, and the wide valley east of Saint-Nectaire le Bas and in the valley east of Neschers. These observations will be discussed going from west to east (away from the Tartaret).

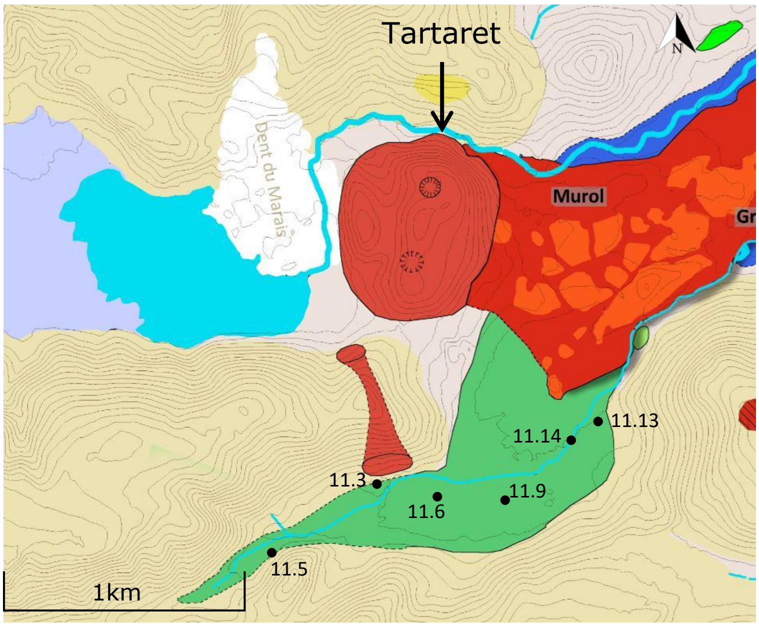


Figure 24: part of the geomorphological map with the La Planchette valley

Figure 25: sediment section in the river bend of la Planchette (11.14). Hammer for scale.

The valley south of Murol, where La Planchette flows through, shall from now on be referred to as the "La Planchette valley". If La Planchette would be blocked for some reason, water could accumulate in the valley, forming a temporary lake. A logical cause for blocking would be the presence of the glacier, using the valley for some marginal meltwater and creating a margin lake. To support this theory a lake deposit (mostly clay, uniform) is expected in the valley. The observations done at five augurings and one cross section observed in an outer bend of La Planchette show however a different pattern (points 11.3, 11.5, 11.6, 11.9, 11.13 and 11.14, see figure 24). The texture becomes finer with elevation (valley inwards): clay becomes more dominant, and finer sizes of sand and gravel are observed. Point 11.3, halfway the valley, contains clay, but also sand and moderate rounded gravel. Point 11.5 contains a smaller and finer sand and gravel fraction. However, the general trend is that the sorting is bad so it could be doubted if it is possible to even observe a trend.

In the bend in La Planchette a 2m thick sediment section was observed, consisting out of different layers of clay, sand and gravel, of approximately 1cm thick (figure 25). The presence of sand and gravel, alternating with clay, might indicate more a fluvial deposit than a lacustrine one. For a lacustrine deposit a uniform clay lake deposit would be expected. However, there has to be clay present in the source area in order for it to be deposited. Since the most important basement rock in the Mont-Dore massif is granite, it could also be that there was simply not enough clay possible to deposit. Even so, sand and gravel are not expected when there is long term standing water.
A fluvial deposit does not seem most likely either. There is no flow direction or clear foresets observed in the layers: there are too many horizontally deposited layers to be a typical river system. It seems like a large total amount of sediment compared to the size of the river and its catchment area (the shoulder).

The irregularity of the different materials in a small spatial scale reminds of a braiding river system, and therefore a glacial-fluvial deposit could be a possibility. Also, it could be that the clay layers refer to short term presence of lake, where the coarser sediments are higher energy systems, but with poor flow channel conditions. So the combination of those two would more look like a low angle fluvial sheet flow. Noteworthy is that the texture gets finer with increasing elevation, which can be associated with greater water depths or a vegetation signal. To sum up, a sandr like deposit seems most likely, but short term accumulation of water (a short term lake) is not dismissed. Since the present valley has not a V shape but a wider shape, and sediment deposits are found, it is at least clear that sediment accumulation, probably from the higher catchment area of the Couze Chambon, took place.

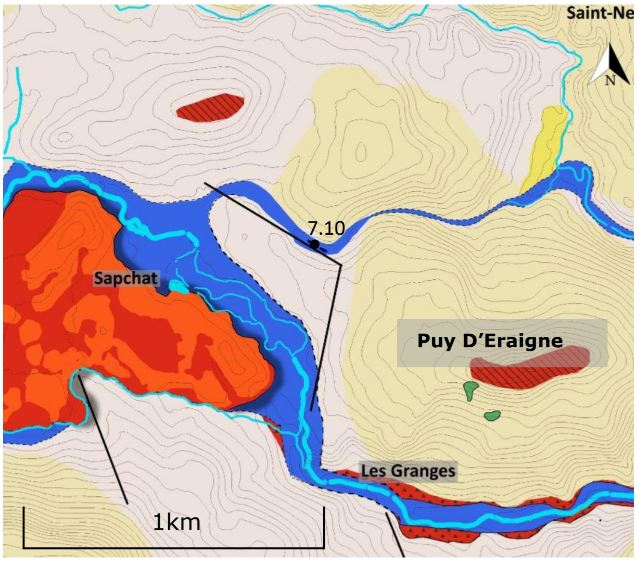


Figure 26: part of the geomorphological map with the dry valley, north of Puy D'Eraigne

Figure 27: ripple consisting out of boulders in the dry valley (point 7.10)

North of Sapchat and the main valley of the Couze Chambon, a so called "dry valley", cut out in granite, is observed (figure 26). This valley of about 1.5km by 100 m is currently not used for water flow. The valley is roughly 10m higher than the Couze Chambon. This would mean that in an event with a water flow of about 10m in depth, this valley might be used. An extreme flood would be such an event. In the valley a strip of loose basaltic and granitic boulders (diameter 0.5 m) is found (figure 27), and on the valley floor unsorted material is found. Both are erratics suggesting it is transported material, deposited before the width of the valley drastically decreases (Judith Maizels, 1997).

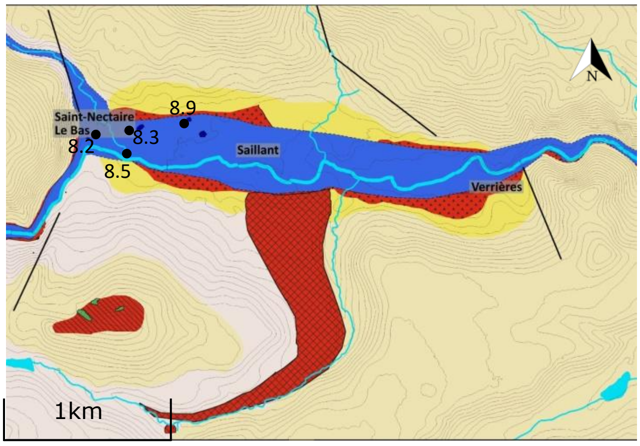


Figure 28: part of the geomorphological map between Saint-Nectaire Bas and Saillant

Figure 29: unsorted sediment deposition. Absence of layers le indicate one event

Between Saint-Nectaire le Bas and Saillant the valley floor is relatively flat and wide (figure 28). In a recent opened trench (figure 29) at least 1.20m of poorly sorted sediments (stones and pebbles of basement and volcanoclastic origin floating in a clayey matrix) are observed. Also, large boulders (e.g. 8.2 and 8.3), ranging from 2.5m to 13m in diameter are observed, throughout the valley. Often the boulders were partially incorporated in the ground and several boulders had extra sedimentation piled up on the eastern slope, indicating a flow from the west. A flood deposit is mapped based on these observations (figure 29). Since the material is for a large part still at the surface, and the lava flow is also thought to have flowed through this valley, it is most likely that the flood deposit is on top of the lava flow. The study of the Allier terraces (Veldkamp & Kroonenberg, 1993) place a possible flood event in the last glacial maximum, which is between 26.5 and 19-20 ka for the northern hemisphere (Clark et al., 2009). Since the flow reaching Neschers is dated 13.700+-800BP (Pilleyre et al., 1992), the chronology of the observations are contradictory with literature. It could be that the LGM and following deglaciation are different for this specific area, enabling a flood after a lava flow in 13.700 BP.

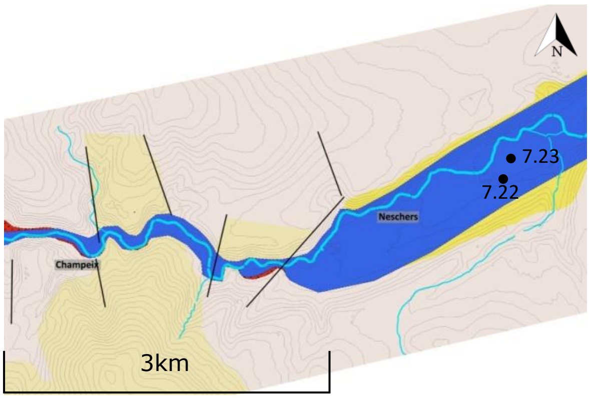


Figure 30: part of the geomorphological map east of Neschers, showing the flood at the surface

Figure 31: Very wide and flat valley east of Neschers

East of Neschers, downstream the Couze, downstream the supposed end of lava flow a wide valley was observed with two clearly distinguishable levels (with 10m height difference), indicative for two former flood-plain levels or river terraces (figure 31). In the lowest level a layer containing clay and rounded gravel of at least 110cm thickness was observed. The mix of material and structures indicates transported material. Terraces like these are indications of a hyper-concentrated flow (Judith Maizels, 1997), a flow with behaviour between "a mudflow and a common streamflow" (Beverage & Culbertson, 1964). To conclude if this terrace is the result of a hyper concentrated flow (as mapped in figure 30), calculations of the required amount of water to transport this amount of sediment (and the large boulders found) is needed.

Castrop proposes three theories to explain the flood features found in the field. The three theories are all examples of catastrophic flood events. Two non-catastrophic events, gradual melting of a glacier and slow discharge of lac Chambon, are also part of the possible causes for the found geomorphological features.
The first theory is the collapse of lac Tartaret. In favour of this is that it would have occurred after the last eruption from the Tartaret, explaining why the sediment after Saint-Nectaire le Bas is on top of the lava (Macaire et al., 1997; Pilleyre et al., 1992). Contradicting this theory is the fact that the Tartaret cone is still blocking part of the outflow of the lake. Since the cinder cone exists out of porous material, a catastrophic flood would likely erode it (Hickson, Spurgeon, Tilling, & Adam, 2013). A non-

catastrophic emptying of the lake would leave the cone relatively untouched. Modelling is needed to test the theory.
The second theory is a glacier outburst flood, in Iceland known as Jökulhaups. A glacier could have been present during the activity of the Tartaret (Etlicher & De Goër De Hervé, 1988; Pilleyre et al., 1992). A Jökulhaup can occur if a glacier covered the Tartaret eruption vent while it starting to erupt. The geothermic activity and interaction with lava will make the ice melt, if this water can be contained (within or on top of the glacier) until it suddenly releases a large volume, it will result in a catastrophic flood (Carrivick, Russell, & Tweed, 2004). Only thick glaciers are able to contain the melt water, in contrast to thin glaciers. Thin glaciers are 100-150m in thickness and thick glaciers are 400m thick or more (Smellie & Skilling, 1994). Since the last Tartaret eruption was after the last glacial maximum (Clark et al., 2009; Pilleyre et al., 1992), and since the fact that the end moraines of the glacier are expected to be in this area (Etlicher & De Goër De Hervé, 1988), it seems unlikely that the glacier was thick enough to facilitate such a catastrophic flood event
The third theory is an ice- margin lake, which could have occurred in the La Planchette valley south of Murol. If the glacier blocked this valley, the glacial meltwater could accumulate in the form of an ice margin lake, which would suddenly drain once the glacier retreated. The deposits found did not solely referred to a lake, a sandr or another stream area is also a possibility. The option of a (short term) margin lake however is not ruled out.

The conclusion is that geomorphological features are found indicating large fluvial events which may have been catastrophic floods. However, without calculations it is impossible to draw the conclusion if there was a flood (emptying lake Tartaret, jökulhaup or ice margin lake) or enhanced discharge (Tartaret lake or melting thin glacier).

3.1.3 Glacial processes

In the following sections the observations and their interpretation that could be related with glacial processes will be discussed from west to east in the study area.

3.1.3.1 U shaped valley

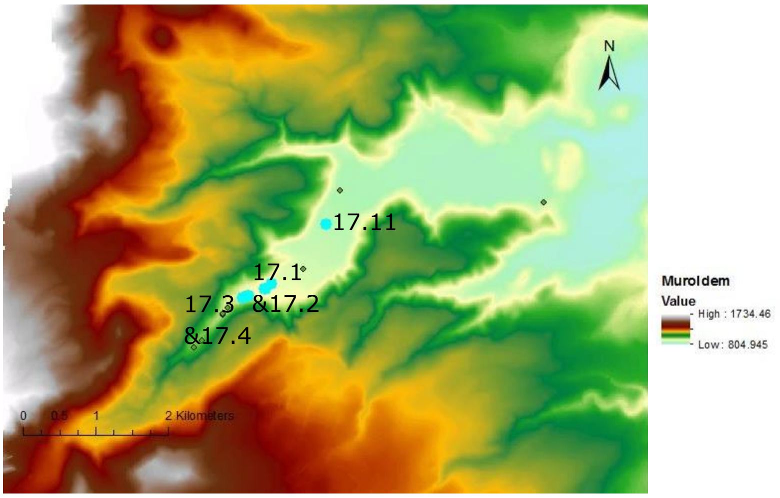


Figure 32: DEM of U shaped valley with data points (in bleu), discusses in this section

Upstream of the Tartaret, a clear U-shaped valley is present, coming down from the Mont-Dore massif. This part of the study area is stream upwards of the area were flooding and lava flows play a role. The U-shape valley is supposed to be untouched by any lava flows or catastrophic flood events, which are all expected to happen downstream of the Tartaret. It therefore offers an insight into the glacial remnants that could be found in the valley downstream. In the geomorphological map it is not mapped in detail, only the Tartaret lake deposit is shown in the east part of the valley, but the observations done in the valley are discussed below. The data points are shown on the DEM in figure 32.

Multiple observations that could be glacial relicts, both depositional and erosional, are found in the valley: large boulders of different lithologies (including granite, basalt). Locations 17.2, 17.3 (figure 33), 17.4 and 17.5 are small elongated hills, of about 5 m high, with large boulders, orientated mostly perpendicular to the direction of the valley. They could therefore have been part of (recessional) moraines. At 17.3 also a stone glacier is observed. 17.1 and 17.3 (figure 33) are small, isolated, hills, elongated in the direction of the valley, and remind of drumlins. A similar shape is found at 17.11 (figure 34), but the sharp downstream (lee) side refers more to a Rôche Moutonnée. However, these are rough interpretations, but it does indicate glacial presence. A sequence of moraines and the presence of a drumlin would indicate a retreating glacier, where a stone glacier points at periglacial conditions. These clues would be in favour of a more gradual retreat from a glacier, as opposed to a sudden disappearance (for instance by a jökulhaup).

Around 2.5km west from the current Lac Chambon, the border of lake Tartaret is expected to be found (Macaire et al., 1997). Everything downstream from here is old lake bottom sediment, covering possible ground moraines. The U valley stops around the Tartaret Volcano.

Figure 33: hill at 17.3, possible part of (recessional) moraine *Figure 34: hill at 17.11 with sharp edge (left in picture), Rôche Moutonnée like*

3.1.3.2 Valley from Murol until Sapchat

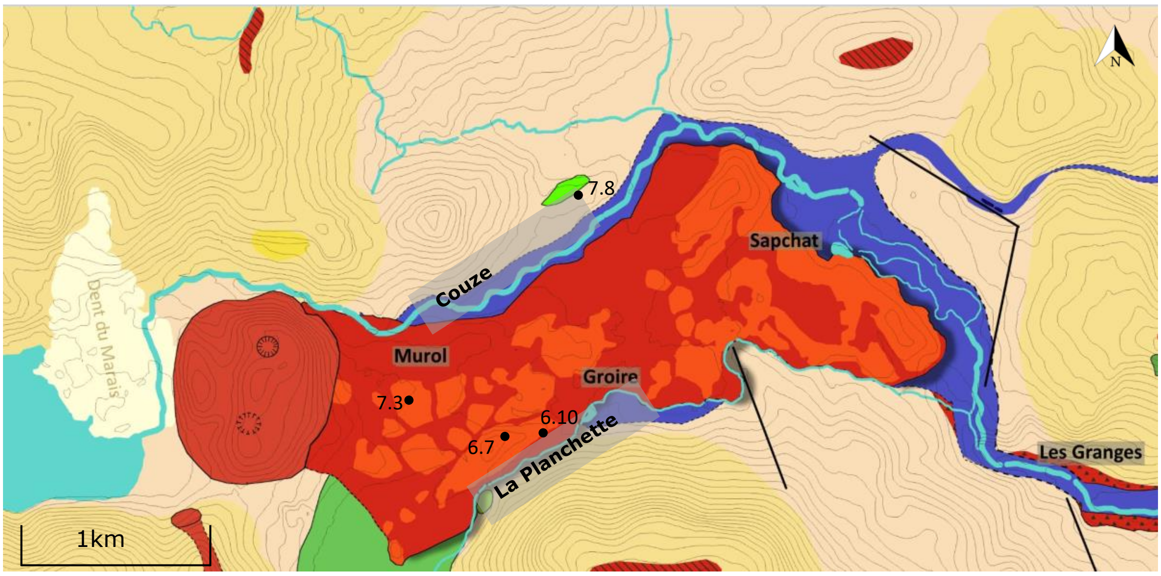


Figure 35: part of the geomorphological map between Murol and Sapchat. The push moraine can be seen in bright green North of the Couze Chambon river. The orange patches are mapped as secondary cones but could have been part of a larger moraine structure

See figure 35 for the detailed map of this section. In this valley a lot of small (until 20m altitude) hills are observed. They consist mostly out of porous basalt and scoria, though dense basalt is observed frequently as well, sometimes in big blocks (e.g. 6.7 and 7.3). See Hofsteenge (2017) for an executive description of these hills, and a summary in section "volcanic structures".
Some hills have features that can indicate they were once part of a moraine: they have a drainage pattern starting without a clear catchment area, and ending on a plain that is not connected to the current drainage system. The catchment area could be a now disappeared glacier, and the plain show sandr like features, for instance at point 6.10.
The theory that all these hills are part of one larger end moraine is however discarded. If all the hills are connected, it results in a very thick band orientated from southwest-NE. This is not fully perpendicular on the orientation of the U-shaped valley, which is what you would expect for an end moraine. Also for a lateral moraine the orientation is not completely logical, and the width is quite large compared to the U-shaped valley and the possible size of the glacier.
Secondly, the material is not what could be expected in a moraine. It is mostly basalt, both dense and porous. A moraine should contain every available source material, unsorted. Hills of mainly one material are therefore less likely to originate from a moraine. What could be a possibility however is that for instance the scoria cones where moved by a glacier all together. However, that seems less likely since there is a sequence of scoria cones. Since scoria is very erodible some of the cones should be washed away by the glarier. Related to that is the last reason why it does not seem likely that the sequence of hills is a moraine: the glacier melted at a certain point in time, and since scoria is erodible it is likely that the hills would have been washed away by the water.

The only feature that could be interpreted as a moraine is found a little north in this valley, underneath the castle of Murol (point 7.8). Here an elongated hill from approximately 10 m in height can be seen. The bottom of the hill consists out of a lava flow on top of what could be fluvial deposits (mixed sediment, including rounded gravel). This is interpreted as a (lateral) push moraine. Main clue for this is the lava flow that seems to be "pushed" on top of the elevated sediments (figure 36).
A bit further southeast, another hill with a similar shape, though larger was observed. This hill contained various possible stream channels and saddles. However it was dismissed that this could be a lateral moraine, due to the similarities with the other hills, the absence of a clear "pushed section" (as in 7.8) and the fact that combined with 7.8 the resulting lateral moraine would be very wide and far to the centre in the valley compared to the valley and the possible size of the glacier.

Figure 36: the hill at 7.8, interpreted as push moraine. Lava flow can be seen on top of the river deposit

3.1.3.3 La Planchette valley South of Murol

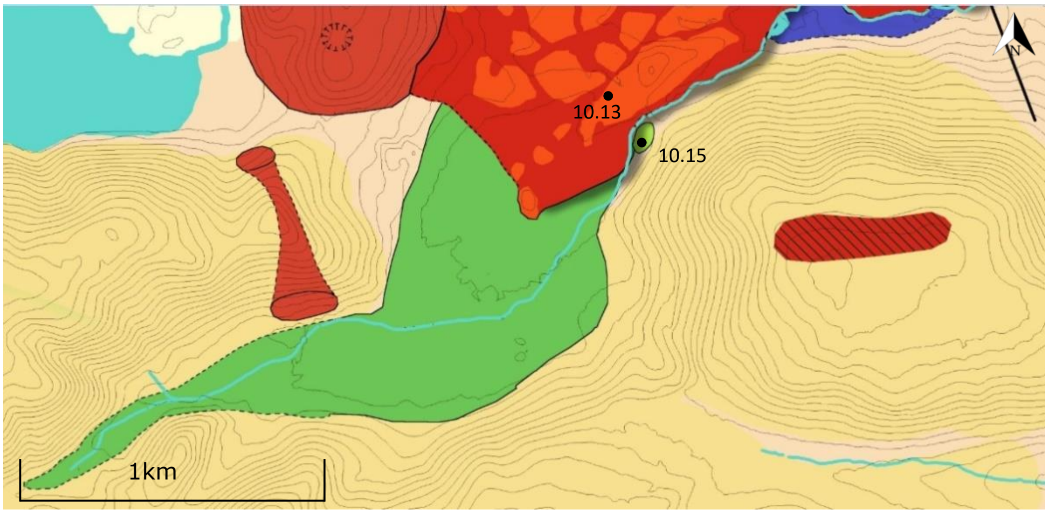


Figure 37: part of the geomorphological map with the La Planchette valley. In the north-east, just east of la Planchette, the sinkhole is present (light green).

See figure 37 for the detailed map of this section. South of Murol, a valley is observed, which is drained by the river La Planchette. In glacial times, this valley could have been blocked by a glacier in the main valley, forming a margin lake. This theory and the observations are discussed in section “flood event”. Conclusion by (Castrop, 2017) is that the valley was most likely a sandr. However, as argued, the theory of a (short term) margin lake is also a possibility.

Another possible glacial landform is observed on the east edge on the entrance of the valley. Here, a low in the landscape of 80 (N-S) by 50 (E-W) m without a clear outflow direction is observed (point 10.15). The size is possible to be a sinkhole or kettle hole ((Flint, 1971) as cited by (J. Maizels, 1977)). Directly downstream the valley narrows into a V-shaped incision, so depositional landforms would be expected here, right before the entrance to the valley. A sinkhole or kettle hole could therefore be present here. Note however that there is no water in this low, either because there is not enough supply or because there is drainage after all. That drainage is however not present in a surface outflow direction, so the interpretation of being a sinkhole is not changed. Other lows were observed as well, but with a clearer outflow direction and not as clear round as this one. Therefore the conclusion of sinkhole was only drawn once, but it must be noted that multiple flatter plains are present (e.g. 10.13, 15.8, 15.13 outside of map)).

3.1.3.4 V shaped valley between Les Granges and Saint-Nectaire le Bas

See figure 39 for the detailed map of this section. In this part the valley narrows into a V-shape, since this part is a horst in the horst graben system. The horst consists of granite and is more difficult to erode than the Oligocene sediments that filled the graben. The V-shaped valley also indicates the fluvial influence over the glacial influence. Since the V-shaped valley is in between two larger outcrops, mapped as Hercynian granite (basement rock) with Mont-Dore volcanism (between 3.2 and 0.2 MA (Nomade, Scaillet, Pastre, & Nehlig, 2012) , here probably 0.6 MA (Nowell et al., 2006) on top, which is due to relief inversion (Harris, 1968). Since glacial activity took place here later (23.000-19.000 years,(Hughes, Gibbard, & Ehlers, 2013)), it is likely that the glacier stopped before this valley, because otherwise a U-shaped valley would likely be observed.

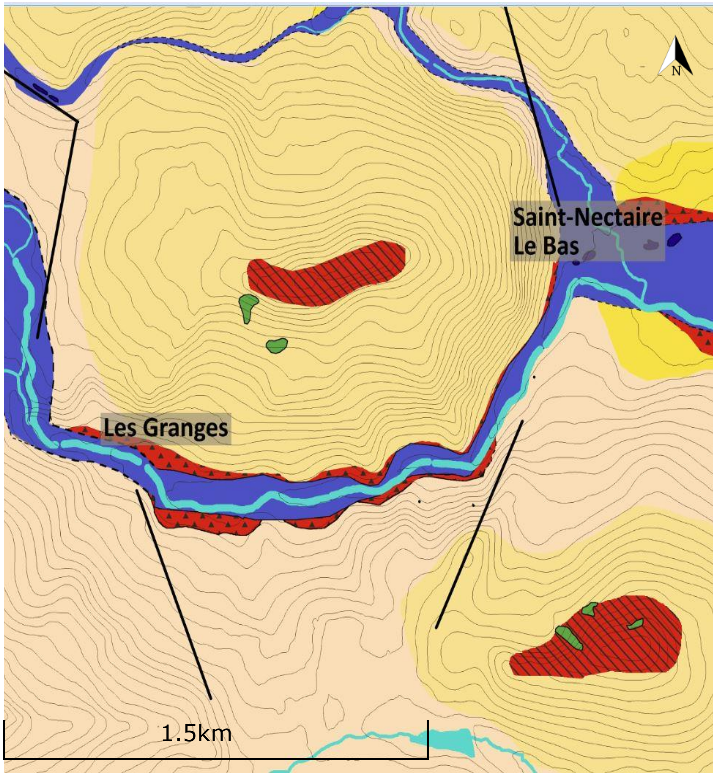


Figure 38: part of the geomorphological map in the V-shaped valley between Les Granges and Saint-Nectaire le Bas. The stone glaciers (green) can be seen at both (north and south) edges of the valley

The periglacial influences that can be seen however are the stone glaciers on the sides of *Puy d'Eraigne* and *Puy de Conche* (figure 39 and 40). Since stone glaciers are a periglacial phenomenon, glacial processes took place here after the deposition of the Mont-Dore basalts (since the rocks in the stone glacier are mainly basalt).

Figure 39: stone glacier at Puy de Conche

Figure 40: stone glacier (in circle) visible at Puy de Conche, seen from Puy d'eraigne

3.1.3.5 Part between Saint-Nectaire Le Bas and Verrieres

See section 3.1.2 detailed map of this section. Here no glacial features as such have been found, however the entire area is covered in a thick (extreme) flood deposit, see (Castrop, 2017). This cover is at least 1.60 m thick, as observed at point 8.5 and 8.9. Boulders and stones, both rounded and angular with a diameter of at least 40-50cm supported in a clay matrix are found. It is much unsorted. This is interpreted as a mud flow or a debris flow. However, this material has to come from somewhere. Taken into account that the valley just upstream is probably too narrow to deposit or erode such a quantity of sediments , the materials must have come from further upstream the valley.
Since end moraines could be expected there but have not been found, there could be a possibility that this deposit is derived from washed away moraine sediments. The presence of large boulders at the surface, described by Castrop as erratics, support this theory, since they could have been part of a moraine complex. To prove this however, modelling is needed to calculate what volumes of moraine sediments.

3.1.3.6 Part between Verrières and Neschers

From Verrieres until Montaignut le Bac the valley narrows and after that until Neschers it widens again. No observations of (peri)glacial landforms have been made, which makes sense since the glacier is expected to have ended upstream, and the main influences here are the lava flow and flood event. However, again a thick deposit is found at 7.22, a flood deposit is therefore also mapped here (section 3.1.2). Also different terrace levels are observed, see (Castrop, 2017). This could indicate multiple flood events. Since this valley is further downstream from the expected place of moraines, it is less likely that they have been the source for all this material, but it could have played a part.

3.1.3.7 Conclusion glacial processes

In conclusion, there are not a lot of glacial relics present in this area because they could either have been covered or destroyed by volcanic and fluvial (flood) processes. However, due to the U-shaped valley, the presence of sediments and materials in the area, the presence of frost processes and the fact that the other two processes relate to flood as well, the presence of a glacier is certain.

3.1.4 Overall conclusion part 1

The sequence of events as shown in the map of figure 39 are first a glacier, which formed the U-shaped valley. After that an eruption, possibly melting the glacier and producing a lava flow reaching to Neschers. At a later time, a flood from either a new glacier, an ice margin lake, or the Tartaret Lake, destroying any moraines and creating a deposit and boulders on top of the previous flow. In these still present wet conditions another lava flow creates the secondary cones around Murol. This would explain why the secondary cones and the Tartaret cone still stand upright, and why there is a flood deposit on top of a lava flow. Because it should be the other way around if they are from the same event. However, as (Hofsteenge, 2017) pointed out, the aforementioned conclusions might be in contradiction with literature.

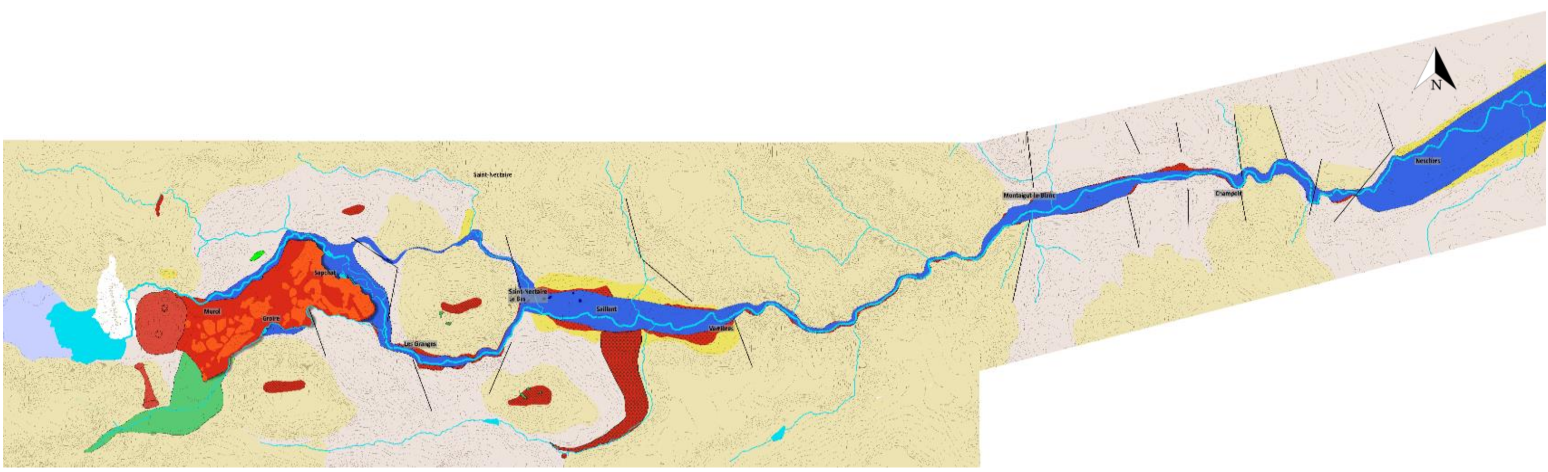


Figure 41: the entire geomorphological map of the study area

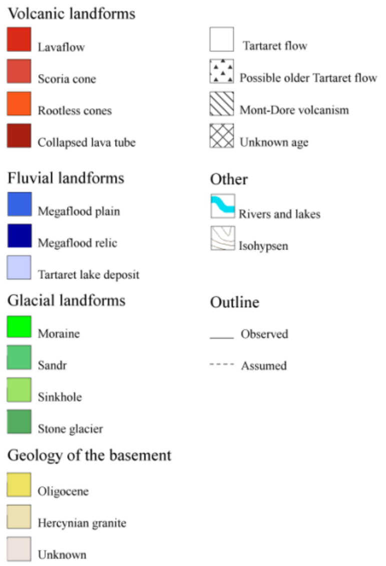


Figure 42: legend for figure 44

3.1.5 Recommendations part 2

The biggest question marks seem to be in the amount of water needed to create the found flood deposition and the origin of this water and the sediments. For lava, the question remains if there where one or two flows and in which chronology. Lastly, the extent of the glacier is still a question mark. In order to answer these questions, further analyses are needed.

Three samples have been taken from locations 9.1, 11.16 and 14.17, two which are xenoliths (granite inside basalt), and one scoria sample (9.1) which is thought to be from the Tartaret cone that caused the blockage of the lake. Those three will be dated if possible with the use of OSL, and if successful, give more clarity about the lava flows and their chronology.

The rest of the analysis will be conducted with ArcGIS. Those analyses are:

- An estimation of the volume of the Tartaret lake
- An estimation of the volume Planchette lake
- An estimation of the volume of the Glacier
- An estimation of the volume of the sediment in the valley Saint-Nectaire le Bas – Verrieres
- Analysis of the profiles of the Couze Chambon and La Planchette
- Estimation of the flow velocity of water and lava through the V-shaped valley

The first three estimations are of the water volumes of the possible sources for an extreme flood event, in which the third also gives more insight in the glacier. The fourth can lead to an estimation of the end moraines, and an answer to the question whether they could have been the source for this sediment. The fifth will give more insight in the rock over which the rivers are incising, and the presence of bedrock or lava flows at different locations. The last one enables an estimation of the rise of water and lava, and the velocity it could have had, which for water relates to the sizes of material it can have transported, which are found further downstream. For lava, it might explain whether or not the found height differences in the lava flows refer to two different events, or if it could have been one flow (or two at the same event).

3.2 Part 2

This segment contains the result and the following discussion of the analysis proposed based on the outcomes of part 1. These analysis were creating river profiles (using Arc GIS), calculating flow times of different water origins (using Arc GIS and the Chézy equation), and determining the age of a rock sample (using luminescence). Since some of the inputs for these analyses were dependent on the outcomes of part 1, those inputs are not discussed yet in the method section and will be discussed here. Next, the results will be presented and discussed, and the section will conclude with an overall discussion of part 1 and 2 together and a look at the broader scope of this research.

3.2.1 River profiles

3.2.1.1 Inputs

The following decisions were made for where to draw the profiles in the flow accumulation map. For the Couze Chambon it started in the source area on the Mont-Dore Massif where two rivers (with lower flow accumulation) unite, until the point where the Couze Chambon joins the Allier River. For La Planchette the starting point was where there was clear accumulation in the Massif, until the Couze Chambon was joined. In figure 45 the flow accumulation map can be seen, showing the streams. The figure is a bit unclear, but two lines (a darker one at the top, Couze Cahmbon) can be seen.

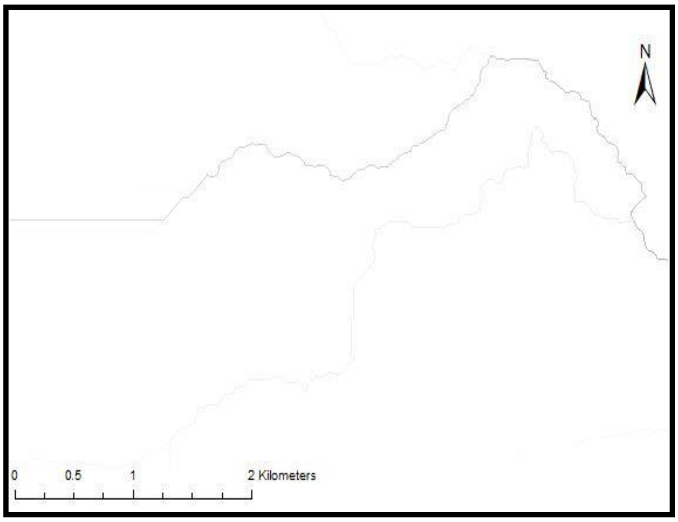


Figure 43: fragment of the flow accumulation map. The darker the line, the higher the flow accumulation is. Darkest line is Couze Chambon (flat part in west is Lac Chambon). Lighter line underneath is La Planchette.

3.2.1.2 Outcomes

Figure 47 and 48 show the profiles of the Couze Chambon and La Planchette. It can be seen in the graph of the Couze Chambon that the total drop is 539 m over a segment of 33.716, leading to an average slope of 0.016, or 1.6 percent.

In figure 46, noteworthy points are marked in the graph. The blue arrows point out sudden drops in the profile. A sudden drop indicates incision cannot happen smoothly, in other words, the river is cutting into bedrock that is more resistant to erosion than sediment depositions. Arrow 1, which is the largest drop, corresponds with the V-shaped valley, which is indeed a location where the river is cutting into bedrock. The second drop (arrow 2) is observed just after where a lava flow of unknown age enters the valley of the Couze from the south. This lava flow would only explain the observed drop if it caused any movements in the middle of the Couze Chambon valley, since the flow itself is a hanging valley and does not interfere with the flow path of the Couze Chambon. The water fall of Saillant, which flows Cleary over in situ basalt (lava flow), and which can also be seen in the DEM, occurs around 12000m and only accounts for a small drop in the profile. The other arrows however do not correspond to anything observed in the field or in the DEM afterwards, though they might correspond with fault lines, as will be explained later on (this was hard to check on the DEM). The parts of the graph encircled in red are where the altitude increases instead of decreases. Since water always flows downwards, this has to be an error. The most plausible explanation for this is an error in the sampling of the graph: a line has been drawn by hand in the flow accumulation map, and could sometimes end up a bit outside of the highest accumulation, therefore taking a wrong altitude into account. Since the altitude increases are only 1 or 2 m every time, which is a small percentage of the entire discharge, they are discarded as measurement errors.

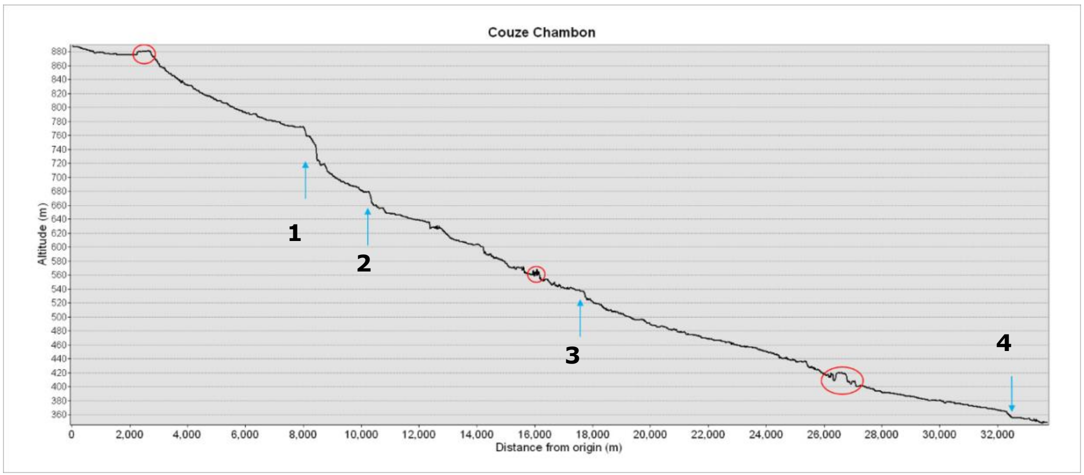


Figure 44: altitude distance profile graph of the Couze Chambon River. Blue arrows indicate sudden drops, red circles indicate where the river according to the graph flows upwards instead of downwards, and this is thought to be a measurement error.

From graph in figure 47 it can be seen that the total drop of La Planchette is 122 m over a segment of 6565 m, leading to an average slope of 0.019, or 1.9 percent.

Here the red circles also point out areas where altitude increases. It is clear that this happens more often than in the graph of the Couze Chambon. Since La Planchette is a smaller river and the total drop is less as well, it is thought that the profile is more vulnerable for outliers and inaccuracies.

The blue arrows point out again sudden drops in the graph. The second drop (arrow 2) is around the exit of the La Planchette valley, the forth (and most steep) drop (arrow 4) is when La Planchette joins the Couze Chambon (just before the V shaped valley of the Couze Chambon). Both drops could be at the end of a certain geomorphological unit, formed differently than the unit coming afterwards. This is supported by the observation in the DEM at the last drop, where the valley of the Couze Chambon seems to be clearly lower than la Planchette. The other two drops (first and third arrow) do not correspond with any field or DEM observations (and are also less distinct than the two discussed before).

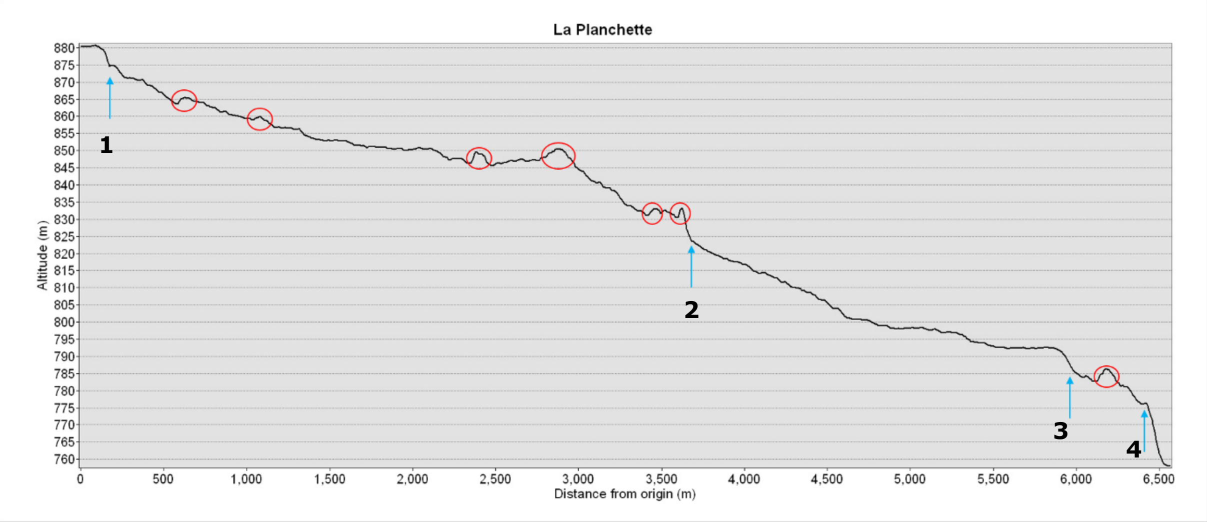


Figure 45: altitude distance profile graph of the river La Planchette. . Blue arrows indicate sudden drops, red circles indicate where the river according to the graph flows upwards instead of downwards, and this is thought to be a measurement error.

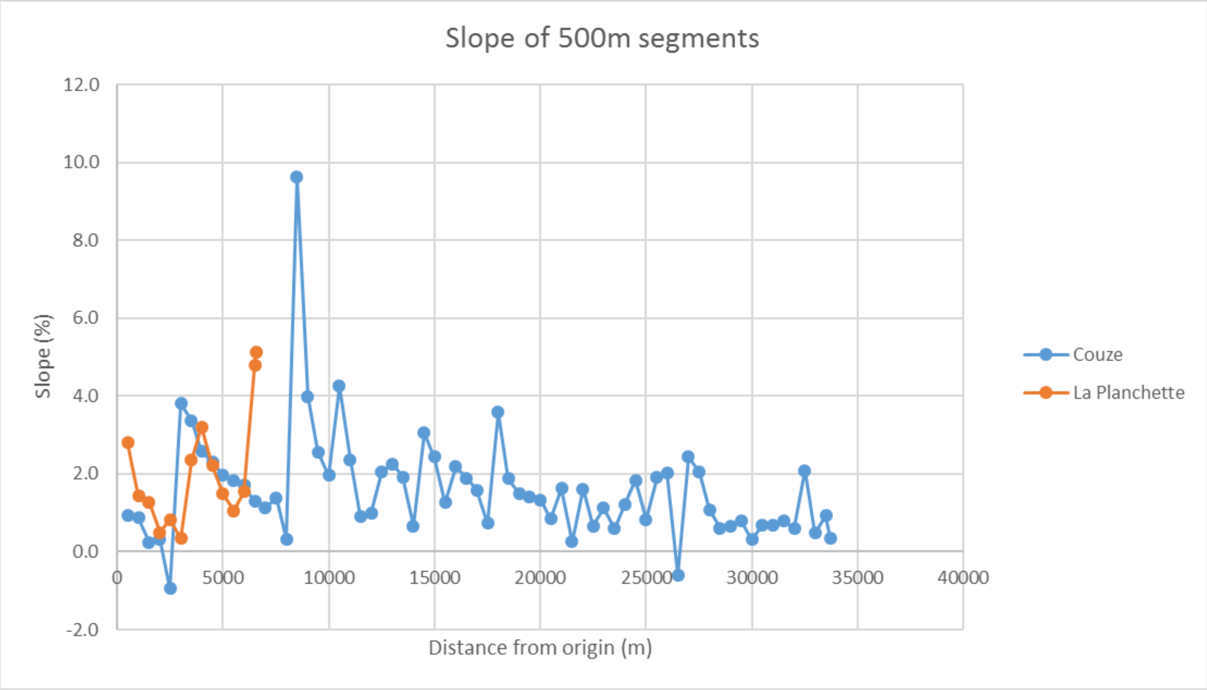


Figure 46: Slope of 500m segments of the Couze Chambon (blue) and La Planchette (orange). Each dot represents the slope of the 500m segment preceding the data point.

In order to get better insight in the change of the profile over distance, the profile of both the Couze Chambon and La Planchette is divided in parts of 500m. Of each segment the slope is calculated and this is plotted in figure 48. Each point gives the slope in percentage of the previous segment. For example, the point at 500 m gives the slope from the start (0m) until 500m. It can be seen for both profiles that there are large drops (the high value percentages), highest ones being 9.6 percent for the Couze Chambon and 5.1 percent for La Planchette. The high percentages logically coincide with the large drops as seen in figure 46 and 47. The errors as given in red circles in figure 46 and 47 are represented in figure 48 as negative slopes (going upwards). It should also be noted that the slopes vary strongly throughout the profile, for both the Couze Chambon and La Planchette.

3.2.1.3 Relevance with literature

When looking at river profiles in general, an profile slope-area is often concave up (Whipple, 2004). This trend seems to be present more in La Planchette then in the Couze Chambon. However, note that those graphs are in fact not area graphs but only use distance, though the trend should be similar. The different trend in the Couze profile could indicate abnormalities, maybe also influenced by the presence of the knickpoints.

According to (Montgomery & Buffingtton, 1997), the channel morphology of rivers can be described in four categories, with characteristics for the gradient, relative roughness and Manning's N. Since from the Couze Chambon and La Planchette only the gradient is known, it is hard to divide it into an exact category. Based on the segment slopes as presented in figure 48, it is hard to put them into a single category, because there is so much variation within the profile. They do not belong to the lower gradient categories, because there are too much knickpoints for that. Frequent knickpoints are typical for steeper bedrock rivers, however, the overall slope is too low to fully qualify for that category, due to the lower gradient sections. Summed up, the profiles have too much steep sections (drops) to qualify as a low gradient river, but too many low gradient sections to qualify as a bedrock profile. So bedrock and erodible sediment sections alternate. This could be due to the fault zones caused by the graben system, where due to subsiding blocks there are some parts where the bedrock sticks out and V shaped valleys will form, and others where sediment infill can take place (around Murol, Saillant and Champeix)(Boivin et al., 2017). However, the drops and irregular pattern could also be explained by multiple lava flows. It is not possible to say this for certain now, based solely on the river profiles. But they at least both indicate that it is not a traditional exponential profile (Whipple, 2004) eroding in sediments, so some other activity (tectonic shifts, lava flows) has to have happened. .

It is also interesting to compare both rivers. The Couze Chambon seems to be incising more easily next to a lava flow than La Planchette , because La Planchette still has to drop remarkably (4.8 percent and 5.1 percent) at the end, to reach the level of the Couze Chambon. Up until that point, la Planchette has been flowing on a higher level than the Couze Chambon. This indicates that there is lava present at the end of the valley, influencing the flow of La Planchette. The influence on the flow is seen at the end of the valley with the heavy drop, where it is also forced past the scoria cones. This seems to indicate that the lava flow invaded the flow area of la Planchette, and possibly even blocked the river, giving another meganism apart from he glacier for creating a margin lake type of structure. These deposits could be (depending on timing) on top of any possible glacial deposits in the La Planchette valley.

It should also be noted that river profiles can be influenced: according to (Whipple, 2004), channel width, sinuosity, extent of alluvial cover, bed material grain size, bed morphology and hydraulic roughness are all potentially important variable in how a river may respond to external forcing. If the rivers would be studied in more detail to differentiate between the graben blocks or lava flows as causes for the drops, those variables are worth taking into account.

3.2.2 Volume calculations

3.2.2.1 Inputs

3.2.2.1.1 Tartaret Lake

As described in the method section, a TIN file was created from points to recreate the isolines from the Tartaret Lake from (Macaire et. al, 1997), as seen in figure 49. The resulting TIN image can be seen in figure 5. This file was then subtracted from the current DEM. The resulting volume is the sediment accumulation from the Tartaret lake phase. It can be assumed that a similar volume was once occupied with water; however, the water will have raised slightly higher that only the highest sediment deposition. Therefore, the volume is calculated from the current DEM (with the same borders as the TIN) to the 920 m level, because this is the highest level in the reconstructed DEM and therefore most likely to have been the highest water level. Those two added volumes give the maximum volume of the Tartaret lake, at the start of infilling (in 12.5ka). The calculated water volume (so without the sediment infill) is probably representative for the end of the lake phase, when sediment filling was complete. Both the added and separate volumes are used in further analysis to get a range of the effects of the Tartaret volume over time. Figure 50 shows the borders of the Tartaret Lake, figure 51 the constructed TIN. Figure 52 shows the model used for the reconstructing, since it is slightly more complicated than the basic model shown in the method section.

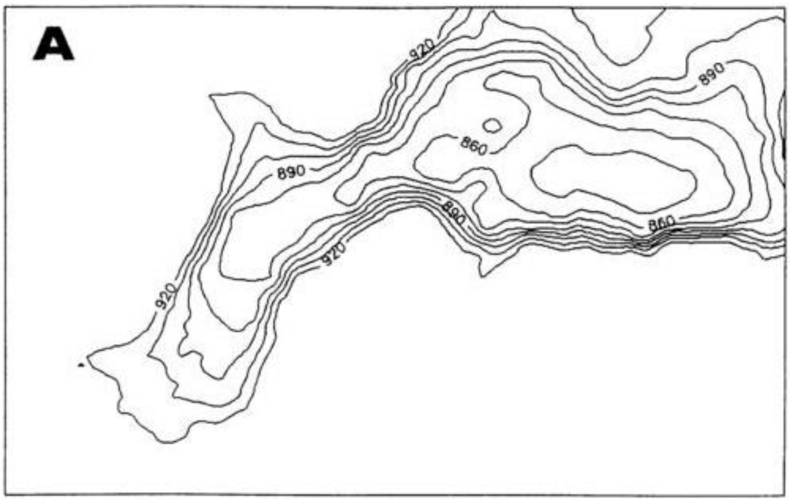


Figure 47: figure from (Macaire et al, 1997) showing the elevation isolines of the basal level of the storage

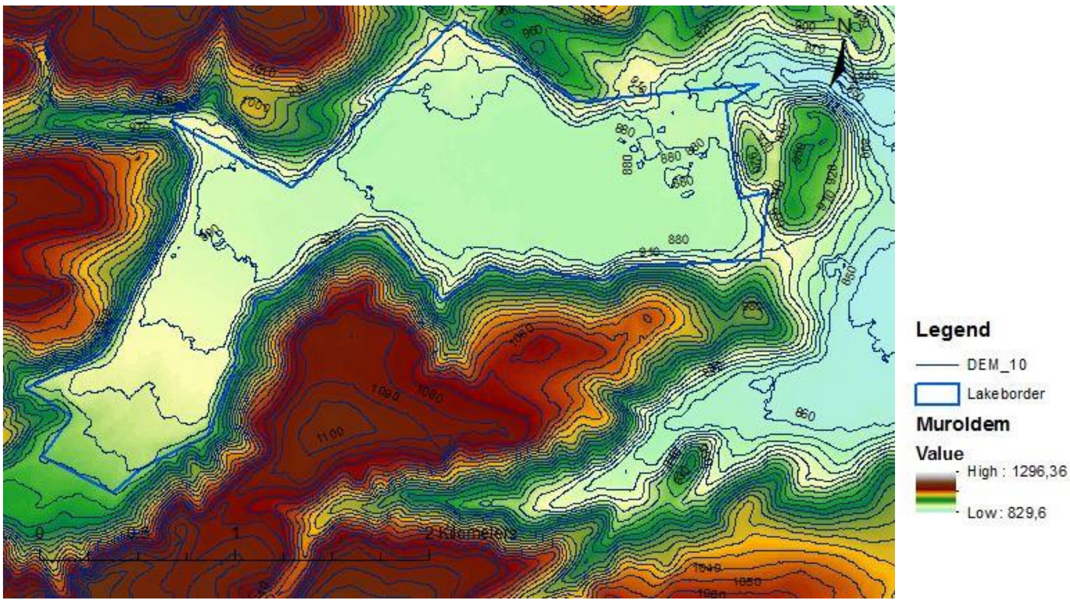


Figure 48: Outline (in blue) of Tartaret Lake used for volume calculations. Outline follows 920 DEM line.

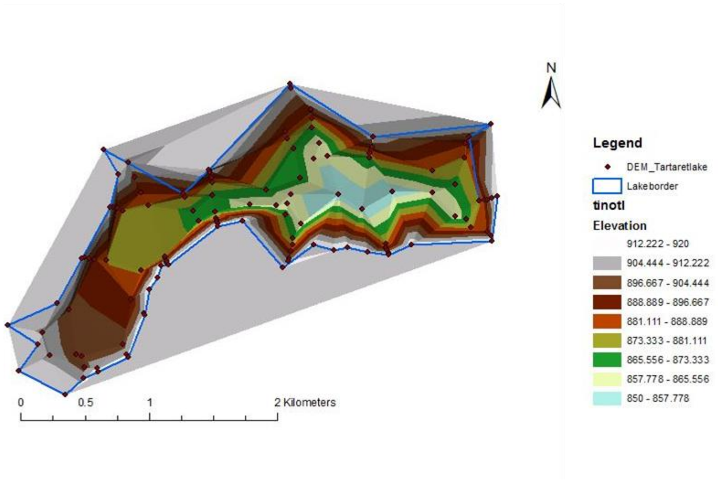


Figure 49: Resulting TIN file used to recreate the contour line map from Macaire et al (1997). Blue line is Tartare lake outline

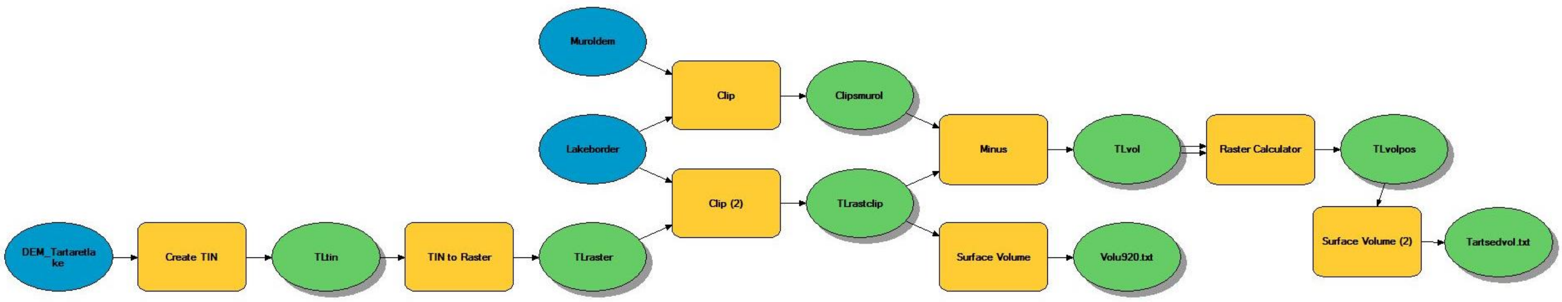


Figure 50: ARC GIS model to calculate water content in the Tartaret lake. A raster is created of points, using triangular DEM. This gives sediment accumulation, water volume on top of that is calculated separately and two txt files are added later.

3.2.2.1.2 Margin Lake

There is no literature available on surface altitudes before sediment accumulation. However, there was a segment of 2m of sediment observed at point 11.14. Since this was the only available clue, sediment accumulation in this valley was taken as 2m. Similar to the Tartaret Lake, the volume was calculated with and without correction, to account for the beginning and end of sediment accumulation. Since there is no literature available here showing previous altitudes, the assumption was made that the current level was representative. The outlines for the lake are shown in figure 53, and where based on the 930 DEM line because this was the line that especially in the east seemed to be the border of the valley. The north border was drawn like the geomorphological map resulting from the field data, because this includes all the landforms considered to be part of the margin lake valley, and excludes the volcanic ones. Since the blockage of the lake was most likely caused by a glacier or some other natural blockage which has now disappeared, there was no clue like a DEM line in the landscape anymore to draw this border. The volume of the lake was calculated with different water levels. Eventually, it was chosen to use a water level of 855 m. This is because there is a plain with fluvial deposits observed at 851 m (point 6.10) so it is likely that water level rose at least until there. On the other hand, at point 6.5 untouched scoria was observed at 859 m. Therefore, 855 is chosen as an average.

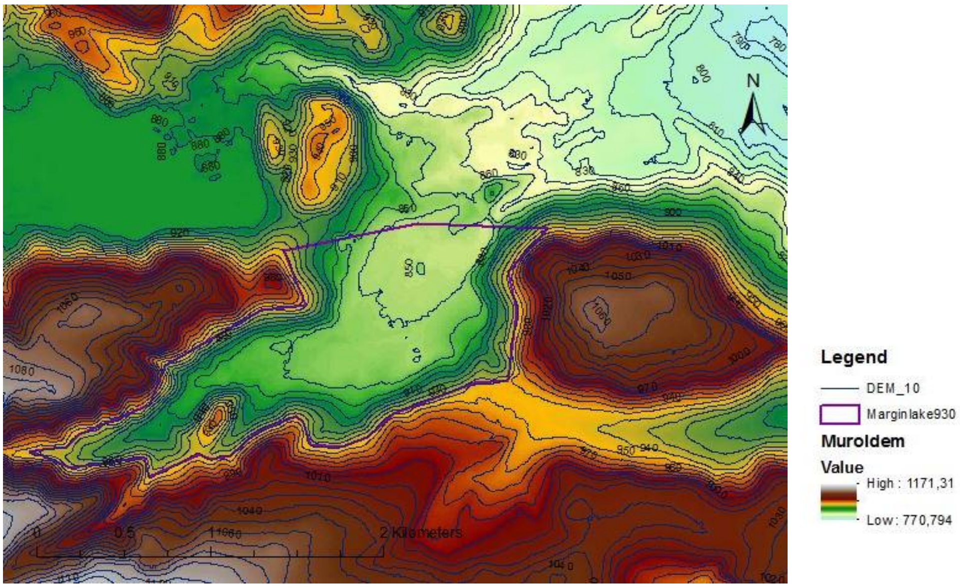


Figure 51: Outline (in purple) of Margin Lake used for volume calculations. Outline follows 930 DEM line.

3.2.2.1.3 Glacier

The glacier in the U-shaped valley is the largest possible water source in the area. The borders for the glacier can be seen in figure 54 and are drawn mostly following the slope (degree) map. Steep slopes were viewed as being part of the valley, everything above it is the Massif. Since rolling topography was observed on the shoulder and glacial tills were also previously mapped here(de Goër et al., 1991) , it is likely that ice was also on top, so on what is now classified as the Massif. However, this line was drawn because it seems likely that the influence of the Tartaret volcano remains within the valley. The border was therefore drawn just above the steep slope. The end in the east was drawn at the bottom of the steep slopes of Puy d'Eraigne. This is just before the V-shaped valley, where it is assumed the glacier has stopped (as will be explained later on). The bottom of the slope was chosen here because it is thought that the glacier was ended by moraines not present anymore, and thus not leaving clear marks in the landscape.

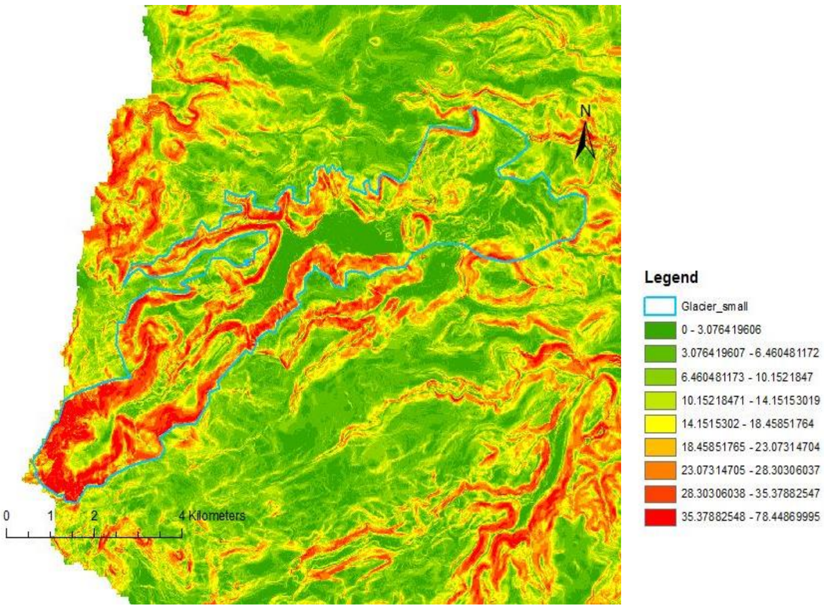


Figure 52: Outline (in light blue) of glacier used for volume calculations, displayed on the slope (degree) map. Outline follows top of the steep slopes.

3.2.2.1.4 Sediment Saillant

The used polygon for the sediment deposition can be seen in figure 55. It is hard to follow a DEM line due to the natural altitude decrease eastwards in the valley (due to the graben system). The polygon was therefore drawn to resemble the corresponding figure from the geomorphological map, which on its turn was drawn taking the current course of the Couze Chambon, locations of large boulders (erratic's), and mostly one altitude into account. The obtained area was afterwards multiplied with a thickness of 1.60m, which was observed in the field.

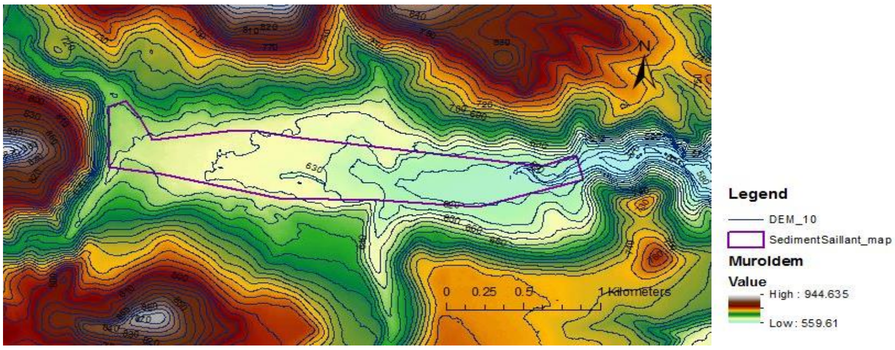


Figure 53: Outline (in purple) of sediment deposition used for volume calculations. Outline follows course of the Couze Chambon and observation points.

3.2.2.1.5 Chézy calculations

The proposed method of using the Chézy formula to calculate flowtimes of the different source volumes through the area was applied at two locations. The first one is at the beginning of the first V shaped valley, around the village of Les Granges, so closer to the possible source areas. Here the difference between the V shaped valley and the altitude of the dry valley in the north, north of Puy d'Eraigne, is taken as indicator for the depth of the water, because depositional features were found in the dry valley, so in order to fill that with water a certain minimal depth is needed.

The other location was just after the valley of Saillant where the sediment deposition is observed. Assuming that not a lot of erosion took place afterwards, the altitude of the sediment gives a starting point for a water level that must have been on top of it, and afterwards flown through the narrower valley, where the discharge can be calculated.

The inputs are seen in table 1 and 2. As can be seen, some of the inputs have ranges. For the first location, the range in h was set as the minimum needed water depth to reach the dry valley, and the maximum depth in which this dry valley would not overflow. For the cross sectional area of the valley, the valley was simplified to a trapezoid, of which the top width was taken out of the cross section for the corresponding water depth, also leading to a range. For the second location, just after Saillant, something similar was done. Here the minimum water depth was taken to the height of the sediment deposition, and the maximum 5m above for a range of water standing on top, and which also seemed to be a natural level in the profile graph. The manning n has a range from literature(Chow, 1959). Multiple scenarios were plotted, based on the ranges of the inputs, and to check the sensitivity of the results to the inputs. The scenarios are: a maximum and minimum scenario using all the maximum and minimum ranges of the inputs, a most likely scenario (of which the input can be seen in the displayed tables), and two average scenarios, one using average input and one using average discharge (which vary slightly due to the non-linear relationships in the equations). All can be seen in table 1 and 2. The volumes, calculated in ARC Map, were also used as an input and can be found in the next section in table 3. The cross sectional graphs made in order to obtain the dimensions with ranges can be seen in figure 57 and 59, the locations of the cross sections in figure 56 and 58.

Table 1: input calculations V-shaped valley Les Granges

V-shaped Valley Les Granges			
Input		**unit**	**Range**
b1	225	m	
b2	10	m	
h	12	m	10-15
g	9,81	m/s^2	
b3	107,5		
c	108,1677		
NO	226,3354		
Rh	6,229693		
n	0,05		0.04-0.07
i	0,096		
C	27,12946		
Calculations			
U	20,98022	m/s	
A	1410	m^2	
Q	29582,11	m^3/s	

Table 2: input calculations valley past Saillant

Valley passed Saillant			
Input		**unit**	**Range**
b1	185	m	175-200
b2	2	m	
h	29	m	27-32
g	9,81	m/s^2	
b3	91,5		
c	95,98568		
NO	193,9714		
Rh	13,97887		
n	0,05		0.04-0.07
i	0,18		
C	31,04145		
Calculations			
U	49,23957	m/s	
A	2711,5	m^2	
Q	133513,1	m^3/s	

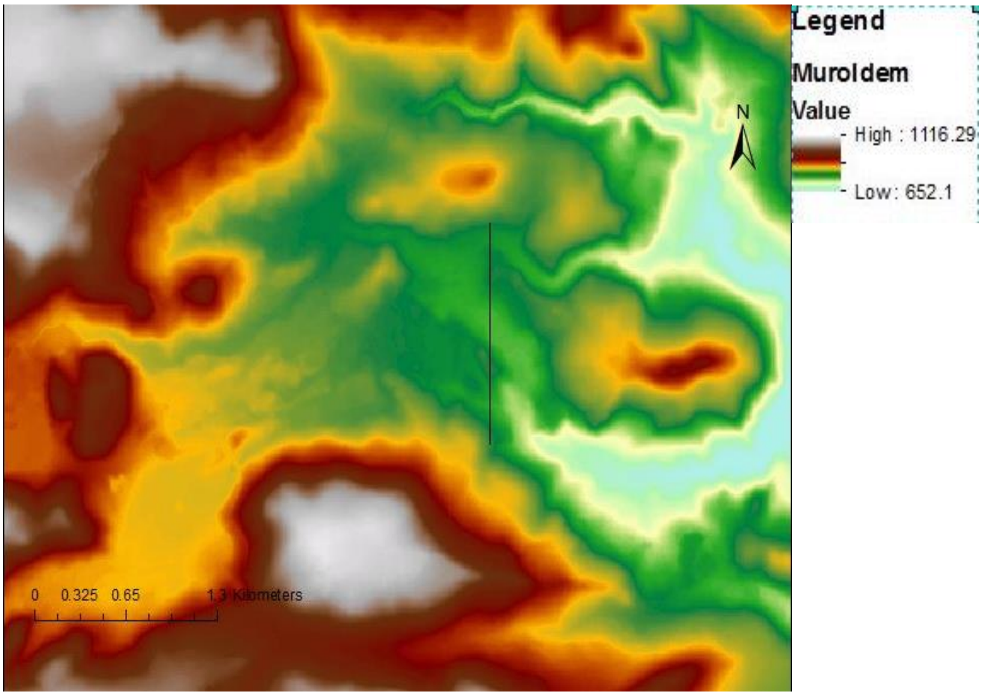


Figure 54: DEM showing where the crossection of figure 56 was made (black line, north to south

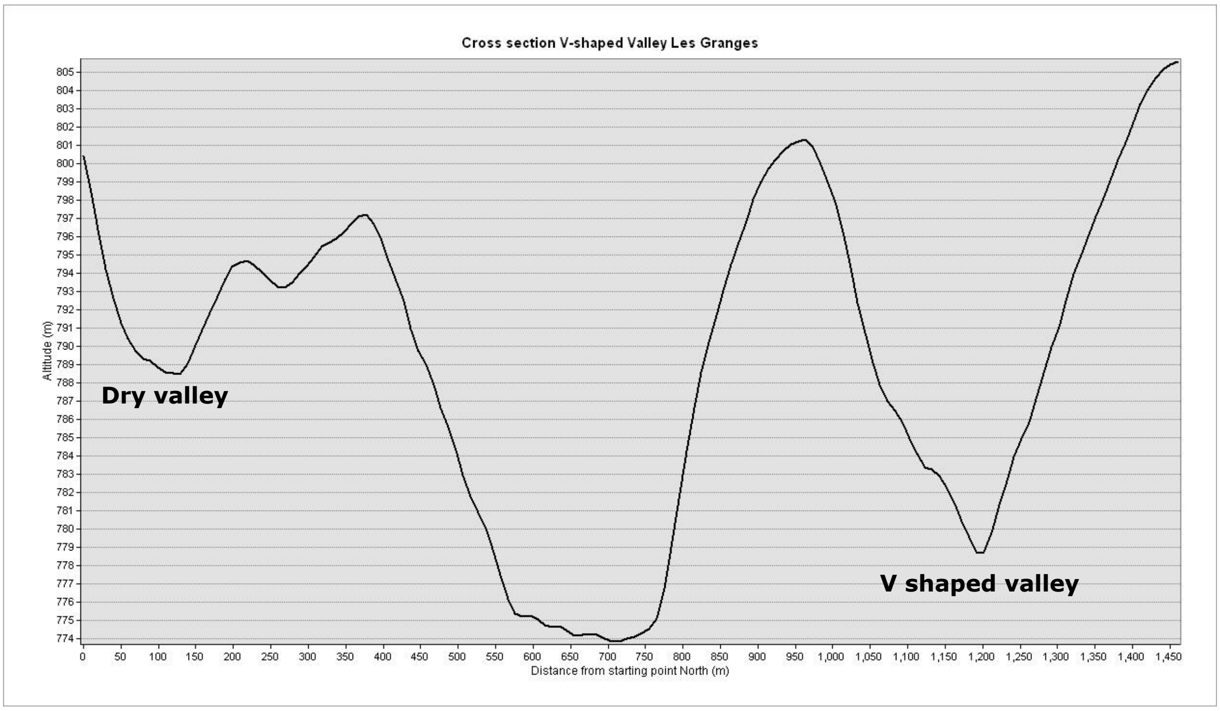


Figure 55: Cross section of topography at the entry of the V shaped valley of Les Granges, used to subtract variables for Chézy calculations. The third depression in the graph is the V shaped valley, the first is the dry valley, and differences in altitude between the two was used for water depth.

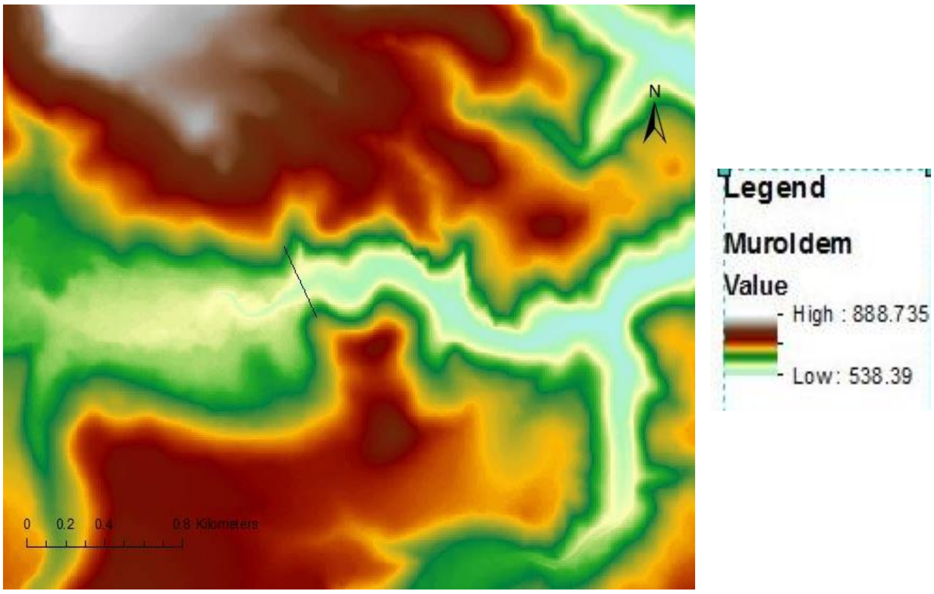


Figure 56: DEM showing where the crossection of figure 56 was made (black line, north to south

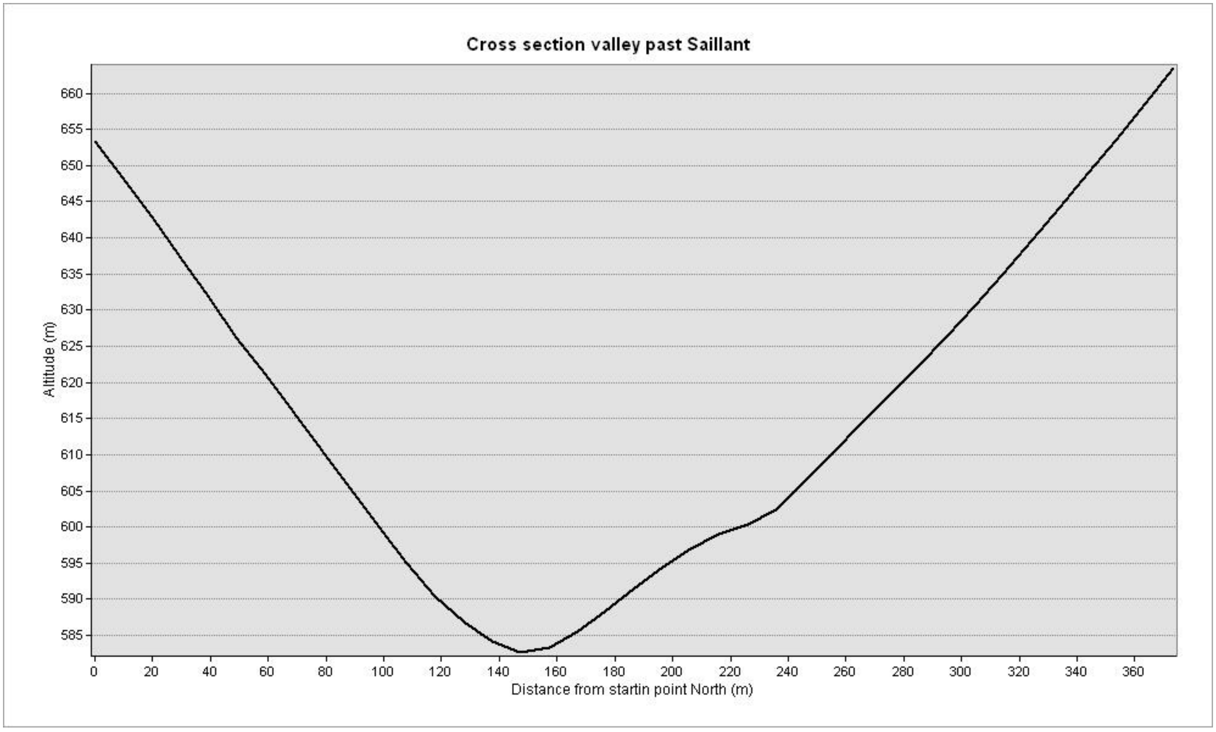


Figure 57: Cross section of the topography at the entry of the valley just past Saillant, so after the sediment deposition. Used to subtract variables for Chézy calculations. The sediment deposition as observed in point 8.9 had an altitude of 610m, which was used for water depth.

3.2.2.2 Volume results

Table 3 shows the results of the volume calculations in Arc Gis. The Zfactor normally gives the height of the plane used as the upper border to calculate the volume. For instance, Margin Lake with a Zfactor of 890 means the volume of the margin lake filled up until altitude 890 is calculated. Exceptions are the Tartaret lake sediment, here the sediment accumulation in the Tartaret Lake is calculated as described before, and the sediment of Saillant, where only the area was calculated and then multiplied with the observed depth in the field (1.6 m)

Table 3: calculated volumes (in m^3) of the possible water sources for an extreme flood event.

Origin	Zfactor	Volume (m^3)
Margin lake	855	2.908.178
Margin lake	890	37.368.906
Margin lake	930	102.404.468
Tartaret lake	890	29.774.547
Tartaret lake	920	105.783.631
Tartaret lake	Sediment	20.240.230
Glacier	1700	18.463.601.698
Sediment Saillant	1,6	1.700.451

What should be noted at the volumes is that the Margin Lake and Tartaret Lake have (roughly) comparable volumes for the same Zfactors, where it is striking that at the 890 Zfactor the volume of the margin lake is larger, where it is the other way around at the 930 Zfactor. This probably has to do with the geography of the lakes and the fact that the margin lake is in a narrower valley compared to the Tartaret lake. Furthermore, the sediment of the Tartaret lake is almost the same volume as of the lake itself (with Zfactor 890), which seems quite high because it would mean that over time half of the lake filled itself up with sediments, which needs a large sediment supply The sediment of Saillant is about 1/20 of the sediment of the Tartaret lake, in which the latter is thought to have been deposited in 4 thousand years (Macaire et al., 1997), and the former possibly in one event. Also, the glacier volume is as expected by far the largest.

3.2.2.3 Calculations to flow times

The above presented volumes were used to transfer the calculated discharge with the Chézy formula into runtimes of the water through the valley. The results of this can be found in table 4 and 5.

Table 4: outcomes flow times of water sources through the V shaped valley at Les Granges. Red values are below the set 1 day run time, in order to create enough build up for sediment deposition. Green values are above this.

V shaped valley Les Granges		Scenario 1			Minimum			Average (inputs)			Average (discharge)			Maximum		
Q ($m^3 s^{-1}$)		29582,11076			53518,15965			31654,27038			34564,99259			15611,82553		
Source	V (m^3)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)
Margin lake (855)	2908178	1,64	0,03	0,00	0,91	0,02	0,00	1,53	0,03	0,00	1,40	0,02	0,00	3,10	0,05	0,00
- Sediment correction	4018630	2,26	0,04	0,00	1,25	0,02	0,00	2,12	0,04	0,00	1,94	0,03	0,00	4,29	0,07	0,00
Tartaret lake (890)	29774547	16,78	0,28	0,01	9,27	0,15	0,01	15,68	0,26	0,01	14,36	0,24	0,01	31,79	0,53	0,02
- Sediment correction	50014777	28,18	0,47	0,02	15,58	0,26	0,01	26,33	0,44	0,02	24,12	0,40	0,02	53,39	0,89	0,04
Glacier (1700)	1,846E+10	10402,46	173,37	7,22	5749,95	95,83	3,99	9721,49	162,02	6,75	8902,84	148,38	6,18	19711,13	328,52	13,69

Table 5: outcomes flow times of water sources through the valley past the Saillant deposition. Red values are below the set 1 day run time, in order to create enough build up for sediment deposition. Green values are above this.

Valley past Saillant		Scenario 1			Minimum			Average (inputs)			Average (discharge)			Maximum		
Q ($m^3 s^{-1}$)		133513,0962			212045,8233			139164,6939			146142,1388			80238,45435		
Source	V (m^3)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)
Margin lake (855)	2908178	0,36	0,01	0,00	0,23	0,00	0,00	0,35	0,01	0,00	0,33	0,01	0,00	0,60	0,01	0,00
- Sediment correction	4018630	0,50	0,01	0,00	0,32	0,01	0,00	0,48	0,01	0,00	0,46	0,01	0,00	0,83	0,01	0,00
Tartaret lake (890)	29774547	3,72	0,06	0,00	2,34	0,04	0,00	3,57	0,06	0,00	3,40	0,06	0,00	6,18	0,10	0,00
- Sediment correction	50014777	6,24	0,10	0,00	3,93	0,07	0,00	5,99	0,10	0,00	5,70	0,10	0,00	10,39	0,17	0,01
Glacier (1700)	1,846E+10	2304,84	38,41	1,60	1451,23	24,19	1,01	2211,24	36,85	1,54	2105,67	35,09	1,46	3835,15	63,92	2,66

As can be seen, the table is colour coded. The coding represents whether or not the calculated time is thought to be sufficient to deposit the found sediment in Saillant. The line between sufficient and not was set on 1 day, meaning that every volume that took shorter than 1 day to run through was thought as not to be a likely origin, and everything that took longer than a day was thought to be possible. The line of a day is based on the amount of time thought to be needed for the water to stand still long enough to deposit such an amount of sediment. As can be seen in this table, only the glacier exceeds the limit of 1 day. In the graph of figure 60, the different scenarios for the different sources are plotted. It becomes clear that all the scenarios calculated based on the first valley take more time to flow through than from the second valley, which makes sense since the first is narrower. Also, the plotted scenario (scenario 1) is slightly above average, and the glacier produces a much larger volume and therefore a longer time in all scenarios than the margin and Tartaret Lake. For both the Tartaret lake and the margin lake, the sediment corrections do not change the conclusion of making the limit in the different scenarios or not. In other words: it does not matter in which phase a flood event happened, the effect would have been the same.

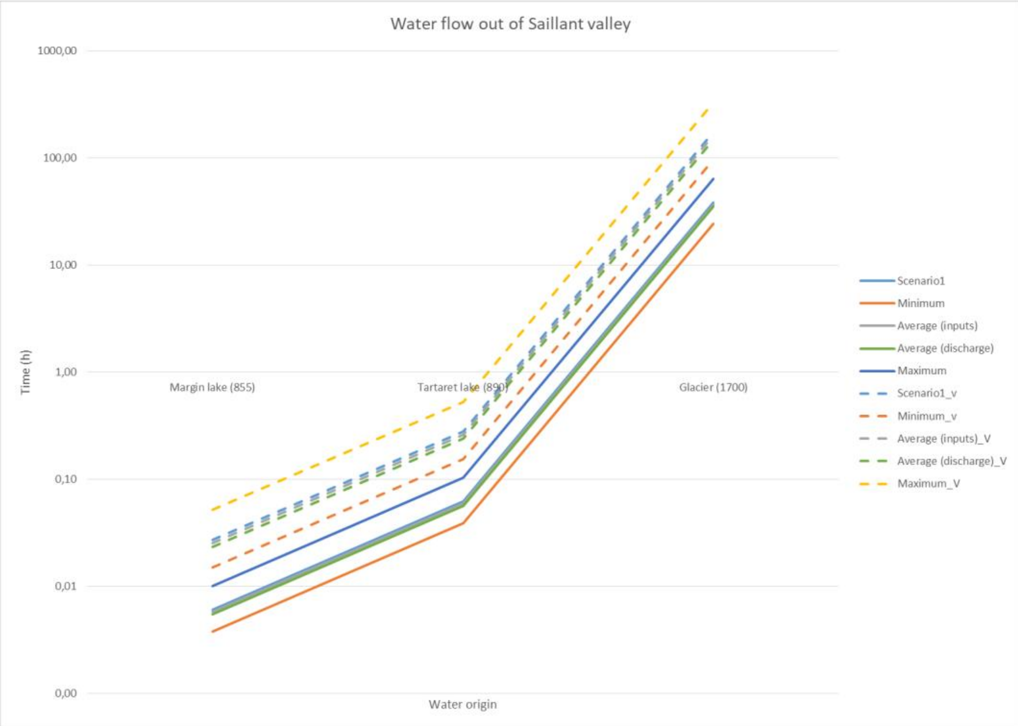


Figure 58: Graph presenting the times needed on logarithmic scale for the different sources to flow through the first V shaped valley (dotted lines) and the valley after Saillant (solid lines).

3.2.2.4 Additional glacial volume calculations

As could be seen in the previous table and section, the glacier is the most likely source (source of origin) for the flood deposits found in the valley. However, in the previous calculations the entire glacial volume was taken into account, all the way on to the Mont-Dore, and assuming a thickness of 1700m throughout, including the area around Murol, where it can be expected that the glacier thinness towards the end. It is not likely that the entire glacier would have melted at once: natural deglaciation does not happen like that, and since the Tartaret is situated at the end of the valley, it is not in the location to melt the entire glacier when erupting. It is therefore more plausible that only the part around Murol melted. That is the part directly affected by the volcano and everything downstream that will crack under the pressure.

To take this into account, a new polygon was created representing the area of the glacier around Murol, as can be seen in figure 61. Different altitudes (Zfactors) were taken for this area, since it could be expected that the glacier thinness closer to the snout. The originally used 1700m line was taken, but also an altitude just on top of the Tartaret (950m) or with a thickness of 400m (so an altitude of 1350), thought to be minimal needed for a glacial outburst flood to occur (Smellie & Skilling, 1994). It was checked of all of these volumes if they would make the 1 day limit. The results can be found in table 6 and 7.

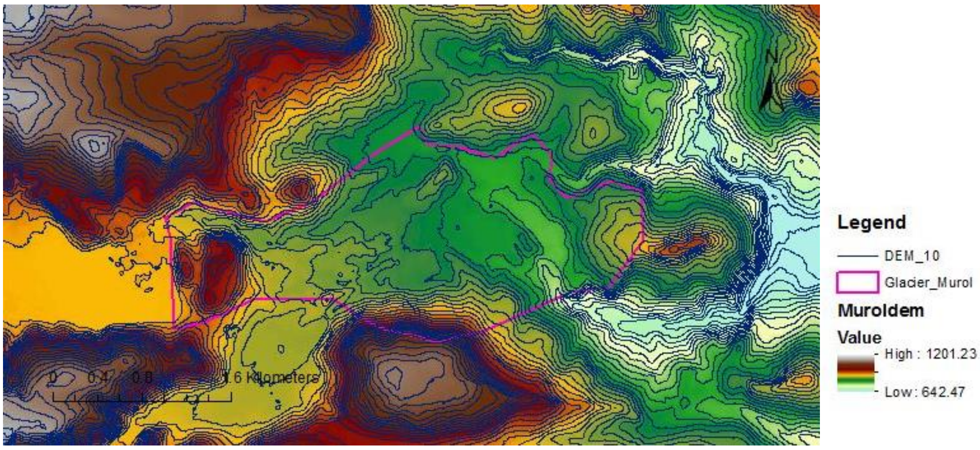


Figure 59: outline (pink) used for volume calculations of glacier section around Murol and the Tartaret volcano.

Table 6: outcomes flow times for the glacier section. Red does not pass the one day limit, orange is sufficiently close (>0.8 day) it could be debated whether or not the available amount of water is enough, and green passes the 1 day limit. This is the case for almost all the scenarios of the 1700m volume, and some of the 1350 volume.

V shaped valley Les Granges		Scenario 1			Minimum			Average (inputs)			Average (discharge)			Maximum		
Q		29582.11076			53518.15965			31654.27038			34564.99259			15611.82553		
Source	V (m^3)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)
Glacier950	594295161.8	334.83	5.58	0.23	185.08	3.08	0.13	312.91	5.22	0.22	286.56	4.78	0.20	634.45	10.57	0.44
Glacier1150	1584883286	892.93	14.88	0.62	493.57	8.23	0.34	834.48	13.91	0.58	764.20	12.74	0.53	1691.97	28.20	1.17
Glacier1350	2576556246	1451.64	24.19	1.01	802.39	13.37	0.56	1356.61	22.61	0.94	1242.37	20.71	0.86	2750.65	45.84	1.91
Glacier1700	4311983926	2429.39	40.49	1.69	1342.84	22.38	0.93	2270.35	37.84	1.58	2079.17	34.65	1.44	4603.33	76.72	3.20

Table 7: outcomes flow times for the glacier section. Red does not pass the one day limit, and green passes the 1 day limit.

Valley past Saillant		Scenario 1			Minimum			Average (inputs)			Average (discharge)			Maximum		
Q		133513.0962			212045.8233			139164.6939			146142.1388			80238.45435		
Source	V (m^3)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)
Glacier950	594295162	74.19	1.24	0.05	46.71	0.78	0.03	71.17	1.19	0.05	67.78	1.13	0.05	123.44	2.06	0.09
Glacier1150	1584883286	197.84	3.30	0.14	124.57	2.08	0.09	189.81	3.16	0.13	180.75	3.01	0.13	329.20	5.49	0.23
Glacier1350	2576556246	321.64	5.36	0.22	202.52	3.38	0.14	308.57	5.14	0.21	293.84	4.90	0.20	535.19	8.92	0.37
Glacier1700	4311983926	538.27	8.97	0.37	338.92	5.65	0.24	516.41	8.61	0.36	491.76	8.20	0.34	895.66	14.93	0.62

As can be seen the calculations at the second valley never make the one day limit, as explained before because the valley is wider. For the first valley however, which is at the source, it is passed or almost passed in a lot of cases, mostly the 1700m and the 1350m (taking the minimum of 400m ice into account (Smellie & Skilling, 1994)). However, it should be noted that quite some of the decisions made are arbitrary: both the area of the ice that would melt and the thickness of the ice are mostly estimations. What is not taken into account here is the possibility for the Tartaret melting the glacier in backwards direction, as was briefly mentioned by (van Orsouw, 2017). This would generate a larger volume, already reaching the requirements in a lot cases.

What should therefore be definitely being taken into account is that the margin lake would probably be emptied in the case of a glacial outburst flood, because the ice damming the lake would then suddenly disappear. Therefore, the volume of the margin lake, though thought before to probably be unsatisfactory to explain the flood deposits, would have to be added onto the glacial outburst volume. This could be just enough to make the set 1 day limit. When the volumes are added (margin lake 855 without sediment correction and glacial 1350), this leads to the results in table 8. This shows however similar trends to table 6 and 7. When taking into account that the volume of the margin lake is a factor 1000 smaller than the volume of the 1350 glacier, it makes sense that this amount of volume will not bring large changes in the results. The complete analysis however shows that despite not being convincing in all scenarios, the glacial area around Murol can definitely be a source.

Table 8: Outcomes flow times for the glacial section (with Zfactor 1350) and the margin lake (Zfactor 855) combined. The addition of the margin lake does not change the trend compared to table 6 and 7.

	Scenario 1			Minimum			Average (inputs)			Average (discharge)			Maximum		
Location	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)	T (min)	T (h)	T (d)
V shaped valley Les Granges	1453.28	24.221	1.009	803.299	13.4	0.55785	1358.14	22.636	0.943	1243.775	20.73	0.864	2753.751	45.896	1.912
Valley past Saillant	322.00	5.37	0.22	202.74	3.38	0.14	308.92	5.15	0.21	294.17	4.90	0.20	535.79	8.93	0.37

3.2.3 Luminescence

The results of the luminesce measurement and calculations are as follows:

Age (faded): 13.7 ka ± 2.3 ka
Age (corrected): 15.7935 ka ± 2.9527 ka

The g-value (amount of fading over a year) that was used for the fading correction was established on 2.733 ± 0.406 %/decade.

The range for the sample would come down to 12,8408 – 18.7462 ka. This means that the age when the lake began according to literature is just in this range, and so is the age of the Tartaret eruption (Macaire et al., 1997). The age does at first sight seem relatively old, following the hypothesis that it is the dated material is a sediment infiltration into the eruptive material of the Tartaret volcano. However, the range is only one time the standard deviation, taking a 2sigma standard deviation will lead to a range of 9.8881 - 21.6989 ka, including the age of the Tartaret eruption. There are more factors that will make the age seem more realistic, as explained below.

First of all, there are quite some comments to be made on the done dating. Fading is taken into account as can be seen, however fading is measured in the lab over a few days and then extrapolated to thousands of years, which is quite a large interpolation. So it could be that there is an overestimation done here and that the sample is actually younger. Also bleaching is not taken into account because there were no data for that, but if the material is not properly bleached before burying, the signal is not reset and therefore an underestimation of age might be made. Furthermore, there was only one sample taken, leading to a large uncertainty.

Also, it is hard to say what has exactly been dated. The dating has been done on feldspars, however this is not a mineral normally present in (basaltic) scoria. It was therefore assumed that the feldspars would come from sand or silts infiltrating the scoria wall, resulting in a clogging of the wall and the forming of the lake. However, the source area does not contain a lot of feldspar rich rocks that could have produced such sediment. In addition, it can be debated whether the theory of sediment clogging a wall of scoria to form a lake is really plausible, since this would have meant a large input of sediment, and it is unclear whether that would be present in the source area. With the sediment theory being possibly unlikely, it could also be that the feldspars came from the scoria itself. Even though normally not present, it could be that such minerals did form. In that case, it is not any infiltration, but the eruption itself that has been dated. In that case, the resulting age is more likely because an eruption is older than a possible infiltration.

When looking at the literature, the most important clue is the 12.6 ka ago dating (Macaire et al., 1997) thought to be the beginning of the lake. However, this is only one measurement, and the fact that it registered at that time does not mean it did not register before. The dating done in this research could hint at an earlier sedimentation and registration of the lake.

In conclusion, it can be said based on this measurement with quite some certainty that the sample is late glacial, meaning it is not a lot older (e.g. 27ka as is though for the first Tartaret eruption (Guérin, 1983; Pilleyre et al., 1992)) but also not a lot younger. It is not Holocene, LGM, or older. However, with the data collected now, it is not possible to differentiate between for instance the 12.6 and 8.5ka (the thought to be begin and end phases of the lake)(Macaire et al., 1997).

In order to be able to make a distinction on a smaller timescale, both more sampling and single grain measurements are needed. More sampling will enable for more equivalent dose (geode term) measurements, leading to a better estimation of the age and a smaller range/sigma. Single grain measurements will give a more precise age.

3.3 General discussion part 1 and 2

The analysis in part 1 and 2 were done in order to explain the geomorphology and geochronology of the area. The following processes seem to have taken place.

Firstly, it seems very plausible that a glacier was present in this area, based on the field observations (U-shaped valley and remnants). Based on modelling analysis, the glacier is the most likely source to have produced enough water to deposit sediment downstream found in the valley of Saillant. Since there was no layering observed in the sediment, it is likely that it was deposited at once in a short amount of time and not over for instance multiple years. To produce the needed amount of water from the glacier in a short amount of time, a rapid melt must have taken place. This is most likely to have been enhanced by the Tartaret Volcano, melting the ice until it suddenly releases in a glacial outburst flood (jökulhaup). If the part around Murol was melted, the resulting flood would also likely have used the valley north of *Puy d'Eraigne*, where nowadays mega ripples with large boulders are found, also a remnant of a mega flood.

Secondly, based on the analysis and observations the possibility of a margin lake forming in the valley of la Planchette is still open. Though the found sediments do not indicate long time presence of standing water, it does not exclude that water could have accumulated in the area for some time. It is possible to picture in the current landscape a glacier blocking and accumulating the water. This could have been released for instance during glacial retreat but also during the disappearance of the glacier at a jökulhaup. Since there are no clues in the landscape observed that could only be explained by water coming from this valley, and since the volume of the valley itself is not enough to explain the clues that are found (boulders and sediment Saillant), it is now thought that the water from the margin lake might have joined the melted water from the glacier in a jökulhaup.

Thirdly, it can be said that the Tartaret produced at least one lava flow that flowed through the study area. This is based on multiple observations of in situ basalt in the field, mostly around Murol. However, the observations of basalt in Neschers and of scoria cones in the Murol area, and the fact that the flood deposition described earlier is visible at the surface, make it quite likely that there were two or more eruptions producing a flow. However, since there is no direct dating done on the material and since there is no direct observation in the field from two separate in situ flows, this cannot be said for sure. It can be said that there were two eruptions, due to the fact that there is an intact cone present now, meaning there must have been some activity after a lava flow. Based on observations and luminescence dating, it can be said at least one eruption occurred in the late glacial, so after the last glacial maximum.

What is most open for discussion is the geochronology: the order end combination of all those processes. In order to have a jökulhaup, the glacier and the volcanic eruption should have happened at the same time. With a last glacial maximum of around 26.5 to 19-20 ka (Clark et al., 2009) and the first recorded activity of the Tartaret already present in 27 ka (Guérin, 1983; Pilleyre et al., 1992) it is possible that these events coincided.
More confusing however is the location and ages of the lava flows, in relation to each other and the flood deposit. As said before, it is expected for the scoria cones to have occurred after any glacial activity since it would otherwise have been eroded away, and since the activity of the Tartaret is dated younger than glacial activity, this could be the case. However, there is a lava flow reaching Neschers that is not recorded at the surface in the valley where the sediment deposit can be found. So this would mean a lava flow below the sediment deposit, reaching all the way up till Neschers, a sediment deposit from a glacial outburst flood on top of that, and at the surface in Murol lava and secondary cones from later eruption(s). However, this contradicts completely with the ages found in literature (Guérin, 1983; Pilleyre et al., 1992). Apart from contradicting with literature, it does not seem like a logical chronology either. Since with glacial outburst floods the flood comes before the lava flow, the lava flow from Neschers cannot be from the same eruption as the flood deposits, indicating a possible older eruption. Below different theories are discussed regarding this seemingly contradiction in the chronological order of results.

Option one is that the datings from literature are not correct. This was also proposed by (Hofsteenge, 2017). Out of this research comes that it is likely that the flow around Murol is older than the one at the Tartaret. This could be achieved by one of the datings being incorrect. The dating of the flow in Neschers is most doubted by (Hofsteenge, 2017)

Option two is that the glacier is not from the last glacial maximum, but from more recent times. This would make the activity of the lava flow reaching to Neschers already closer in time to the assumed activity of the Tartaret. Crucial for this it's that the glacier can build up in the given time. It seems like a short amount of time for a glacier of that extent to accumulate, but it should be investigated more in order to conclude this.

A third option would be that the flood is not caused by a glacier, but for instance the Tartaret Lake. This would make the time for build-up of the glacier unnecessary, closing a time gap between to possible flows (the one to Neschers and the one around Murol). However, based on the analysis of this research the glacier did appear to be the most likely source, so unless other analysis (using additional field data) tell otherwise, this does not seem like a likely theory.

The forth option is that the flow reaching Neschers did happen later than the flood, but did not record in most places except Neschers. This is weird however: if the flow velocity of water decreases enough in this valley for a sediment deposit to form, a lava flow should also leave some traces there.

Overall, to solve the matter of geochronology, additional dating, field observations and modelling are needed.

3.4 Relevance to literature

To put this research in a broader perspective, it is wise to look at the relevance with other researches. To start in the area, it has been noted in the terraces of the Allier river (which the Couze Chambon joins) that a sudden larger burst of sediment is present (Veldkamp, 1992). This could be caused due to a possible outburst flood. The dating in the Allier terraces is up till now thought to be between 18-20 ka (Veldkamp, 1992), so this could just coincide with the outburst flood as it is presented in this research, though the signal might be a bit too young (Clark et al., 2009). However, as discussed before, there is still much to say about this date so it could be investigated further how the two are linked together.

An important part of what has been descried in literature about this area are the timings of the processes, mostly the volcanic outburst. As argued before, these do not match with the outcomes of the research, which indicate either an error in the research or the previous datings. The dating at Murol by (Pilleyre et al., 1992) seems doubtful. It is not only the volcanic datings, but also the ones of the lake phase that do not match. As explained, the determined age came out earlier of what is known in literature. This could either be an error in the dating (which is as said, likely possible). It could also however be that the dated 12.6 ka (Macaire et al., 1997) is not the start of lake formation. The lake started to record at that time, but it could be that water was already standing there or filling up the scoria wall, before sediment deposition and thereby recording even started. For the bigger picture, this could change the moment of presence of the lake and a possible drainage, and possibly link it to the signal found in the Allier terraces (Veldkamp, 1992). However, this would have to be investigated more but it is at least an interesting mismatch to start on.

When it comes to dating methods, this study aimed to explore a so far untested method of dating basalt. Most dating methods on basalt are indirectly, at least in this area (Nowell et al., 2006) and so is this one, but dating of the xenolith has the advantage of knowing your dated material belongs to a certain eruption, in contradiction to for instance dating ashes. However, this method turned out unsuccessful in this research, since the material did not contain a significant signal. However, this could also be a specific case of this sample. Which was mostly limiting was the amount or depth of sample, mostly since the samples were quite shallow and a part that was not influenced by light is therefore very sparse, probably even non-existent. If this method would to be tested again, it is of importance to have a xenolith large enough but especially deep (at least 1cm) enough. It could be with other samples that this method is successful, however based on this study there is no reason to believe so yet.

When looking at other areas, this study differs from most of the literature on glacial outburst floods, because they most often happen at ice caps (Judith Maizels, 1997). The dynamics of those are completely different, since they span a larger area and have more ice supply. Also, an outburst often does not wash away all of the glacial relics because of the area with glacial relics being normally bigger than the outburst flood. In the case of an alpine glacier as here, the area is much more confined. This study showed that it is important to have information on the dimensions of the glacier, even if they are not visible in the landscape.

4 Conclusion

In conclusion, it can be said that presence of a glacier, an extreme flood event, and at least two eruptions of the Tartaret of which at least one produced a lava flow has highly influenced the area downstream of the Tartaret volcano until the Allier River. Most of the glacial landforms are gone, probably done due to an extreme flood, caused by the melting of the glacier by an eruption of the Tartaret volcano. Due to the amount of water needed to explain the sediment flood deposits in the area, the glacier is thought to be the most likely origin, over a possible margin lake and the Tartaret lake. The presence of a margin lake is not irrefutably proved, but it is not ruled out either and could well be that water accumulated in the valley of la Planchette, most likely because of the blockage of a glacier. This water probably contributed to the water volume of the flood event; however this does not make a significant difference in the magnitude of the flood. The Tartaret lake most likely had a normal outflow, due to that there are no significant extreme flood relics that can be linked to a Tartaret lake drainage, and the fact that the Tartaret volcano is still largely intact The Tartaret volcano most likely had at least two lava flows, one reaching to Neschers and one producing secondary scoria cones in Murol, probably under the influence of the previous flood. However, there are no definite clues found in the landscape showing the two flows.

The geochronology of all the processes is still largely unexplained. The proposed lava flows contradict with the ages from literature. The activity of the volcanic chain and of glacial conditions can be at the same time. The signal of a flood found in terraces of the Allier does not correspond with the glacial activity and the associated flood. The dating done on the Tartaret Lake does not seem to completely match with that found in literature, though within the range of measurement errors it does match. The uncertainties about the geochronology could in all cases be dedicated to either the results of this research, or the ones it is compared to, either because of errors in those previous researches, or the lack of exact information. Therefore additional research is needed to mostly solve the geochronology.

5 Recommendations

There a still quite a few questions at the end of this research which may be answered in coming researches. The following recommendations for coming research are thought to answer the most important of these questions.

First of all, as it became clear from the discussion, there is still quite a lot unknown about the timing of all events. There are several ways to get more insight into this. The done measurement on the scoria wall of the Tartaret volcano could be improved, either by taking more samples or doing a single grain measurement. Both measures will decrease the insecurity in age.
It would also be very interesting to get more dating done. On in situ basalt would be the best, but the tested method in this research was unsuccessful and so far there does not seem to be more suitable material or methods available. A location that is known now and would be suitable for dating is the section in the river bend of La Planchette, in the valley where the margin lake is projected. Here different sediment layers and therefore contact surfaces are present. Determining the age of the sediment will tell more about the presence of water in that valley, and the possibly existing link to a glacier or a flood in the main valley.
Also it would be very worthwhile to know more about the moment of presence and the extent of the glacier. More specific literature on the timing of the LGM in this area would help, but also modelling with taking deglaciation rates into account. This will enable to see if it is possible to have the Tartaret and glacier were present at the same time.

Another modelling practice that would be very useful is of the lava flow from the Tartaret. Using specific models like proposed in (Pinkerton & Wilson, 1994), outflow patterns can be modelled. This will answer questions about lava rise, explaining in situ basalt found at different heights to be one or different flows, but also about recording or not in some places, explaining why often there is no basalt found, and also entire extent, going all the way to Neschers .

Finally, this research has focussed mostly on modelling an extreme flood event. As was explained, a lot of the standard methods could not be used because paleo stage indicators were not observed in the landscape. However, even without those it might be possible to model with the large boulders found in the landscape. This was briefly attempted looking at minimum flow velocities, but did this not succeed because concentrated flows have a different power to move sediments than ordinary water. If some equation or model for hyper concentrated flows, added with maybe new field data, can be found it would be worth it to look more into explaining the boulders to get a better estimate for the source of the flood. It could also very well be that the boulders have a different origin (e.g. landside from the current valley sides or sides of collapsed lava tunnels) Extra modelling will hopefully give insight in this.

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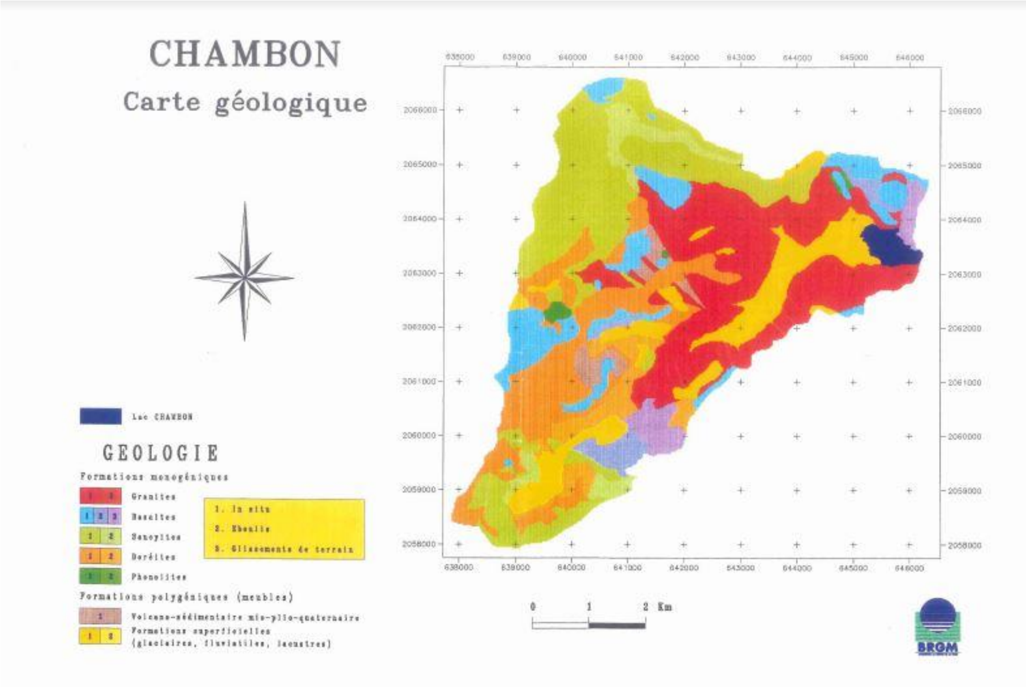
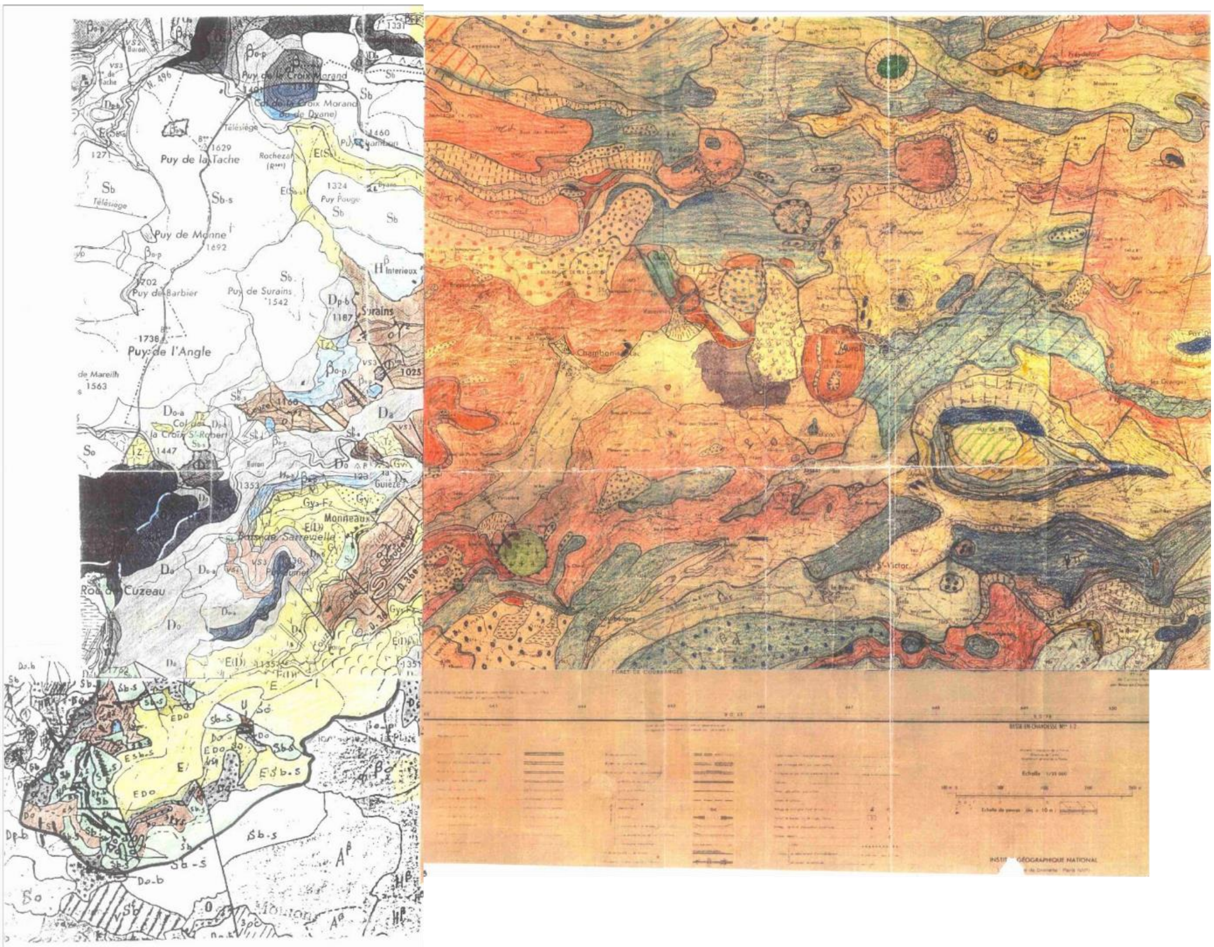
7 Appendixes

7.1 Geological maps





7.2 Field Form

Field form thesis Chambon Tartaret area , France	
Observers: Evelien Castrop, Marte Hofsteenge, Liza van Kapel	Date: 2-10-2017
GPS coordinates: 0494590, 5046987 Altitude: 789m	(GPS) label: 5.7
Position in the landscape: slope	Parent material: Glacial till
Slope (degree): 12	Aspect: 102
Landuse: Forest	Sample taken: yes/no If yes, code sample: 5.7 Method: OSL/C14/TL/other:

Material								
Name layer	Depth	Texture (min size in mm)	Texture (max size in mm)	Structure	Sorting	Stoniness (%)	Roundness	Remarks
1	0-20	Clay (0.002)	10	Crumbs	Bad	15	Bad	Lots of gravel

Landform	
Estimated size (m) 50*200	Maximum height difference (m) 30
Assumed geomorphological unit Side moraine	Shape (roundness) Elongated

7.3 Fieldwork notes

The following are the rough field work notes (raw data).

26-9-2017: 1st field day

1.1a

Low in landscape, thought to be a possible crater. Soil augering done in low. No calcium measured. Mixed sample taken. Augered until 70cm, after that it was difficult to auger.

1.1b

The NW slope of the low described at 1.1a.

1.1c

The ZO slope of the low described at 1.1a, less steep than 1.1b.

1.2

Poreus scoria found on top of Tartaret.

1.3

U-shaped valley described from the top of the Tartaret (1.2). Mountains at the side of the valley are smooth. Valley seems to go around the corner

1.4

Poreus basalt block. On the slope, lower than the block, lots of scoria, with occasional pieces of basalt, are observed.

1.5

Dense basalt block obsereved in road. Along the road both blocks of dense and porous basalt have been observed.

1.6a

Slope at the lake side. Scoria observed. Slope thought to be part of another cone, since a possible crater was crossed just before.

1.6b

Lower on slope, scoria less porous than before. Also some porous(?) basalt found that is darker on the outside, maybe weathering?

27-9-2017: 2nd field day

2.1a

Natural shape? Hole filled with water. Slope measured down from hole (because up was not accessible.

2.1b

Moon shaped. Rest is comparable with 2.1a.

2.2a

Drawing

2.2b

-

2.3

Steep slopes. Drawing.

2.4

Slope, aspect and land use only north facing side. Drawing

2.5a

Low part south side, length out of sight slope perpendicular to the low part. Drawing.

2.5b

Sample taken. Looks like appearance like the scoria block one on the Tartaret. Scoria bomb of porous basalt?

2.6

Drawing for length of ridge of bare basalt. Entire height difference road till top: approx. 40m. After first 20m there was basalt at the surface until the top. In the west the ridge stops very sudden--> think it is unnatural, removed by humans because of the road that goes through it. Higher part at the other side of the road might still belong to this landform.

28-9-2017: 3rd field day

3.1

Height difference measured with gps (804). Bobbely ridge. ZO descends calmy, NW side is very steep. Wavy at all sides. The north side is steeper, the shape is elongated towards the castle.

General note

Saddle northside of the castle in the direction of the ridge.

3.2

In NW direction, there is a V-shape (dry valley). South of this, there is a wavy shape in the direction of the castle. The total height decreases in the direction of the castle. Above the assumed dry valley is a round, large rock outcrop (about a few 100 m wide). Perpendicular on the dry valley is a wave observed: maybe a terrace? Left of the dry valley is a low in the landscape: sinkhole? See drawing yellow book.

General note

Basalt outcrop spotted, North North west from blob 1 (picture).

Theory

Landscape inversion: lava flowed on top of (easily erodible) material, in the lower parts of the existing relief. The basalt protected the areas it flowed in, while everything else eroded away.

3.3

Augering in field. Drawing

3.4a

Ridge (OW) on top of blob 1. Various rocks covered in moss.

3.4b

Flow down from top blob 1. Connected to 3.4a? Both granite and basalt found, basalt assumed to be on top of granite and therefore taken as parent material of this landform.

3.5

Augering in forest → glacial till?

29-9-2017: 4th field day

4.1

Very specific high in landscape with trees in it. Surrounded by crops that seem to be in a larger low. See drawing

4.2

Look into a fairly deep incised line.

4.3

Field without fence.

4.4

Sampled one side of the valley, but took entire valley (only grass part, not all way to top) for width.

4.5

Parralel to valley

4.6

Terrace blob 2? See drawing. Saprolite

4.7

Ridge on slope. Lavaflow, comparable to 3.4 (for bobbliness and rocks)

_4.8_
End of top blob 2

_4.9_
Other side ridge. Basalt outcrop. Whole ridge seems to be on top of granite. Classic basalt.

View from point 4.9:
- Debris flow on NW slope of blob 3
- Tartaret looks very flat
- Lavaflow on top of granite
- Mont-Dore Massif multiple high and potential cirque locations: one at the first steep slope at the right side of the massif (very large). At the left side of the highest point are also various depressions.
- Megablob contains basalt, but is higher than the Tartaret

_4.10_
One column described, multiple columns visible.

1-10-2017: 5th field day

_5.1a_
Slope and aspect of depression in flow. Both 5.1 a & b seem to be part of one laveflow in which the road has been cut out. The flow continue to the river la Panchette. Blobby basalt

_5.1b_
Maybe human made, or part of the flo described at point 1.5a. Blobby basalt

_5.2_
Wall in sharp v-valley. There is a river in the valley. Otherside also rock observed, basalt? First observed point where the sharp V-shape valley started. Slightly weatherd basalt

_5.3_
Layer 1 weathered granite, layer 2 less clay compared to layer 1 and 3, layer 3 contained most clay. Every layer contained singular mica's.

_5.4_
Wall, dense and porous basalt found

_5.5_
Second layer is saproliet! It's a wall on a slope on a ridge. Lowest point we found granite. Very clear cut of soil and granite(saprolite) reallt looks like to seperate deposition. Layer one, the soil, looks sorted with the biggest rocks the deepest. In layer 2 ook normal pieces granite (no saprolite). In Saprolite are red oxidation lines visible between these lines it is gray.

_5.6_
Stone glacier dense basalt and crystalline

_5.7_
Stone glacier

_5.8_
Top blob 3

03-10-2017: 6th field day

Punt 6.1
Scoria wall in query the layers within the wall suggest a direction towards one of the cones. Dry white clay covered scoria. Probably because of water transport trough the scoria.

Punt 6.2
Volcanic bombs close stacked against each other. How is this transported and is it on top of the old scoria cone? Could be transported by a glacier after the eruption?

A few meters higher seem to be a younger scoria cone with also layers in it. The layers seem to point towards another top compared to 6.1. Another volcano? Also, this scoria is higher a red so no evidence of a waterflow through it.

-aspect “second cone” 102 ^{0}

Punt 6.3 (neck close to the spar)
dense basaltic rocks could be a potential neck of a lava flow? The denser to slower it cooled so closer to the source.

Punt 6.4
A ridge that seemed attached to the neck described at 6.3. Seems to contain porous, old/weather basalt and dense basalt. It also looks transported this could be done by a glacier or mega flood? Because it is a high ridge it seems to be transported by the glacier. Could it be a separate neck or has the glacier pushed pieces of the tartaret in front of him?

- This shape continuous until the road with an aspect of 72^{0}

Point 6.5
Clearly through the air transported material also the volcanic bombs “koeienvlaai”. Maybe we are close to an eruption source or is it displaced material from the potential neck observed at point 6.3

- Aspect of the slope close to the road 40^{0}

Point 6.6
Basaltic Bomb (in situ) on top of hill described at point 6.5.the bomb is suggested to originate from the west. This is the direction of the Tartaret and the presumed neck 6.3.

The whole hill could be a part of the Tartaret. Or another very big volcano wall and we are standing on the remnant of the cone wall of it. In both scenarios, it is probably displaced by a glacier.

Still on hill with at highest point 2.6 we still observe porous basaltic rocks.

Point 6.7
In the side of the hill a small cave is found in the basalt. With layers of scoriaceous basalt (scoria or weathering of basalt) and dense basalt in layers in the whole side of the wall of the hill. A steeper slope to the east is observed

Point 6.8(general shape)
Elongated shape with blocks with an orientation. Higher on the west side with a steeper slope on the north side.

Theories for the shape.

- lateral moraine, Not random enough?
- Mega flood, orientations of the blocks, but a very high structure.

Point 6.9

Saddle point in the elongated shape. Could be melywaterchannel

- higher in west side and declines to the east.
- North- south length is 30 m

6.10 (drilled on small sandr)

Small sandr or result of a flood. Other land use, meadow, rest of shape is forest.

Drilled 85 cm depth fine sandy material with gravel poorly sorted light brown and weathered. Top of soil contains more scoria and clay.

- To the east the "sandr" suddenly ends 50 ^{0}

6.11

Again, a plain like 6.10. Plain is not linked to the current drainage system. North is the lowest point of the plain and in the south, there is a river incising.

6.12 (side valley)

West of megablob (side valley) relatively flat open and wide landscape could be a sandr.

6.13

A assumed melt water channel originated in the u-valley. Highest point in the direction of the u-valley (where once a glacier was.)

Theory

Old tartaret was (partly) moved into the U-valley and the new tartaret had the fase 1 lake as result.

Extra note 5.4 (where Liza super awesome didn't fall)

Could be an old flow because it is too high for a young Tartaret flow. A lot has been cut out by the couze chambon to be young enough for a tartaret flow.

6.14

Contact of granite between and a lava flow(young) with a paleosol between them. Can we date this?

6.15

mini flood features parallel to the nowadays couze chambon flow. Boulders and an empty streambed.

6.16

Flood features more convincing on this side compared to 6.15 bigger boulders.

6.17 (waterfall + general)

Waterfall flows over basalt.

- End lava flow? Newer flow with older underneath it this older one flows al the way to Neschers?
- Collapsed lava tunnel? downstream of the waterfall on both sides there are caves in the basalt.
- Active fault? Not likely because of the timescale.

Upstream of Saillant village southside of the couze. There is a meadow wide and wavy, could this be a buried lava flow? Northsides same structure but smaller and a small step lower.

6.18

High isolated rock of 10 m high (8 x 8 m width and length). Rocks basalt and porous basalt

Weird shape too high for young flow too low for old flow?

- Mega flood, how much water do you need to fill the up this valley and transport this.
- Tectonics, old lava and it fell towards the valley?

6.19

Block of granite so not very blob is basalt here. Tectonic blocks that started moving?

-size 2 X 4 m

6.20

Basalt close to river, small shallow flow.

6.21(pinnacle)

Block in river 28.5 m high rock on the riverbank of the couze chambon unknown but could be basalt is the consensus.

04-10-2017: 7nd field day

Point 7.1 (scoria cone Tartaret)

Comparable with 6.1. Same direction of the layers in scoria as white scoria in 6.1. Again white because of the clay deposited between the scoria parts, due to water flowing through it.

Point 7.2 (hill in front of Casino supermarket)

Small hill with trees perpendicular to the Tartaret. On north side no loose materials. Smooth slopes. Basalt boulders lower on the slope. Shallow rooting depth. Looks like morene, but quite strange place for it and huge height difference. Low on the north slope we found basalt that looks like pillow lava. Maybe small neck? Lava flow? Unclear.

Point 7.3

Same hill as 7.3. Here basalt blocks on Tartaret side of the hill. Alternating porous and dense basalt blocks. Side of Tartaret steeper. This rug looks transported.

Point 7.3

Big dense blocks on Tartaret side of the hill. Looks in-situ. This rock wall is 50 m in E-W direction.

View from the castle

Is the flow path of the Couze at the edge of the lava flow?
Are there blocks, relics in the meadows? Next to the Couze?
We didn't found sink holes yet in the valley, they are maybe close to entrance v-shaped valley?
We didn't find a nice flow just under the Tartaret, only scoria.
There is a lot of basalt used for the castle. This is also a way how the basalt can be removed.

Point 7.5 (old lava flow)

We found old (Mont-Dore) basalt.

Point 7.6 (artificial placed scoria)

A lot of reddish scoria. No stratification. Looks artificial.

Point 7.7 (old lava flow)

Old Mont-Dore basalt. Clear vertical columnar structure. Also within the columns blocks, due to weathering. This can be a possible place where they got the basalt which is used in the castle.

General on road back to Murol

Driving from top down to Murol we found first basalt, then granite and then Oligocene. We would expect the Oligocene on top of the granite, we can check this later again on our bikes.

Point 7.8 (lateral morene under castle)

Nice platy basalt as slightly loose parts. Looks there are also some bigger parts of basalt. This hill is elongated and in direction of the Tartaret. Could this be a flood ripple? Side morene? Looks like basalt (flow?) on top of river deposits. It is most likely a lateral morene. The material looks like a push morene of an advancing glacier, which pushed the bottom layer of the valley and pushed on top the lava flow . The valley on the south looks really smooth and could be perfect place where the lava flow can be.

Point 7.9

We found granite. Can be perfect place where mega flood has passed, especially since there is no river at the moment.

Point 7.10 (flood ripple)

Flood ripple with blocks of basalt and granite. No big height differences between the flow paths. Possibility that the glacier was in front of the V-shaped valley and blocked it, so the flood had to go in this valley. Other possibility is that the lava accumulated in front of the v-shaped valley. Note that it is just a small height difference to enter also this valley instead of only the v-shaped valley.

Point 7.11 (Les Granges)

This is lowest point where we found granite.

1.1.1.1 yPoint 7.12 (Les Granges)

Here we found basalt (highest point?).

General note

When the valley gets wider, we expect big (basalt) blocks (deposited by glacier/mega flood). In these valleys we see on the sides of the valley Oligocene deposits. Just before Verrières it looks like there are two levels towards the river.

Point 7.13 (basalt in side valley)

We found basalt. This is located at a quite high altitude, 80 m above the waterfall in Saillant. Is it possible that this flow comes from the Tartaret?

Point 7.14

We still see basalt next to the road. Looks like there are two valleys, one of the two goes into the valley in direction of the Tartaret.

Point 7.15

Granite.

Point 7.16 (basalt block next to Couze, in situ?)

We found basalt next to the Couze Chambon. Looks crystalline (more and bigger crystals), meaning that it solidified slowly. Looks slightly like a basanite (more felsic lava). Is this lava in situ? Reasons why we don't see the lava here: (1) narrow valley with big gradient resulting in a lot of erosion that removed all the lava, (2) the gradient was too high here that the lava only passed this part but didn't solidify here (check in literature!), (3) the river is on top of the lava, but we cannot see it yet. Another option is that this basalt block is not in situ and placed here by a mega flood. Sizes of the basalt block is approximately 5 x 4 x 4 m. Next to the river we see a lot of granite here.

Point 7. 17 (where side river Rivalet joins the Couze)

At this point the small side river (Rivalet) joins the Couze Chambon. We find a small flat terrace where the side valley enters the Couze Chambon. Here we also find basalt what looks like pillow lava. Could it be that the lava solidified here in contact with water from the side river? It is also possible that the lava flow from the Tartaret blocked this side river, which caused the forming of a small lake and it's deposits is the reason why we find now this flat plane at the crossing of the rivers. We also find blocks of granite. It is also a possibility that a mega flood had more space here and deposited material. We also see a small rug of stones of 2 x 7 m with a direction into the side valley.

Point 7.18

We find basalt next to the river (south). Most likely the river has incised on the contact between basalt and granite. We walk on a flat strip south of the river and this looks like a lava flow. It seems that the river has incised on the north side of the lava flow (Check with DEM that this flat part was south of the river).

Point 7.19

Big block of granite and basalt. In situ? then it would be an old lava flow. If not in situ, then it could be placed there by a flood or as loose material out of the valley.

Point 7.20 (columnar basalt next to Couze)

We found basalt with vertical columnar structure. Basalt has a height of approximately 4 m.

Point 7.21 (end lava flow Neschers)

Basalt with columnar structure in house next to the river. Approximately until a height of 4 m above the river. Looks like this is the end of the lava flow. After the village the level drops. Seems that this is the end of the lava flow and whole village of Neschers is built on the end of the lava flow. On the north side of the Couze we see a light colored outcrop, Oligocene deposits (maybe chalk).

General east of Neschers

We see clearly two levels in the valley. A lower level in the north of the valley and around ten meters higher south in the valley.

Point 7.22 (lowest level)

We are on the lowest level (of the two) now. A huge wide, flat meadow. We find a lot of rounded stones with sizes up to 5 cm on the edges of the field (varying basalt and granite). We also find bigger stones in the field, for example a stone of basalt of approximately 30 cm. We did a soil drilling here: we find clay up to very rounded gravel. We find a lot of clay. Up to 110 cm we see 'verbruining' of the soil. Because of this it is more likely this deposition is colluvial and not in situ.

Point 7.23 (edge two levels)

We are on the sharp edge of the two (terrace) levels now. Step of 10 m and contains rounded stones, probably with Oligocene material under it. This terrace is very wide, most likely because it is incised during the deglaciation.

Point 7.24 (Oligocene material)

Sedimentary rock, from the Oligocene.

05-10-2017: 8th field day

General on mapping of the Murol valley

We should map also the valleys/depressions in the valley when they have a clear direction. They can be formed as irregular pattern of collapse and still intact tunnels of lava. These reliefs due to collapse of tunnels are formed most recently. We should also map the sharp edge before the V-valley after Sapchat.

Point 8.1 (relics in valley)

Erratic (relics) boulders observed heighest point is 5 m.

Point 8.2

Boulders stacked together height is 13.70. A wide valley on the north-west side of the river is also observed

Point 8.3

A boulders in a meadow overgrown with trees. With sedimentation behind(east side) of the bolder. You would expect that sedimentation would be left on the east side of the boulder if a flood comes from the west. Height is 2.50 m

Soil in west side of the boulder (in flow direction) clay with rounded pebbles in it. Maybe lava flow is beneath the soil?

Point 8.4

We standing in a meadow with boulders that are overgrown with trees. Described at point 8.3 the valley is not completely flat but with a small relief.

Point 8.5

Looked in the Couze Chambon in a fast flowing corner. 1.60 m soil in riverbeds no lava flow observed. There was poorly sorted material in the riverbeds.

Point 8.6

In a strait part of the river still no basalt. Why is it not a wider or deeper incision, what's keeping it from it? Is it flowing on top of the lava? In side of the valley pebbles are obserbed of 1 m diameter.

Point 8.7

Again a hill with stones on it in a meadow. Could be slightly human enhances because if you do not use a spaces you bring the stones you can transport to the nearest hill of stones.

General remark reliks found

Clear erratic with a streamline in them and maybe a direction. There is a slight height difference from the road to towards the west side of the valley around 1 m. In general seems most of the trees overgrown bumps in the meadow contain boulders

Point 8.8

Basalt observed quite dense in situ or not? There is soil between them lava flow or still a relic of a flood?

Point 8.9(mudflow?)

Clay matrix supported stones, super unsorted mud flow or debris flow? Both rounded and angular stones with a diameter of 40-50 cm at least a depth of 2 m.

General note valley after v-valley

Maybe st-necterin where stream ripple was observed also ends in this valley

Point 8.10

Both side of the road small hills containing basalt bolders observed overgrown with trees.

Theory lava flows and megaflood

Before Saillant we didn't find basalt next to the river. Since we have a thick basalt layer in the waterfall in Saillant and a clear step across the whole valley it could mean there was lava in the whole valley until here, but under a thick soil (at least 1.60 m, see previous points). Since we found relics of a flood on top of the lava there are a few theories:
(1) The (mega)flood happened during an eruption of the Tartaret and the flow (here!) is from a previous eruption of the Tartaret. In this case the latest eruption of the Tartaret still could have a lava flow but not in this area, since there are mega flood relics on top. (However, we still have a scoria cone, which looks there wasn't a second lava flow at all because the flow would have destroyed the cone. It is also a possibility that the volcano erupted some scoria after a flow was released). If the dating on the lava flow in Neschers is right, this flow should be the 'newest' flow, which is not in agreement with the theory above. Therefore we should have a critical look on the dating done on the flow in Neschers.
(2) The lava flow is from the second/latest eruption of the Tartaret and the flood is caused by a break-through of the Tartaret lake, flooding of the ice margined lake or the deglaciation. But does these event have enough force to explain all the reliks. Also in the smallest part of the valley there seems to be "steps" this could mean multiple floods.

Point 8.11 (end flow after waterfall)

Basalt next to the road. Clearly after the waterfall and with a height of 2 m above the road. This could be the end of the flow (also note the N-Z edge of the lava flow on the DEM).

Point 8.12

Basalt. This also seems to be the end of the flow here.

Point 8.13 (artificial side gully)

Side gully of Couze Chambon made by human. In the wall we see a soil of 2m and below basalt. We also see basalt blocks in the walls, probably artificial.

Point 8.14

We see basalt in the walls of the gully. The basalt has a white color on the outside, probably caused by clay on it. The human made gully is 3 m deep. We pointed this point on top of the gully. Unclear if the top layer is a mega flood deposit. The river Couze is located 10 m lower.

General remark valley after Saillant

The river Couze Chambon gets more gradient driven. Resulting in deeper incisions, and less meandering as before.

Point 8.15 (mega flood relics)
Boulders with forest on it. Several blocks, 1.5 x 1.5 m. Total collection of blocks is 10x10 (width x height)

Point 8.16
Valley next to the Couze on northside wide and flat, with subtle relief. This can be a lava flow with on top deposits of a flood. We see big boulders with trees and bushes on it and also human made walls of stones (probably out of the valley). Approximately 300 m in North-South direction.

Point 8.17
Relic with trees on it. Boulder: 2x2 m. Whole blob: width 20 m, height 10 m.

Point 8.18
Basalt and granite in the flood direction. Both width of 3m and length of 2m.

General note
Lot of granite along the steep hills next to the road (as in picture of 8.18)

To do Marte
We would expect that this steep narrow valley is a good place to find basalt, since the river can incise far in the lava flow. Or no lava at all because it passes this valley (because of gradient) really fast and has no time to solidify? Study literature to find an analogue of what happens if a lava flow flows through a small valley with a big gradient. At point 8.18 there seems to be no basalt at all.

Point 8.19
We find basalt, at a height of 12 m above the level of the river. Can this be the Tartaret lava flow?

Point 8.20
Basalt at an altitude of approximately 7 meters above point 8.19. This could be (1) the top of a lava flow (looked weathered) or (2) basalt blocks deposited by a mega flood.

Theory thick lava flow
(1) The lava flow found at 8.19 (and 8.20?) is an older lava flow

(2) The lava accumulates just before the point where the valley gets narrower.

The pinnacle of basalt in Verrières seems to have the same height as the lava from 8.20. We also see this basalt on the other side of the river (south), where there is also an noticeable plain.

Point 8.21
Basalt in the village Verrières. It looks like there are different levels down to the river level. Jeroen thinks this is due to filling of the valley by lava and subsequently incision by mega flood(s) (they are not river terraces).

Point 8.22 (basalt in side valley)
Basalt with nice columnar structure. West of it a nice wide and flat meadow with boulders of +- 1 m in a few of the bushes. This nice basalt looks older then the Tartaret. We expect it has approximately an age of 100.000 years or older. When we drive further into the valley this flow lies in the direction of the Tartaret (we were not able to follow the basalt in this valley sadly).

Point 8.23
Basalt next to the road.

Theory flow path north of blob 1
It is very unlikely that the flow of the Tartaret or mega flood would go north of blob 1, because the height difference is to big.

Point 8.24 (basalt top mega blob)
We find basalt on top of mega blob. Granite under it.

Theory ice margin lake
The quite flat area south of the Tartaret, west of mega blob, can be a perfect place for an ice margin lake. This lake then would have been dammed by the glacier. This ice margin lake can have been emptied with a flood when the glacier melted away. This could have been together with a mega flood. The flood could have gone to the southerly dry valleys.

Point 8.25
Here we found granite on mega blob, under the basalt.

Point 8.26
Boulders and blobs, possible end morene of the glacier. The material can be anything.

Point 8.27
Beginning of the Tartaret lake (first lake phase).

Theory mega flood
Possible causes of a mega flood:
- flooding of ice margin lake
- deglaciation (slower timescale)
- flooding of the Tartaret lake
- cause by (one of the) eruption(s) of the Tartaret

To do Evelien
How much water do you need to fill up the whole v-shape valley to explain the biggest boulders? Can this come from one or a combination of the lakes?

06-10-2017: 9th field day

Point 9.1
We took a sample for dating here of the scoria cone of the Tartaret (with clay in it).

07-10-2017: 10th field day

Point 10.1 (slope Tartaret)
A plain on the slope of the Tartaret (point taken on slope under the plain). We did a soil drilling until 20 cm. Bad sorted material. Sandy material until gravel with a diameter of 5 cm.

Point 10.2
Porous basalt blocks. Three blocks with a diameter of 30 cm in a direction with aspect of 80° and slope 10°. We also see different porous basalt blocks without a clear orientation → volcanic bombs?

General note
On this slope we don't find basalt of a lava flow on the surface. It might still be there but buried under scoria.

Point 10.3 (blob with house on it and scoria boulders)
We are on higher point in the landscape and see several blocks of porous basalt, with a diameter of 1,5 m. On the east-side we see a orientated plain. On the slope of this shape (covered with forest) we see basalt that can be part of a bigger basalt structure or blocks that are incorporated in the soil.

Point 10.4
Plain on the eastside of the higher point of 10.3. This plain is a meadow and has a height declining in south-

easterly direction. Estimated size: E-W: 150 m and N-S: 300 m.

Point 10.5

Higher part in the landscape. We find loose porous basalt blocks, up to 20 cm in diameter. They might be transported by glacier or flood. The shape of this higher part is elongated in east-west direction. Steeper on the west-side and has a gradually decline on the east side. Forest on it.
Might be in situ material, transported by air from the Tartaret? We also observed some blocks of 1 m diameter every now and then. On the east-side we see a flat strip on the lower slope, which is 3m wide and with a height of 1,5 meter above the base of the blob. On the east side there is again a lower part with grass on it.

Point 10.6

A low between the small hill of 10.5 and the 'neck at the Spar, 6.3'.Wider on the west and gets narrower in north-east direction. The low has a decline in height towards the Spar supermarket. It is covered with grass.

Point 10.7

A low with grass, elongated, with aspect of 252°. Low looks like a valley and lowest point in westerly direction. There is no water flowing here. Estimation: 200 m N-S and 600 m E-W. We did a soil drilling here: bad sorted, rounded and with scoria and basalt in it. This low probably continues where there is now the camping with the chalets build on it.

Point 10.8

Blob with basalt blocks. Trees on it. Basalt has big crystals in it, but we also see porous basalt. Looks like a block with two structures. Size of the whole shape: 3m high and 5 m in diameter. A block separate: 1,5 m in diameter and 1m high.
As a whole it looks build up from separate blocks → transported? The shape is elongated in north-east direction (37°)

Point 10.9

Blob with a lot of trees and bushes (in bigger meadow valley). Height: 15 m. Individual blocks from 1,5 up to 3m in diameter. But looks pushed or transported (ice/water). Quite high → ice more likely? South-east side is steeper and looks more like a rock wall. North-west side has a more gentle slope with clearly separated blocks.

Theory

15m pushed blocks, more likely for a glacier? With a mega flood we can expect big blocks but then they are maybe more placed behind each other instead of on top?

Point 10.10

Basalt, looks bumpy from the outside. Here it is higher than at the meadow around. The basalt is not clearly as separated blocks. Can be incorporated in the soil or in situ as lava flow. On the west side of this basalt there is also a higher point with basalt as well, but here not clearly separate blocks as well. On other sides no clear stones or sediments. The shape is elongated in northwest-southeast direction. There are bushes on it, barely trees.

Theory

It seems that point 10.11, 10.9 and 10.13 are placed in one line → morene? Can be broken through by a flood? Flood might have made the shapes as 10.10?

Point 10.11

Higher point with blocks of basalt, diameter of 0.5 m and with trees and bushes on it. The blocks on the south-west side and they look like they are placed next to each other. South-westerly orientated. On the top blocks with a diameter of 2m.

Point 10.12

Soil drilling: very bad sorted material, not rounded. We drilled until 20 cm, we expect the soil to be thicker but too many stones to drill deeper.

Extra note

We also observe a blob with (basalt) blocks 100 m easterly from 10.10 in the middle of the meadow. We didn't go here because there were a lot of cows..

Point 10.13

A high in the landscape, with trees on it. We observe scoria with diameter until 25 cm. No big blocks observed. Comparable with blob next to camping l'Europe. Low on the east slope we find basalt, with clear crystals. Unclear if this basalt is a separate block of incorporated in the slope or in situ (unlikely). On the north-east side there is a open side with a lot of porous basalt and loose scoria. No layers in the scoria visible → not the in situ cone? → pushed? Transported? Many colours: red, purble, yellow and grey scoria. This scoria and point 6.5 may have formed one structure?

Point 10.14

On the base of shape described in 10.13. Dense basalt, clear blocks. Shape of 10.14 and 10.13 is elongated from NE to SW.

Point 10.15

Low in the landscape → artificial? Round structure. Small extension in north-east direction. Bushes on it. Sinkhole? Sandr? Artificial? No clear direction. Size: 80 m N-S and 50 m E-W.

Point 10.16

Big basalt structure next to the river. We think in stie → flow? No clear blocks. Basalt looks bumpy but is dense and with crystals, not porous. This basalt is located at westside of La Plancetta. Top basalt at 2m above the water level. With imagination you can see a columnar structure.

Point 10.17

West side of the road, big basalt blocks observed, 2m Ø. 3m above the road. Under it there are blocks basalt, not clear if they are separate blocks or in situ.

Extra note

In the field north of the river there are rows of stones, 0.5 – 1m Ø with trees on it. Seen in direction of 300° from 10.17. Perpendicular on the river. Approximately 30m south of point 10.17. It looks like behind this one there is another row with stones parallel to it.

Point 10.18

Elongated strip along the south-east side of the river. Grass on it. Decline in height towards north-east. Estimated size: EW: 30 and N-S: parallel along the river.

8-10-2017 11th field day

Point 11.1

At the side of the road igneous/metamorphic granite? Clearly no basalt. No calciumcarbonate present.

Point 11.2 (black scoria wall with nice man)
Black scoria seen in wall at the side of the road

- With the friendly owner
- Clear border with soil above
- No layering in "wall"
- Datebale? --> permission to take a piece
- Soil on top contains gravel, with large rocks (see sample in bag). Between all the black scoria (homogeneous) sometimes pieces of white rock --> gneiss?

Same scoria as west cone (1.6) Tartaret?

According to friendly landowner scoria is called pouzzolane.

Point 11.3
Low in the landscape, covered with grass. Elongated in East-West direction (500m), North-West – South-East 150m. Outflow direction is West.

Soil drilling:
Seems to become more clayey over depth. Upper ±50cm sandy, below that is an sudden change to clayer material. In the clayey material is smaller and less gravel. In sand larger rocks. All rocks are angular. Total depth is at least 120cm. Bedrock was not reached.

Top layer contains more sand, lower layer more clay.

Stones in top layer: granite, basalt, gneiss?
Stones in second layer: scoria (black)

Point 11.4
Granite observed at the side at the side of the road, in situ.

Point 11.5
Plain covered with gras. Elongated in NorthEast-Southwest direction. Outflow directioj is also NorthEast.

Soilaugering:
Dominantly clayey with lots of gravel with occasionally rocks with 1,5cm Ø. Lots of oxidation (red) spots with less clear reduction spots.

- lots of colours
- gravel is small, close to sand
- stoniness 10%
- structure: subangular blocky
- roundness = angular (bad)

sorting = bad
depth is 30cm, but maximum depth not reached --> due to ocasionally present rocks

We are close to a river (la planchette)

Width = Northwest-Southeast = 100m
Length = 500m

Point 11.6
Elongated meadow in Southwest-Northeast direction 1km wide. 300m wide southeast-Nnorthwest. Outflowdirection is towards northeast.

Daugering:

Occasionally large gravel (3cmØ). Both angular as nicely rounded pieces of gravel.

Point 11.7
Elevation in landscape with rocks. Elevation is covered with trees, while rest of the plain is covered in grass. Size of rocks is very unclear since the shrub cannot be entered.

Point 11.8
Narrow elongated shape in meadow. Shape is covered in Eat-West direction about 100m long and 3 m wide. The southside of this shape is a little step higher than the North side, about 1m.

- ➔ Sediment capture? Men made. Is there erosionrisk here?
- ➔ Sandr?

Extra note
Meadow in wich landform 11.7 and 11.6 are descends in North direction.

Point 11.9
Elongated plain with meadow, height decreases towards the northeast. Length 600m, width 100m. Augered here.

Lots of small gravel. Roundness both good and bad. Stoniness 35%. Structure crumbs. Sorting average (better than earlier today).

Plain has relief: augered on slightly higher part (flat, not a peak)

Extra note
In general soils today are fairly brown and reach deep (colluvial?)

Point 11.10
Basalt spotted in meadow. This point is covered with trees. Not convinced that it is a point because there is only 1 block of basalt observed of 50cmØ. Delete this point?

Point 11.11
A strip of loose rocks observed -->transported
The shape itself is covered with trees and on both sides is a meadow. At the southeast side the field looks 2m lower.
--> Streamlined shape?
- Rocks have a diameter of 0,5 m Ø
- Field at the Northwest side is situated at more or less same height

Theorie
- This side valley remindes us more about:
- Sandr? --> sorted?
- Gletsjerplain? --> do we see a ground moraine?
- Do we see rolling topography?

We think the material is not sorted enough and not clayey enough for a lake.

Not a lot of clues to a flood or an ice margin lake

Point 11.12
Meadow with stream direction southwest. No river is flowing here?

Southwest = 800m
Width = 250m

Point 11.13
Meadow with outflow direction mostly towards la planchette (northeast). Scattered bushes and trees without clear orientation or reason.
northeast-southwest direction: 400m
Northwest-Southeast direction: 300m

Augered:
Large (3,5cm) angular piece of basalt. Also gneiss?

Point 11.14
Outside curve of la Planchette (Southeast side). Soil profile in wall. Lots of layers, mainly gravel (dark/black) and orange/red sand. Also layers of clay, a thick layer

(about 1cm) about 35 cm down from the surface. About 70cm down from the surface is a more firm part, seams to be layers of clay, switched with gravel and sand (and wither stuff, saprolite or granite?).
Layers --> river/maring lake?

Point 11.15
Lake. About 2m above above la Planchette, northwest side. 500m in Northeast-Southwest, 300m in Northwest-Southeast.
Maybe artificial? (beach)

Point 11.16
Dense basalt found at North side Tartaret, untill 10m above the road. In situ. On top there seems to be scoria, with clay inflitration.

9-10-2017 12th field day

Point 12.1
Basalt found on a hill overgrown with trees. The "hill" is between a house and the road. The basalt looks transported →ice?

Top 0,5 meter seems more lose and smaller compared to the rest → scoria or weathered?

West side is less obvious transported could this be in situ, or still transported by a glacier?

Point 12.2
2 meter of soil visible with a lot of angular stones. Doesn't look sorted or layers. It is observed in a garden on the west side of the road.

- biggest stone is 15 cm
- smallest 1 cm scoria.

Point 12.3
Basalt boulders (Lose?)on a hill covered by forest with smaller stones around the boulders. The hill has a gradually slope with no significant steeper slope on either side(east-west side). The shape is elongated in north-south direction. Basalt boulders varied there were both bobbly and dense boulders found.

- Size of the boulder is in average 1.5 meter diameter.

The porous basalt blocks seems to be aligned could this be

→transported?

→in situ, Vulcanic bombs?

- Total height if this hill is ± 8,9 m

Point 12.4
Hill covered by forest. On the west side of the hill we see a boulder of porous basalt of 3 m wide and 1 m high. The south side of the top of this hill we observed a lot of big boulders. The average size of these boulders is 3 m diameter. It is unclear if all the boulders are lose or part of a larger structure. Also some boulders seemed to be aligned against each other → by ice? To high for lava flow and to big structure for a flood?

Point 12.5 (drilled in soil)
Elongated plain in the landscape(at least lower than the hills around it) it is covered in a meadow. The plain is elongated in east-west direction and drainage direction is to the east.

- Size east-west is 250 meter
- North-south is 100 meter

Soil drilling:

Layer one is 30 cm we couldn't go further because of the stones soil could be much deeper. The texture is clay to stones (3 cm) with a lot of gravel with only sporadic a stone.

Point 12.6
Large boulders basalt on a hill that's covered by forest. Point 12.5 lies on the north side. On the northside of the hill we see a basaltic rock 2 meter high but it is still half in the ground. On the top we see clearly big lose basaltic boulders with a size of 1 m diameter.

Point 12.7
Low in the landscape looks like a meltwater channel? In the shape that's dominated by shape described in point 12.6

- Size North – south 15 meter
- East-west same wide as point 12.6.

Drainage direction is in east direction. In the west it looks the end in "nothing" because this was where the glacier was.

- Height difference meltwater channel and plain is ± 15 meter

Point 12.8
Hill with large basaltic boulders the basalt is porous and bobbly. Boulders looked to be aligned → transported.

- Size boulders ± 15 meter

Point 12.9
Plain west of point 12.8 used as a meadow. Elongated in north-south direction and drainage direction is to the north

- size north-south 200 meter
- size east-west 30 meter

Point 12.10
Elongated in north-south direction hill in a low with lose boulders basalt (20 cm diameter) with crystalline structure.

- Height is 1.5 meter

Point 12.11
Low with a circular shape used as a meadow. The shape has a "channel" shape trough it in east-west direction. The lowest point seems to be in the circular shape could this be a sinkhole?

- Height diference in circle is 0,5 meter
- Diameter circle 1.5 meter

Point 12.12
a hill with forest on the top that we couldn't access due to a fence. On northeast side we see a part of soil, a lot of lose stones with a size of 10 cm diameter. Height of the hill is ± 5 meter

Point 12.13
Close to the road on the south side we see an elongated low parallel to the road ± 15 meter lower compared to the road. We think this is the same on the north so this part of the road is on a higher level.

Point 12.14
Point is taken on the south of a low in the landscape covered by a meadow. Drainage direction is to the south. The meadow is surrounded by forest or houses.

- Height difference is 5 meter compared to the road but this could be artificial.

Point 12.15 (Scoria)
Hill in the landscape on the east side dense basalt observed that could be in situ because it was very large. On top of this basalt lies black scoria also very fine grained scoria sand/ash was seen (see sample). On the southeast side a lot of scoria is observed with some denser basalt in it. A lot of colours.

- Height whole hill is ±15 meter

Point 12.16
Low in landscape used as meadow drainage direction is to the northeast. Could there be a lava flow under this?

- Size north-south 300 meter
- Size east-west at least 500 meter

Point 12.17
Open meadow plain drainage is to the north on the south east side a hill covered by trees that looks like a ridge in the landscape.

- Northeast-southwest 100 meter
- Northwest-southeast 30 meter

Point 12.18
Hill with forest overgrown pinned on the top. On this top a boulder with bobbly porous basalt looks like scoria material that was packed together with an orientation to the west. Also a lot of lose scoria surrounded the rock. Rocks mostly on south side and the highest part was on the west side declines to the east.

Point 12.19
South side of this point a hill observed covered by trees Looks like to contain lose boulders with a diameter of 1,5 meter total height of the hill ±15 meter. In meadow on the east side probably a similar structure was observed stones where seen but it was covered in a lot of trees.

Point 12.20
Hill in landscape covered in trees pinned on the north side. Basaltic boulders on south east side with a diameter of ± 2 meter looks to be aligned against each other. On the north side basalt on top of scoria see photo. Elongated in south east-northwest direction

-height difference ± 20 meter

Point 12.21
Wall where part of the hill(covered by trees) is partly excavated so would observe a thick layer of porous basalt, dense basalt and scoria with no layers →pushed?

Mostly scoria sometimes "koeienvlaai" volcanic bomb observed everything is mixed so not in situ. Scoria is mostly reddish but also yellow and black is seen.

- Height difference hill is 6 meter
- Southeast-northwest 150 meter.

Point 12.22
Plain in the landscape with an elongated shape in northeast-southwest direction used as arable land. Drainage direction is to ne north west but there is not a lot of topography in this low.

- Size northeast-southwest 500 meter
- Size northwest-southeast 10 meter

On the other side of the plain (southeast side) we see a elongated height. This height is elongated in NO-SW direction.

- height is 10 meter
- length is 200 meter

Extra note:

Jeroen thought this could be a collapsed tunnel.

Point 12.23
Hill covered by forest big lose basaltic boulders average diameter 2 meter. Also a very large boulder (3 x 3 meter) with column structures? But clearly transported.

We observed a lot of very large boulders, almost no small ones. It looked mostly lose →transported.

But also parts that made us think of the neck at the spar because it was more dens basalt. Boulders of dense and porous basalt where stacked randomly against each other. And steep edges on both sides.

-total height ± 20 meter.

10-10-2017: 13th field day

Point 13.1
On the northside of this road we see in a field four times a small hill with trees on it, with clearly big stones on them. We couldn't go here because of a lot of fences. Stones are ± 1m Ø. They all look almost circular of shape. The height difference for the hills are approximately 4m. The hill closest to the point we pinned is the highest, ± 6m. The width of the hills is 20 m maximum.

Point 13.2
Elongated flat part in the landscape, covert with grass. Elongated in E-W direction. Descending in easterly direction. Size NS: 100 m. EW: at least 500m. In western direction we see a small hill in the field, probably with stones. South of the river there is small relief in the field.

Point 13.3
We observe boulders 10 m south of the road, looks like basalt. 1,5 m Ø. Trees on it. Shape itself: 4m Ø.

Point 13.4
On the south-east a forest with every now and then a lot of stones. Small relief and every now and then little higher by a heap of stones. Stones are basalt. Stones ± 1,5 m Ø. This area is around 100 x 50 m. Looks random distributed.

Point 13.5
Plain, meadow. Elongated in NW-SE direction. Descending in NW direction.
Estimated size, NW-ZO: 150 (until where arable land starts), width: 100 m. South-west in the field there is a hill with trees on it, looks artificial.

Point 13.6
Elongated high in NW-SE, with trees on it. Big blocks blobby basalt. Quite loose material. Porous basalt? Squeezed scoria? Really big stones, from 1.5 m Ø to 3m Ø.
In the middle of the shape there is a channel perpendicular to the

direction of the shape. Channel descending in SW direction. Height difference in shape: 10 m. Transported. Pinned on the top.

Point 13.7
Plain, orientated in NE-SW direction. Descending in NE direction. Meadow, forest around. Width (NW-SE): 30 m. Length not visible, at least 200 m. Pinned NW side of the road (on the road, the meadow is slightly lower located).

General note
Everywhere were we see trees here, we also see stones on small hills. The meadows are more flat parts.

Point 13.8
On N-E side of this road we see a bigger hill with forest on it. We see a lot of big stones of dense basalt. Blocks: 2m Ø. Width along the road ± 40 m. Total height: ±20 m.

Point 13.9
Pinned in the middle. Meadow, almost circular, plain. No clear descend in the shape. Looks like there is a small wall around → artificial? Size: 20 x 20m. On the northside there is a meadow as well, but a level of 1,5 m higher.

Point 13.10
On a slope, on the edge that is visible on the DEM. Lot of boulders . Quite big boulders, 3m Ø. With some imagination columnar structure, but under it we see more loose stones. ± 1 m Ø. Dense and more blobby basalt. Big and small boulders. Very bad sorted. Height difference in shape: ±15 m. Slope: 22°

Point 13.11
Pointed on the hill. Small hill with boulders of 2m Ø on it. Height difference ± 8 m. In the same meadow another blob with stones, 1.5 m high.

Point 13.12
Dense basalt next to the road on north side. On top more blobby and lower behind the rocks. Looks more in situ then before. But strange that around this stone everything is lower, doesn't look part of a bigger flow. Height: ± 6m.

Point 13.13
South side of the road we observed basalt. Could it be in situ? Quite big blocks, 4m Ø and kind of columnar structure. We see clearly separate blocks as well. Located on a slope. Height difference ± 6m. Longer elongated higher shape, along the road.

Point 13.14
Flat strip on west side along the Couze, SE-NW orientated. Meadow, descending in SE direction. Perpendicular to this meadow there is on the SW side a elongated high with rocks (13.13).
Other side of the Couze a meadow as well and looks quite flat too. Width: 20 m.

Can this be place where a flood passed? Possibility that the Couze incised this?

Point 13.15
Still on the same high as 13.13. Wall of big basalt blocks. Behind the big basalt block it continues being at high level, as a plateau. We can see columnar structure. Height: 2m. The bottom of the columns 1,5 m located above the road. And the road 0.5 above the meadow (13.14).

General note
Quite big height difference between slope with basalt and the Couze river. Along the whole high there is a flat strip meadow before the river Couze. Why? Did the couze incise this? Megaflood?

Point 13.16
Big basalt blocks. Looks from the top again still this elongated high, in SE-NW direction. In NW direction after the top the hill descends again. (First we had the impression it was more flat). Here the height difference is higher as well. 20 m height difference. Pushed? Relics on a lava flow? Did the lava flow pile up here before the v-valley? Height basalt block: 6 m. Slope: 34 °. Aspect: 29°. Height difference to high for the Couze to have incised?? Did the lava flow just stop here?

Point 13.17
We did a soil drilling in this low, a meadow. Elongated in NW-SE direction, parallel to the river. For a long distance! Width (NE-SW): 100 m. This low is connected to 13.14.
Soil drilling:
Clay – 2.5 cm stones. Mainly sandy material. Stones out of the drill whole wall. Bad sorted. Bad rounded. Crumps. Stoniness 5 %. On top dark brown, greyish under it and brown under it. 0-20 cm humus layer. 20-30 eluviation layer. 30-40 illuviation layer. Stones are black and red porous basalt.

Point 13.18
Wall of basalt, very hard and dense, nice basalt! 5 m heigh, 10 m width. In situ? Behind there looks a row of loose small stones behind this wall. Maybe other small stones flooded down this slope, bit these got stock behind this wall of basalt? This row has an aspect of 51°. There is also other basalt blocks on this slope, with nice columnar structure → lava flow? Can it be this high?

Height difference from road to top is approximately 15 m. On the other side of the top it descends gradually. This side, of the Couze, is steeper. The meadow is again 2m lower than the road. The meadow on the other side of the Couze looks 1 m lower.

Point 13.19
Suddenly sharp decline in height. Decline in height in west direction.

12-10-2017: 14th field day

Point 14.1
We are standing in a gorge, in between two walls of basalt on east and west side. On the north side a steep slope, upwards from the bottom of the gorge to the top. The basalt looks bobbly, no columnar structure. The west side looks like one wall of 6m high and 25 m wide. The east side also looks like a wall but with some interruptions. On the slope we mentioned above there are a lot of loose rocks. Slope: 27°. Aspect: 179°.

Blobby basalt → can this be squeezed material? Not dense enough for lava flow? However, it is a big wall and that makes it look in situ. Could this be a collapsed lava tunnel?

Point 14.2
Peer-shaped stone of porous basalt, standing on a slope on a kind of 'sokkel'. Aspect of the slope: 184°. On the underside the material looks to be eroded away, by water? The top of the peer points in NO direction. Looks separate block on a 'sokkel'. Size: 3x2 m. Height: 1m.

Around there are a lot of loose basalt blocks, from 0.5 m Ø up to 3m Ø.

We see a comparable shape of heights and slope on the northside as 14.1, but this time more rounded and less height differences. Parabola shaped. By glaciar? Slope on the north side: 27 °.

Point 14.3
Flat strip on the west side of us, elongated in E-W direction. Descends in W direction. Width (NZ): 30 m. Length: long, at least 200 m. The flat strip is located 2m lower then where we pinned it.

Point 14.4
Elongated plain, meadow, on the north side. Elongated in E-W direction. Descends in west direction. Width, NZ: 20 m. Length: 80 m. Height is 2 m lower then were we pinned it.

Point 14.5
Elongated gully shaped valley. Orientation: SE-NW. Descends in SE direction. Width: 15 m. Length: 150 m. Slope: 9°. Aspect: 113°. Trees on it. On both sides slopes (ZW slope behind 14.2 of 27°)m

Point 14.6
Saddle, with trees on it. Direction of ridge of the saddle: N-S: 15 m. Elongated in E-W direction. Descends on both sides. (E & W).

General note on this shape (around 14.7)
A lot of local heights and lows on this bigger hill. The height differences are all quite gradually. Multiple saddle and gully shaped parts. Big moraine? The ridge looks gradually .

On the south we see the most stones and height differences. Not so many loose stones on the ridge(top of whole shape).

Point 14.8
Big boulder: 6m wide, 2.5 m high. Material with many crystals, no basalt. Located on lower slope where we also see smaller blocks of granite and basalt (0.5 m Ø). Placed here by mega flood? Can also be granite from the slopes?

Point 14.9
In dry valley. We see a lot of basalt blocks but also granite. In shape that is elongated, in the flow direction → flood ripple? There are weeds on it. Small blocks, in soil incorporated.

Point 14.10
Row with trees in the field, blocks in it: many are granite, one is basalt. Aspect: 40 °. Flood ripple?

Point 14.11
Lower small ridge in the meadow, with some stones: basalt & granite. Next to it there is a well, this might be artificial ridge?

Point 14.12
On the northside of the road we see a strip meadow SW-NE orientated. Not as flat als we saw at 14.9, looks a little more v-shaped. Descends in NE direction. In the middle there is a small (almost dry) stream. On the other side of the road there is a small dry stream as well. On both sides of this valley there are slopes.

In the field in the middle there are basalt rocks visible above the grass. Could this be in situ? that the lava flow is below here? Could also be loose blocks, incorporated in the soil.

Point 14.13
Chalk! Reacts heavily on hydrochloric acid. There is a small stream in this valley, a little v-shaped (like 14.12). In the middle of the stream some granite, a little higher up I find the chalk, Oligocene material. A little back in direction of point 14.13 there is a clear big outcrop of granite visible. We didn't find basalt here.

Point 14.14
On NE side of the road big blocks basalt and granite. Flood deposition? Granite big and looks more like an outcrop higher up.

Point 14.15
Elongated meadow, in NE-SW direction. 30 m wide. Descends towards the river. Goes on for a long time along the river. Place where lava flow can be?

Point 14.16
Dense basalt, along the road. Looks in situ. Can this belong to the Tartaret? 7 m above the river. Or to high for Tartaret flow?

Point 14.17
Granite in basalt. We took a sample. Basalt 4m thick, and we see more to the left also basalt a bit higher. This basalt starts at the height of top of the lower basalt and is 4m thick.

Point 14.18
Waterfall, in westerly direction from this point. On both sides basalt. Height of the waterfall: 3 m. On northside basalt with nice columnar structure. 4m on south side, we expect it to be basalt as well, no columnar structure.

On the east side of us, on south side of the Couze also rock outcrop, probably basalt. Looks more loose and bobbly, no columnar structure. Height 10 m.

Why is there a waterfall here? Collapsed tunnel? Is this the same lava as 6.17? Or different?

Point 14.19
Small waterfall, +- 1 m height difference. On north side we see basalt, probably in situ, thickness of 2m. We also see basalt on the south side.

Point 14.20
Another waterfall. Height difference: 2,5 m. There is a water power plant upstream, this makes it suspicious? Did they make this to loose speed again? Name of water power plant: 'usine de saint nectaire'.

On both sides basalt again, 2m. North side 3m. Southside looks a little less in situe, can this be blocks? Placed here to make the Couze narrower?

Point 14.21
End of this road: the water power plant. Granite wall & loose blocks. Height of 30 m, 15 m wide. Blocks are 2x 2x 1. On the side of the road.

Point 14.22
Basalt wall. Pointed on base of the outcrop. Height: 6 m. Base at height of 4m above the road. South side of the road. In situ? Because it is gigantic big! 15 m wide. On top it looks like there are horizontal columnar structure coming out of the rock.

Between the rock wall and river, semi flat strip on both sides of the road. Approximately 30 m wide.

North: grass, south: forest. ½ m above the Couze.

General note

Data is added with the hand, we should check to be sure that the altitude is correct in the attribute table. We also should recall it points day 14

13-10-2017 15th field day

Point 15.1

Scoria. Underneath this point, which is above the road, mostly scoria with sometimes piece/layer of dense basalt --> boms?

Point 15.2

Couze flows wide, seems to have plenty of space. No in situ basalt observed.

Point 15.3

Basalt with pretty column structures, 0.5 m above the road. 2.5 m thickness visible.
Also continues backwards (western direction), about half a meter higher? In situ

General note

Note about the Couze untill 15.3: No clear in situ basalt, lots of loose blocks, lots of artificial structures.

Point 15.4

Basalt, columns, in situ. Height from the road until top basalt: 6m.

Point 15.5

Basalt in side of house, seems to be in situ. 1,5m height.

Point 15.6

In situ basalt, with some imagination columns. Height: 3m. Base of the basalt is 4m above the road.

Point 15.7

Basalt in wall, seems to be in situ, however there is also a lot of artificial stuff mixed in between. There is more bubbly basalt. Basalt is 3,5 in height (from road).

Point 15.8

Strip of meadow south of the road next to the Couze. Declines towards Couze and to the east. Width: 30m. Length: follows the Couze, at least 200m. Between the meadoow and the Couze is a part covered in trees, also seems to be fairly flat.
No in situ basalt found next to the Couze. Excevated? Couze flows on top of the basalt?

Point 15.9

At NW side of the road, slope with loose pieces of basalt in it, about 0.5m in diameter, but also small rocks and gravel.
Height of the material is at least 2m, but probably higher.
Slope of the castle? Moraine?

Point 15.10

Lots of loose basalt blocks. Still no clear in situ basalt. Nor a little more downstream. However, there is a fairly large block of basalt (2 blocks, 1.5mø each) next to each other, could be in situ?
At both sides of the Couze semi flat strips of gras.

Point 15.11

15m east of us in a slope is a large piece of basalt. Maybe in situ? Basalt piece is 3 m in height. Lots of cracks, column structure with lots of imagination? Next to it we see soil on the slope.

Point 15.12

Part overgrown with forest, with basalt blocks.From small to large blocks. Also a seperate block of 2m height. Seems to be in situ wall? With columns?

Point 15.13

Pinpoint at road, but augered in the middle of the field, which is 1m lower. Flat strip of meadow in NE-SW direction along the Couze. Declines in NE direction. Width: 30m Length: 150m (field in which augering was done, but low continues).

Augering:
Layer 1 0-40 cm, silt-rocks of 1cm diameter. Badly sorted, badly rounded. Stoniness 10%. Stones are granite and basalt. Quite some gravel. Structure subangular blocky. Little black gravel lower in the profile --> basalt?
In the Couse lots of rocks on the side, seems to be artificial.

Extra remark

Tried to follow the Couze where it takes a turn (from parkinglot), but lots of trees and meadows filled with cows made it impossible to enter.

Point 15.14

Followed the Couze from the road at Sapchat until here. No in situ basalt observed. River is close to the surface, land on both sides is flat and covered in grass. River seems to have enough space, no steep incision. Did find loose blocks of basalt.

Point 15.15

In the inner curve of the Couze at the NW side of the GPS point is a flat meadow, 1m above the Couze. 150m length, 60m wide, see drawing for shape of meadow and directions of width and length. West of the meadow is a higher area covered in forest.

14-10-2017: 16th field day

Point 16.1

A little further (west) away from this point I found a outcrop of Scoria with clear layers, which pointed in the opposite direction of the Tartaret slope, meaning a cone top in the north.

Dense basalt blocks, height: 1m. Width: 5m.

Point 16.2

Big wall of scoria & big volcanic bombs. Alternating scoria and denser basalt. Doesn't look dense enough for a lava flow or neck of the volcano. Height of the outcrop: 10 m, width: 200 m.

14-10-2017: 17th field day

17.1

15-20m SE of the road are 2 elongated higher shapes in the landscape, 2.5m high and 10m long (SW-NE), overgrown with shrubs & elongated rocks. NE side seems more steep, but it is not super clear. Maybe drumlins? (or Rouche moutonee or moraines?). Aspect: 244

17.2

Field, multiple large bolders. NW of the road, 1-3m wide, situated withyin the field, field also seems to be higher here than further up in the valley: moraine? Other side of the road is also a large bolder (at the edge, maybe artificial?). Bolders seem to have NS oriantation (same as valley).

17.3

2 units:

S side road is a small hill, 2m high (and 1 abve the road). Elongated in same direction as the road (EW direction). Lots of loose bolders in it, around 0,5-1 m. Other side of the hill is not visible, so it might be elongated in a different direction (note: seems to be like that later on). Pinpoint before as moraine and with new direction it could be like that.

Behind first unit in side of the valley is a stone glacier, about 12m high (see drawing). Stones 0.5 m or smaller.

17.4
NW road small hill covered in shurbs, 3m above meadow of which 1 m is an edge of stones. NS elongated, bit strange oriantation. 2 larger blocks (1.5m) on top of it and larg block (3m) in the field. Spotted blocks in the field earlier on as well, field is wabvy (moraine?)

17.5
SE side road, little hill (path cuts through). NE-SW orientated, 4m high. Elongated (a bit), large blocks next to it and inside of it (at least 2m, might be higher but not visible). Moraine? (strange orientation).

Rocks are a very weathered orange granite and a greyer rock (also granite?). The greyer one is the one that is found most often through the valley.

General remark
Valley seems to have narrowed and narrow even more at the next curve in the road.

17.6
Furtherest point in the valley that was reached, because road goes out of valley here. Seems to be end of the V shaped valley.

17.7
Start of the wall of the V shaped valley

17.8
Waterfall

17.9
Meadow just before V-shaped valley, between wall of the valley and road, 40m wide (SE-NW), 300m long (next to road). Across the road it goes steep down into the valley. Plain seems to continue in the entire U shaped valley, after the waterfall there is also a meadow covered plain at the other side of the road. Picture taken from capture area glacier from this location.

17.10
Meadow across from 17.5, NW side of the road. 30m wide, NNW-SSE. Infinite long. Drilling, in the slightly higher part of the meadow. Silt to rocks of 1cm, subangular blocky structure, bad sorting and rounding, 10% stoniness.

Little bit sticky, but not really. Maybe bit of clay in it??

Lots of small gravel but not really rocks.

17.11
Rouche moutonee?

17.12
Picture taken from old lake

17.13
More or less 200m from the pin point (towards W?) a small hill, about 2 m high (see picture). Elongated. Drumlin?

17.14
Drilling:
125mm-1cm, subangular blocky, average roundness and sorting, 2% stones. Reduction mottles. Mainly sand, no gravel, only rocks from 1cm.

17.15
Black scoria. At least 50cm, on top of humus, sand, gravel and rounded stones of basalt. Black scoria looks like the one at the other side of this unit, at 11.2 Observed in gully on a slope: erosion.

15-10-2017 18th field day

18.1
Basalt in wall (of a building), looks unlogical to be put there by humans, so has to be in situe. 1m high, 2 m wide.

18.2
Basalt, visible from 2m above the road. 2m high. 1m wide (in between the houses) Looks in situ.

18.3
Basalt sticking out at the side of the road. Also seems like a wierd location to have been put by humans --> in situ.

18.4
Clearly layering. Upper 1.5 m is homogeneous black scoria (to the left it is thinner, about 0.5m). Underneath scoria is 0.5 m of different layers, with larger and smaller gravel. There is a lot of badly rounded gravel. Because of the layers the deposit looks fluvial. Very stony. Scoria & other rocks.

Underneaht seems to be a soil with large pieces of (parent)rock. Saprolite.

18.5
OSL sample taken. Soil on top of black scoria.

Also bag with scoria with rocks inside taken (rock might be granite?). For dating.

7.4 Coordinates field points

Name	POINT_X	POINT_Y	POINT_Z
1.1A	2.936243	45.573484	938
1.1B	2.937334	45.573145	968
1.1C	2.935711	45.573351	946
1.2, 1.3	2.935117	45.569691	950
1.4	2.935242	45.574139	941
1.5	2.934996	45.573224	937
1.6A	2.932415	45.571818	947
1.6B	2.932167	45.571821	931
2.1A	2.942472	45.577241	900
2.1B	2.942631	45.576849	887
2.2	2.950679	45.575401	827
2.2B	2.950411	45.575646	821
2.3	2.950848	45.573565	850
2.4	2.948754	45.571302	830
2.5	2.948837	45.570569	846
2.6	2.948854	45.56978	884
3.1	2.954958	45.580055	880
3.2	2.959756	45.585229	808
3.3	2.960836	45.585288	819
3.4A	2.970592	45.585049	882
3.4B	2.97075	45.585346	870
3.5	2.967141	45.586886	839
4.1	2.963471	45.577787	816
4.2	2.976242	45.579822	802
4.3	2.97381	45.580795	790
4.4	2.9794	45.579778	776
4.5	2.978787	45.578299	802
4.6	2.983146	45.574468	861
4.7	2.985635	45.574393	890
4.8	2.991337	45.574166	924
4.9	2.988332	45.573607	922
4.10	2.987156	45.573694	910
5.1A	2.970168	45.574337	811
5.2	2.992034	45.567959	686
5.3	2.990678	45.567873	705
5.4	2.981202	45.567465	724
5.5	2.993367	45.562763	788
5.6	2.999913	45.563576	803
5.7	3.00343	45.563748	871
5.8	3.00334	45.563163	904
6.1	2.932914	45.574702	872
6.2	2.932339	45.574573	908
6.3	2.945094	45.569988	869
6.4	2.944071	45.569543	894
6.5	2.947798	45.569272	859
6.6	2.948358	45.569497	891
6.7	2.9491	45.57012	872
6.8	2.950589	45.570115	866
6.9	2.950617	45.570243	865
6.10	2.951352	45.570208	851
6.11	2.947749	45.568341	867

Name	POINT_X	POINT_Y	POINT_Z
11.1	2.937087	45.56263	862
11.2	2.935034	45.56231	869
11.3	2.932786	45.56172	865
11.4	2.93074	45.55968	883
11.5	2.92685	45.55892	870
11.6	2.936573	45.56126	859
11.7	2.939607	45.55972	866
11.8	2.939387	45.55956	863
11.9	2.940289	45.56089	860
11.10	2.940624	45.56162	856
11.11	2.941511	45.56105	859
11.12	2.943335	45.56198	855
11.13	2.94574	45.5641	853
11.14	2.944141	45.56335	863
11.15	2.944536	45.56392	849
11.16	2.938734	45.57462	860
12.1	2.945371	45.5718	849
12.2	2.945214	45.57187	858
12.3	2.946794	45.57222	857
12.4	2.947672	45.5723	845
12.5	2.947704	45.57166	849
12.6	2.947878	45.57124	848
12.7	2.947542	45.57059	859
12.8	2.947347	45.57073	844
12.9	2.947115	45.57089	847
12.10	2.94712	45.57091	850
12.11	2.948661	45.57097	839
12.12	2.949799	45.57196	863
12.13	2.95111	45.57128	842
12.14	2.952401	45.57154	838
12.15	2.95204	45.57205	831
12.16	2.953235	45.57521	820
12.17	2.952122	45.57446	830
12.18	2.953665	45.57299	848
12.19	2.95792	45.57641	829
12.20	2.959256	45.57576	810
12.21	2.959739	45.57668	823
12.22	2.960493	45.57638	809
12.23	2.959169	45.57481	813
13.1	2.96051	45.57155	811
13.2	2.961156	45.57132	818
13.3	2.963621	45.57162	825
13.4	2.962713	45.57417	816
13.5	2.962641	45.57428	808
13.6	2.963183	45.57451	819
13.7	2.963376	45.57444	808
13.8	2.964151	45.57564	810
13.9	2.964768	45.57691	803
13.10	2.965046	45.57767	804
13.11	2.963791	45.57804	811
13.12	2.9629	45.57768	807

6.12	2.947027	45.561491	889
6.13	2.941561	45.569349	868
6.14	2.995583	45.568515	661
6.15	2.996131	45.568434	676
6.16	2.99652	45.568265	692
6.17	3.013952	45.572284	637
6.18	3.013395	45.571231	656
6.19	3.022486	45.573957	640
6.20	3.023015	45.572239	625
6.21	3.036463	45.572076	613
7-1	2.934306	45.57538	849
7.2	2.943727	45.571731	881
7.3	2.943776	45.571206	878
7.4	2.9438	45.570949	871
7.5	2.939797	45.578794	908
7.6	2.935909	45.584329	958
7.7	2.935292	45.585312	978
7.8	2.954071	45.578815	797
7.9	2.982806	45.580231	753
7.10	2.976345	45.579056	779
7.11	2.98117	45.569304	736
7.12	2.979806	45.56931	718
7.13	3.009407	45.557336	717
7.14	3.005624	45.553614	755
7.15	3.058539	45.57191	554
7.16	3.059954	45.572189	550
7.17	3.059406	45.571449	549
349	3.058754	45.571727	550
7.18	3.058746	45.571727	550
7.19	3.059582	45.571184	570
7.20	3.098246	45.584926	485
7.21	3.164685	45.591836	402
7.22	3.175137	45.59496	387
7.23	3.174168	45.593006	408
7.24	3.181443	45.595465	395
8.1	3.000568	45.574055	661
8.2	3.001488	45.574318	666
8.3	3.003983	45.574592	658
8.4	3.004148	45.57399	647
8.5	3.004094	45.573496	645
8.6	3.003926	45.572883	658
8.7	3.005159	45.574875	657
8.8	3.009227	45.575176	647
8.9	3.008975	45.575092	646
8.10	3.011198	45.574047	652
8.11	3.017648	45.573493	635
8.12	3.017699	45.574211	634
8.13	3.030244	45.571541	607
8.14	3.03173	45.571869	605
8.15	3.031804	45.572715	613
8.16	3.031338	45.57254	607
8.17	3.033074	45.572983	609
8.18	3.054317	45.570778	581
8.19	3.040089	45.573967	601

13.13	2.968433	45.57703	784
13.14	2.96947	45.57692	802
13.15	2.969665	45.57655	783
13.16	2.971757	45.57474	804
13.17	2.973571	45.57428	775
13.18	2.972972	45.57409	798
13.19	2.974603	45.57288	775
14.1	496960	5047109	817
14.2	496942	5047091	819
14.3	496886	5047044	825
14.4	496924	5047121	824
14.5	496959	5047135	820
14.6	496966	5047191	838
14.7	496971	5047287	834
14.8	497960	5047376	783
14.9	497951	5047407	782
14.10	498340	5047307	766
14.11	498340	5047307	766
14.12	498895	5047363	728
14.13	499241	5047577	696
14.14	499799	5046371	668
14.15	499799	5046371	668
14.16	499758	5046280	692
14.17	499644	5046114	676
14.18	499417	5046056	686
14.19	498418	5046115	709
14.20	498375	5046134	713
14.21	498287	5046122	722
14.22	498287	5046122	722
15.1	2.935044	45.57532	883
15.2	2.935179	45.57559	856
15.3	2.942048	45.57416	850
15.4	2.943823	45.57425	837
15.5	2.942726	45.57452	848
15.6	2.94292	45.5738	859
15.7	2.94216	45.5738	849
15.8	2.946427	45.57543	831
15.9	2.947409	45.57566	832
15.10	2.948863	45.5756	819
15.11	2.947605	45.57458	822
15.12	2.947202	45.57443	831
15.13	2.954172	45.57873	809
15.14	2.96811	45.57839	789
15.15	2.969143	45.579	781
16.1	495113	5046863	889
16.2	495149	5046846	892
17.1	2.883633	45.55705	949
17.2	2.882446	45.55637	953
17.3	2.879627	45.55558	961
17.4	2.87941	45.55561	966
17.5	2.878527	45.55528	965
17.6	2.870031	45.54917	1008
17.6B	2.871452	45.54996	1031
17.7	2.875104	45.55315	983

8.20	3.038103	45.573374	607
8.21	3.034094	45.570885	616
8.22	3.020237	45.567663	673
8.23	3.007259	45.554307	753
8.24	2.951572	45.565324	1010
8.25	2.952817	45.563216	1004
8.26	2.880234	45.555725	987
8.27	2.8913	45.560043	929
9.1	2.932556	45.574643	909
10.1	2.940157	45.571856	886
10.2	2.940002	45.571628	892
10.3	2.941863	45.57143	861
10.4	2.942368	45.571197	862
10.5	2.942972	45.570386	867
10.6	2.94254	45.569938	855
10.7	2.944064	45.568102	854
10.8	2.944501	45.56757	860
10.9	2.943998	45.566862	857
10.10	2.943002	45.565949	856
10.11	2.943001	45.566395	850
10.12	2.942491	45.565971	852
10.13	2.946594	45.568624	884
10.14	2.946566	45.569139	865
10.15	2.947721	45.567122	858
10.16	2.947655	45.567425	858
10.17	2.94736	45.567184	854
10.18	2.946399	45.565144	861

17.8	2.875058	45.55338	974
17.9	2.875883	45.55404	978
17.10	2.878168	45.55543	968
17.11	2.882608	45.55643	941
17.12	2.889247	45.55891	927
17.13	2.893212	45.56437	902
17.14	2.895663	45.56863	888
17.15	2.931669	45.56719	948
18.1	2.942832	45.57362	847
18.2	2.942644	45.57335	849
18.3	2.942315	45.57447	840
16.4	2.933248	45.56265	890
18.5	2.932952	45.56261	899