

GEOLOGY OF THE ROCHECHOUART IMPACT STRUCTURE

A GUIDE TO SITES OF INTEREST

Philippe Lambert

METSOC-2009
EXCURSION GUIDEBOOK

GEOLOGY OF THE ROCHECHOUART IMPACT STRUCTURE

GUIDE TO SITES OF INTEREST

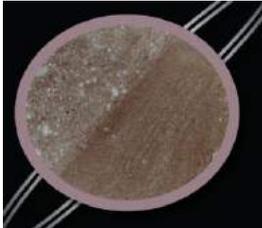
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Field Guide- Meteoritical Society 2009

Cover Images:



Fine grained impactoclastite material, Chassenon: Optical view showing the contact between two fine-grained layers. The coarse one on the left is identical in composition and texture to the host suevite but is 1 order of magnitude finer. The second on the right is 1 order of magnitude finer than the coarse layer is free of glass particles and displays fine laminar flow features. Width of field of view: 20 mm



Planar deformation features in a quartz from the horizontal impactoclastite deposited on top of the Chassenon suevite. Optical microscope view in plane polarized light. Width of field of view: 70 μ m



Babaudus impact melt rock. Optical microscope view in plane polarized light showing the boundary between two melts of different composition. Width of field of view: 400 μ m



Impact: Artist view. Water colors, 25x45 cm, Original by Marie Pierre Guiet, 2009. Special command for the MetSoc 2009 field guide



Aerial photograph (courtesy of Rochechouart Community) of part of the Rochechouart impact structure with positioning of the main crater fill deposits

FOREWORD



Aerial view of Rochechouart city- Photo courtesy of Rochechouart City Mayor-2006

By no mean, this field guide pretends to be exhaustive and complete. Also the style and form are not optimized, due to lack of time and capabilities. As an explanation (but not an excuse), the author was not part of the academia at the time it was written and his research work on meteorite impact and on Rochechouart over the preceding two decades was seen as his “little dancer”. SHE required, like any other mistress, a significant amount of time and energy... Yet there are limitations and the understanding of the reader is kindly requested for all the mistakes and weaknesses of the document.

Please also note that the author has received a significant and appreciated help from many contributors. The author is especially grateful to Claude Marchat. Claude’s precious and constant efforts in promoting and developing the knowledge about the Rochechouart impact structure over the last two decades force the admiration of all. He is the initiator of the National Natural Reserve that nowadays protects the site. The pioneering works of François Kraut who discovered the true nature of the site toward the end of his career need to be pointed out. The understanding of the geology of the site has also benefited from the interest and dedication of Philippe Chèvremont and Jean Pierre Floc’h, the two main authors of the current version of the 50 000 geological map published by the French Geological survey (Chèvremont et al, 1996).

The author is also very grateful to the population of both the department of Haute-Vienne and Charente for allowing geologists to do their “mission”, while facilitating access to their properties and accepting the inconveniences.

Last but not the least, the local authorities at all level in both administrative regions concerned by the impact, the City of Rochechouart, and the “Communauté de Communes du Pays de la Météorite” are warmly thanked for their interest, for their time, for their investment and their support at all the stage of the organization of the field trip. A special thank is addressed to Pierre Delage for his thorough assistance and for his friendship.

The present document was aiming at helping the participants of the 2009 MetSoc field trip.

It is declined in two parts. Part 1 describes the petrological and geochemical characteristics of the various lithologies encountered both in the basement rocks and in the impact deposits, and reviews the major characteristics of the Rochechouart impact. Part 2 locates and gives a field description of the rocks and sites planned for the MetSoc 2009 field trip. It refers to part one for the detailed petrological and geochemical characteristics of the rocks encountered at these various sites.



Artist view of the heavy bombardment of protoplanets in the early ages of the solar system

The Rochechouart impact structure is unique. It is unique not only because it is the only case of confirmed large meteorite impact in France. It is also unique in the scientific patrimony as it bears a complete record of rocks and related mechanisms expected at a large meteorite impact crater. Both the record of what happened above and below the crater floor/wall in a large impact crater is fully recorded. The whole sequence of material and mechanisms involved at the formation of a large meteorite impact is exposed at Rochechouart and is remarkably accessible (despite of some limitations as we will see). Indeed, erosion has ruined the initial morphology of the crater at Rochechouart. But the central part is preserved and is locally intact. Cross sections through the entire crater fill deposit section and down to the underlying bedrock are naturally provided by Mother Nature. There is no need for costly and punctual deep drillings such as at Bosumtwi, Chicxulub and Chesapeake Bay where international investigations have recently mobilized large fundings. Yet, as seen during the field trip and as experienced by Pierre Delage, there is a significant need for “digging” at Rochechouart in order to get beneath the important vegetal and soil cover masking a large part of the field data.

Additional “digging” would also be required to restore the small quarries and sites that have been filled in over the last decades. In fact this unique scientific patrimony at Rochechouart is endangered. Natural and man erosion has caused dramatic damages over the last century and the expected life time for meter thick units such as Babaudus melts is short if no appropriate measures are taken. In that context the French Government has just set the basis for protection and scientific valorization of the site, establishing the area since late 2008 as the “Natural National Reserve of the Astrobleme of Rochechouart-Chassenon”.



Jean Louis Borloo-
French Minister of the
Environment

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Texte 15 sur 110

Décrets, arrêtés, circulaires

TEXTES GÉNÉRAUX

MINISTÈRE DE L'ÉCOLOGIE, DE L'ÉNERGIE, DU DÉVELOPPEMENT DURABLE ET DE L'AMÉNAGEMENT DU TERRITOIRE

Décret n° 2008-977 du 18 septembre 2008 portant création de la réserve naturelle nationale
de l'astroblème de Rochechouart-Chassenon (Haute-Vienne et Charente)

Eventually the Rochechouart impact structure has received relatively little attention compared to other impact structures of its size on Earth. With only three doctoral thesis and some 35 full papers dealing in full or in part with the Rochechouart impact published in peer review journals, the bibliographical record at Rochechouart is at least 3 orders of magnitude below that at Ries. “Centuries” of man effort would be required to raise Rochechouart at a level of knowledge comparable to Ries. Such a gap cannot be filled by the French Scientific Community alone. It calls for a mobilization of the International Community. In that context, the author together with the local communities is leading a project to facilitate access for the Scientific Community interested with shock and impact metamorphism, for “ground truth data” mining the Rochechouart impact site. The proposal has been presented at the 4th edition of the conference “Large Meteorite Impact and Planetary Evolution” held in 2008 in South Africa. It plans to establish a research support facility on site and a curatorial office for both samples and scientific data¹ gathered on site, that will be open the international community.



Slide from the presentation at the 4th edition of the conference “Large Meteorite Impact and Planetary Evolution” held in 2008 in South Africa

¹ Since 2009 this project became a reality. In 2013 the local public authorities endorsed the author's proposals to drill Rochechouart and to establish a research/resource facility on site. In 2016, the Center for International Research on Impacts and on Rochechouart was created. In the fall 2017, the first drilling campaign in the Rochechouart impact structure will be led by the CIRIR in the sites of the National Natural Reserve which endorses and funds the drillings.

Finally, the last but not the least, the dedication and the hospitality of our hosts on site (and the quality of living in the Rochechouart-Chassenon area), is adding to the scientific reasons to come back and to develop further link with this unique site.

As all is eventually related to “feeling” I shall finish with a feeling, hoping you will take as much pleasure as mine, while working on that site and while preparing this field trip for you.

Thank you.

Philippe Lambert
July, 2009

CONTENT

FOREWORD.....	3
CONTENT	7
GEOGRAPHICAL SETTING.....	9
PART 1: INTRODUCTION TO THE GEOLOGY OF THE ROCHECHOUART IMPACT STRUCTURE.....	12
SUMMARY	13
INTRODUCTION	14
ROCHECHOUART TARGET	15
Geological setting	15
Geochemistry.....	18
Morphometry of the crater floor	22
AUTOCHTHONOUS AND sub-AUTOCHTHONOUS IMPACTITES.....	25
Shocked rocks with no macroscopic fracturing or fragmentation	25
Shatter cones.....	25
Monomict lithic impact breccias.....	26
Breccia dikes.....	28
ALLOCHTHONOUS IMPACTITES	36
Rochechouart allochthonous impact breccia deposits.....	37
Polymict Lithic Impact Breccias	41
Suevites.....	42
Impact melt rocks	50
The geochemical record of melt at Rochechouart.....	58
The relative inefficiency in homogenizing and mixing of melt at Rochechouart.....	59
The Rochechouart Impactoclastic Deposit.....	60
Impactoclastic Intercalations (dikes) in suevite	70
Morphometrical characteristics of the Rochechouart crater and of its deposits	75
Crater floor morphology.....	75
Size of the original Rochechouart crater	76
Target Composition	78
Stratigraphy of impact deposits.....	78
Initial volume of deposits and the relative inefficiency of cratering at Rochechouart	78
Projectile contamination	79
Paleoenvironmental considerations: Impact and postimpact regional implications	81
Ground zero	81
Depth of the nearby sea.....	81
Tsunamite	81
Post-impact sedimentary shielding of the crater	81
Post-impact erosion.....	82
Post-impact hydrothermal alteration.....	82
OPEN QUESTIONS AND PERSPECTIVES	83
PART2: SITES OF INTEREST: ROCHECHOUART IMPACT STRUCTURE	84
INTRODUCTION	85
OUTSIDE THE IMPACT	85
Montbron area: Stops 1-2	88
STOP 1: Montbron.....	89
STOP 2: Ecuras.....	92

IMPACT ZONE	97
Rochechouart Area: Stops 3-6	98
Stop 3: Puyjoyeux leptynite quarry	99
Stop 4: Chez Richard	103
Stop 5: Rochechouart	105
Stop 6: Rochechouart “Allées du Chateau”	110
Center of the structure: Stops 7-13	113
Stop 7: Babaudus	113
Stop 8: Babaudus bedrock	115
Stop 9: “Hauts de Laurière”	116
Stop 10: Moulin de La Brousse quarry	117
Stop 11: Moulin de La Brousse microgranite	120
Stop 12: Valette	123
Stop 12a-Valette Impact melt: Valette village	124
Stop 12b-Basement at the eastern exit of Valette	124
Stop 12c- Valette basal suevite	124
Stop 13: Grosses Pierres	128
Peripheral melt rocks: Stop 14	130
Stop 14: Montoume quarry	130
Chassenon deposit: Stops 15-18	134
Stop 15: Champonger quarry: bottom of the crater fill	134
Stop 16: “Grosse Piece” quarry: Top of the crater fill	138
17: “Stratified suevite” quarry: Top of the crater fill	141
Stop 18: Impactoclastites intercalation ridge	142
Megablocks-Stop 19	144
Stop 19: Champagnac quarry	144
Stop 19a. Panorama stop	148
Stop 19b. Megabloc zone	149
Stop 19c. Felsic-Mafic intercalations	149
ACKNOWLEDGEMENTS	154
REFERENCES CITED	154

GEOGRAPHICAL SETTING

The Rochechouart structure (45° 50'N and 0° 56'E) is located in the central part of France at ca 350 km S-SW of Paris (Figure 1). The Rochechouart region is characterized by rural environment and a dispersed farming housing which has not significantly changed over the last 3 centuries.

Bearing no industrial resource and located at the bottom end of 3 regions, the Rochechouart-Chassenon area has been “forgotten” and remains outside major communication and economic axis. As a result the historical and cultural identity has been preserved so far, as well as the natural environment, which are now seen as a value for the future development (Figure 2).

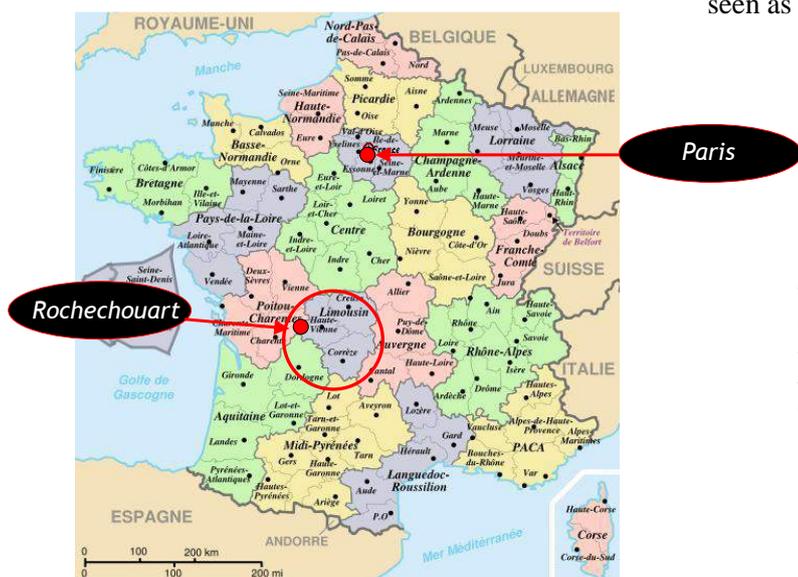
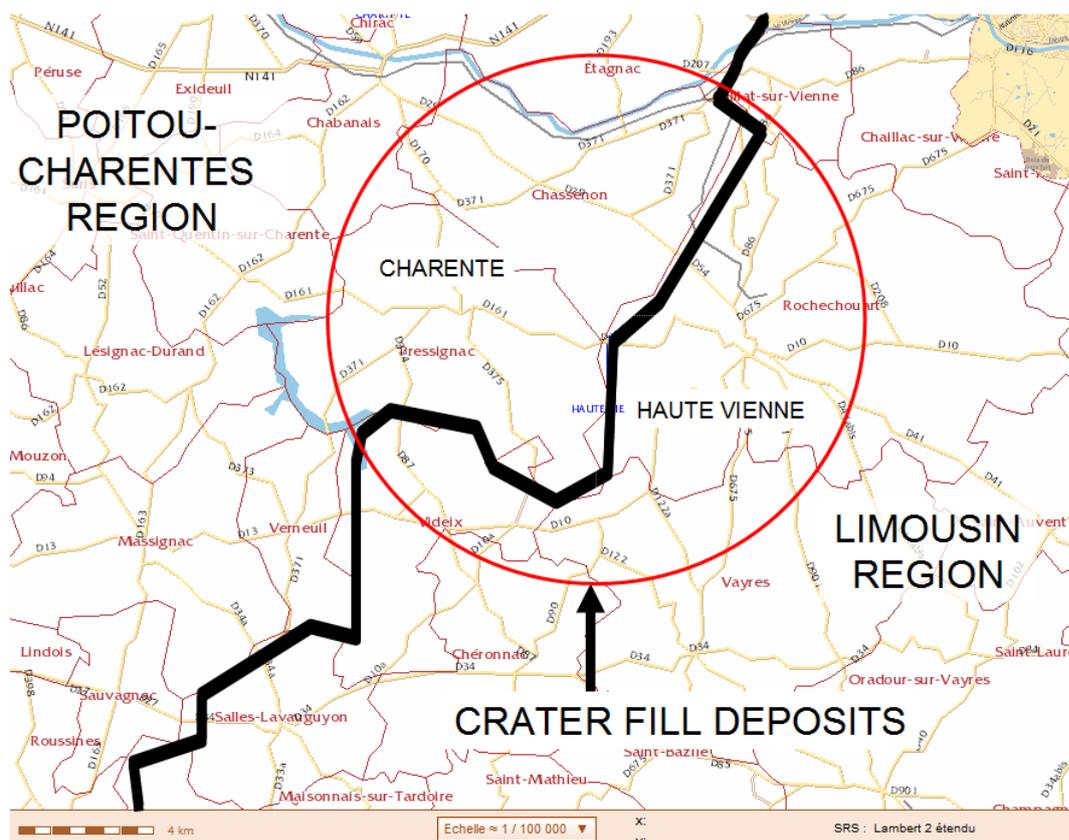


Figure 1: Left: Administrative map of France and position of the Rochechouart impact structure.

Bottom: Administrative map of the Rochechouart-Chassenon area. Red line: Communities limits



The Rochechouart impact structure is diametrically transected by the administrative limit between Limousin region (Haute Vienne department) on the east and Poitou-Charentes (Charentes department) on the west (Figure 1). The patchy character of the impactite deposits and the variety of the textures observed explain why the earliest impact related works may have referred to both Rochechouart and Chassenon localities. Yet it is the Rochechouart

name that remained in the scientific literature. Rochechouart in Limousin is the largest community (ca 4000 inhabitants) on the structure. Chassenon (ca 1000 inhabitants) is the largest community on the Charente side of the structure.



Important cultural heritage...

Biennac 12th century Roman church

Medieval sarcophages...

Made in impactites ...

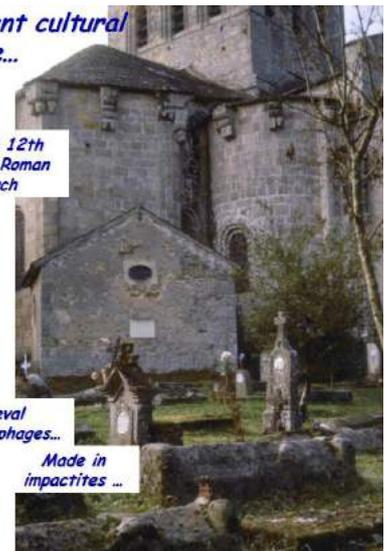


Figure 2: Typical views of the Rochechouart-Chassenon country side environment (aerial photograph courtesy of Rochechouart Community). Note the flat and gentle hill topography. No topographic expression of the crater.

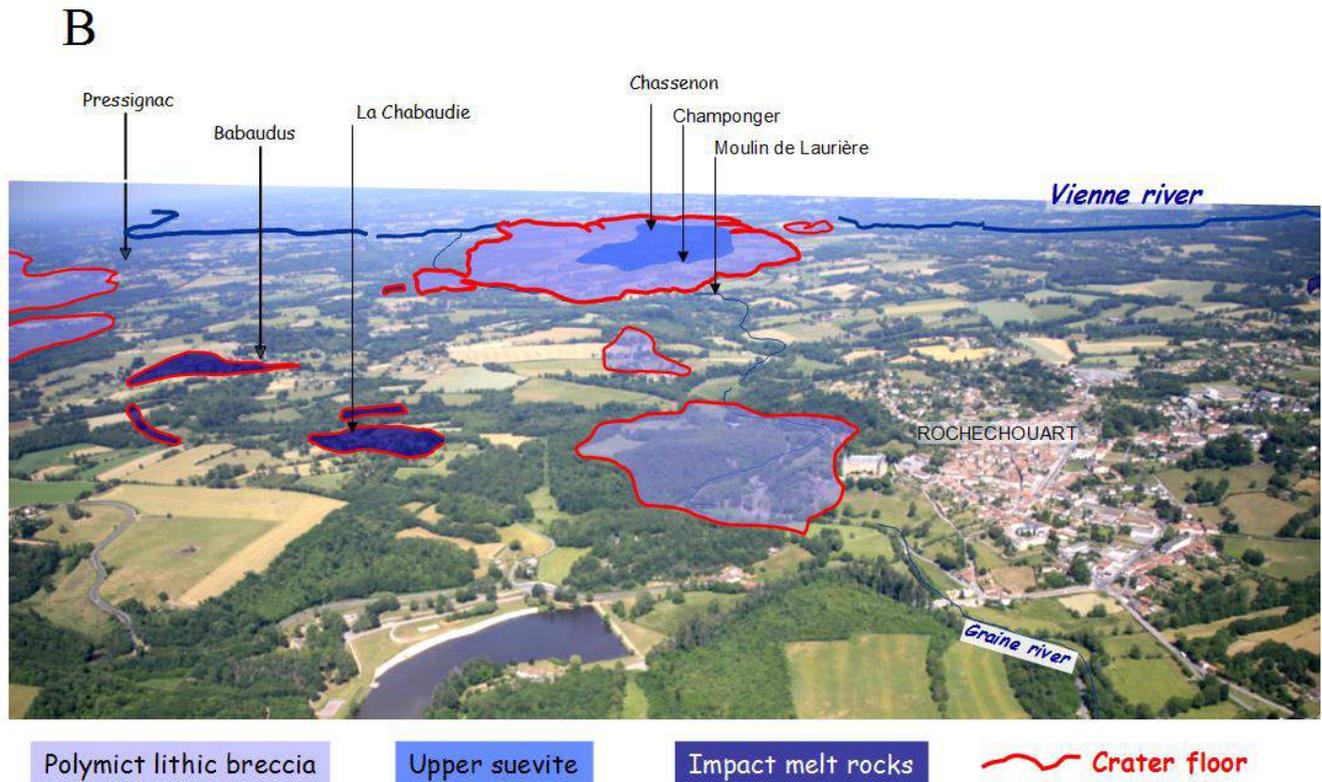


Figure 2B: Same aerial view as at the bottom of Figure 2 with the positioning of the main crater fill deposits as exposed today in the field.

The impact has lost its topographic expression (Figure 2). The remaining crater fill deposit is forming a discontinuous sheet with “patches” (Figure 2B) bearing very distinctive and distinct textures explaining why they have been referred by locality (Rochechouart breccias, Chassenon volcanic rocks...), before and even after the impact origin was established (Chassenon suevite, Mountoume breccias, Babaudus melts...).

The remnant of the crater fill deposit in the Rochechouart impact structure spreads over a ca 180 km² zone. Yet the structure is larger, and the zone affected by the impact and displaying traces of the event is at least 400 km². As we shall see, some features suggest the structure may be even larger.

PART 1: INTRODUCTION TO THE GEOLOGY OF THE
ROCHECHOUART IMPACT STRUCTURE

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Field Guide- Meteoritical Society 2009

SUMMARY

The 200 Ma old, 24 km diameter Rochechouart impact structure formed in granitic intrusive and metamorphic rocks of Variscan age (400-300 Ma) close to the margin of the Mesozoic sea. Fractured basement and autochthonous breccias form a several-decameter-thick semi-continuous zone over a 18-20 km diameter zone. Impact melt rocks, suevite and polymict lithic breccia spread over a ca 15 km inner zone forming a centro-symmetric deposit inclined 0.6° north. No topographic expression of the central uplift exists. The crater floor is at the same elevation (ca +/- 50 m) over a zone at least 20 km in diameter corresponding to the central part of the original crater. The pre-erosional diameter of the crater is probably larger than previously thought and possibly reached 40-50 km. Despite the patchy character of the remaining crater fill deposits, the structure is much less eroded than it looks, as the sequence of crater fill is complete as exposed near Chassenon. The suevite in Chassenon is capped by an ash-like horizontal deposit of very glass-poor, fine-grained, lithic debris derived from basement rocks. Material with similar grain size and composition is observed in centimeter- to meter-thick multi-layered glass-bearing intercalations (dikes) cutting through the suevite. The integrity of the Chassenon sequence strikingly contrasts with the age and morphology of the structure, implying a rapid and thick sedimentary deposit has covered the crater to protect it from erosion. The impactoclastic top deposit also firmly constrains the thickness and volume of the initial crater fill which appears extremely depleted (by a factor of 5 or more) compared with similar-sized impact structures and model based calculations. This anomaly remains unexplained. All the impactites including the glass-poor and glass-free impactites are characterized by a prominent K-metasomatism signifying pronounced post-impact hydrothermal activity. Exposed in isolated occurrences from the center to the periphery of the inner 15 km diameter zone, impact melt rocks are extremely unlikely to have formed a continuous sheet. They display a large variety of textures grading from pure melt rock into basal suevite distinct in composition texture and setting from the main suevite body forming the top of the impact deposit. Heterogeneity and relative inefficiency in mixing is characteristic of the whole impact deposit, resulting in heterogeneous melts at the scale of hand specimens but also at the kilometer scale, as suggested by close ties between the composition of melt-bearing rocks and the subjacent target rocks.

INTRODUCTION

From the geological point of view, the Rochechouart structure is located at the northwestern edge of the Massif Central (Figure 1), one of the largest pieces of the Variscan Belt, which formed as a result of a complex interplay of rifting, convergence, and collision between the continents of Laurentia, Baltica and Gondwana, and several microcontinental terranes (Matte, 2001).

The 23 km diameter reported in the Impact Data Base (<http://www.unb.ca/passc/ImpactDatabase>) has no physical or phenomenological significance. It does not relate to the diameter of the initial crater. It corresponds to the diameter of the impact structure defined as the extent of damages in the target that are attributed to the impact and reported by Lambert (1977a-b).

The Rochechouart crater is eroded and has lost its original topographic expression (Figure 2). The size of the original crater is thus unknown. Its initial morphology is unknown too. But we know Rochechouart is not a central peak crater and thus departs from the model admitted for impact craters of its size range on Earth. The center of the crater is precisely what is exposed, and it is characterized by a large flat depression filled by impact deposits lying at the present day horizontal. Everything else (walls, inner rim?, annular depression?, outer rim) has been eroded away, implying it was standing higher in elevation. The size of the crater and its morphology thus count among the various enigmas of the Rochechouart impact.

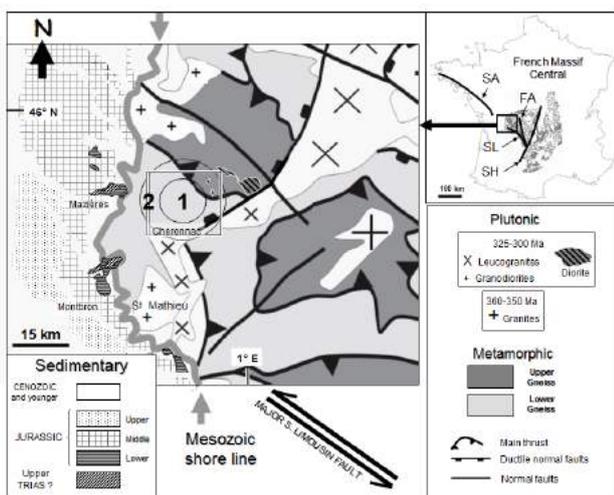
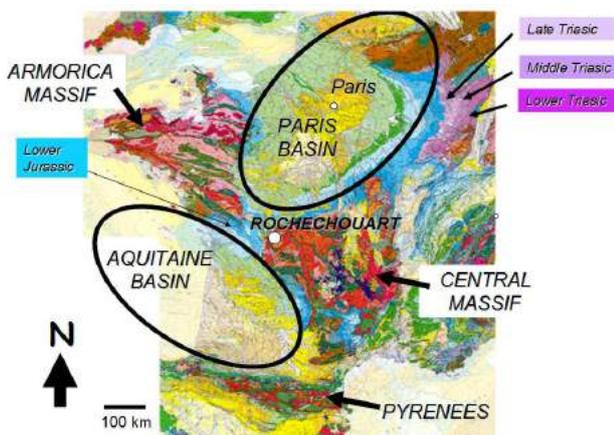


Figure 3: Top: Geological map of France and position of the main sedimentary basins and Variscan massifs.

Bottom left: Regional geological setting of the Rochechouart impact structure showing the contact between sedimentary cover and Variscan basement at the western edge of the « Massif Central » and the setting of major units (adapted from Ledru et al., 1994). The inner circle (1) represents the extent of the impact deposit. The outer circle (2) indicates the outer limit of brecciation in the basement rock.

Frame intersecting the circles = area covered by Figures 2A-B. Right insert: Position of the French Massif Central and major Variscan faults (SH= Sillon houiller, SL= South Limousin fault, FA = Argentat fault, SA = South Armorica fault).

The age of the impact has long been a matter of debate. Previous studies, including K-Ar, Rb-Sr, apatite and glass fission track, as well as paleomagnetic dating (see Kelley and Spray, 1997, for a summary of ages), resulted in a broad (Middle Triassic to Late Jurassic) time window for the Rochechouart impact. More recently, $^{40}\text{Ar}/^{39}\text{Ar}$ laser dating of pseudotachylitic breccia from Champagnac yielded a 214 ± 8 Ma, Late Triassic, age (Kelley and Spray, 1997), which is currently accepted as the most robust age for the impact.

It has also been cited as supporting a theory that Rochechouart is a member of a ~214 Ma terrestrial impact crater chain (Spray et al., 1998). This hypothesis has, however, not been confirmed by the two most recent ages of 201 ± 2.3 Ma for the impact event obtained by Schmieder et al. (2009), which corresponds to the accepted age of the boundary between Trias and Jurassic (referred below as T-J boundary) (Verati et al., 2007; Schaltegger et al., 2008).

The evidence for geochemical contamination of Rochechouart impactites by the projectile was presented in the mid 1970's (Lambert, 1975). Since then, the identification of the projectile has been a matter of debate: interpretations have ranged from iron meteorite to chondrite projectiles (Janssens et al., 1977; Palme et al., 1980; Horn and El Goresy, 1980; Koeberl et al., 2007; Tagle et al., 2009).

The ordinary chondrite hypothesis is currently considered the most probable, based on Cr isotope studies by Koeberl et al. (2007). However, this hypothesis was recently contradicted by Tagle et al. (2009) based on platinum group element patterns and Ni/Cr/Ir inter-element ratios that were interpreted to favor a stony iron (non-magmatic iron) projectile.

Rochechouart impactites were first recognized by Kraut (1969) and the structure was studied in detail by Lambert (1974, 1977a). Ejecta deposits are widely exposed at Rochechouart; however, the knowledge of these rocks remains rudimentary compared to other terrestrial impact structures. Although the Rochechouart structure has been investigated continuously by the international scientific community since its impact origin was established, most studies have focused on specific issues such as dating the event or identifying the

projectile (see references above). Full-scale field investigation remains limited to mainly French geological work by Kraut and French (1971), Lambert (1974, 1977a), and Chevremont et al. (1996).

ROCHECHOUART TARGET

Geological setting

The Rochechouart target rocks comprise a variety of metamorphic, plutonic and subvolcanic rocks (Figure 4). Two of the main metamorphic units associated with the Variscan orogeny are represented in the area, the Lower and the Upper Gneiss Unit (Floc'h, 1983). The Lower Gneiss Unit (LGU) is represented by para- and ortho-gneisses. Plagioclase-rich paragneisses with phyllosilicate contents of up to 8 vol% are the dominant rock type in the Rochechouart area.

Paragneisses tend to be dark gray or gray, contrasting with lighter-colored "orthogneisses" referred to here as "leptynites". Leptynites are the second most widely exposed metamorphic rock type in the target area, occurring in the southwestern region of the target (Figure 4).

They derive from pre-Variscan alkaline granitoid intrusions of mainly Early Ordovician (480 Ma) and Early Cambrian (550 Ma) ages (Faure et al., 2008). Small intercalations of paragneiss as well as lenses of migmatite are common in the leptynites. The migmatitisation is related to the first of the series of synmetamorphic ductile deformation events involved during the formation of the French Massif Central. This earliest deformation is developed coevally with an intermediate pressure/intermediate temperature metamorphism and anatexis dated around 385-380 Ma (Quenardel and Rolin, 1984; Costa, 1992; Roig and Faure, 2000).

A small unit of serpentized peridotitic rocks intercalated with the gneisses of the lower part of the LGU occurs 12-15 km south of the center of the structure, at the eastern edge of the Cheronnac granite (Figure 4).

The primary structure of the rock is essentially lost. Antigorite is the major constituent. The Lower Gneiss Unit is interpreted as Proterozoic-Early Paleozoic remnants of the northern Gondwana margin that experienced crustal thinning and rifting in Ordovician times (Ledru et al., 1994).

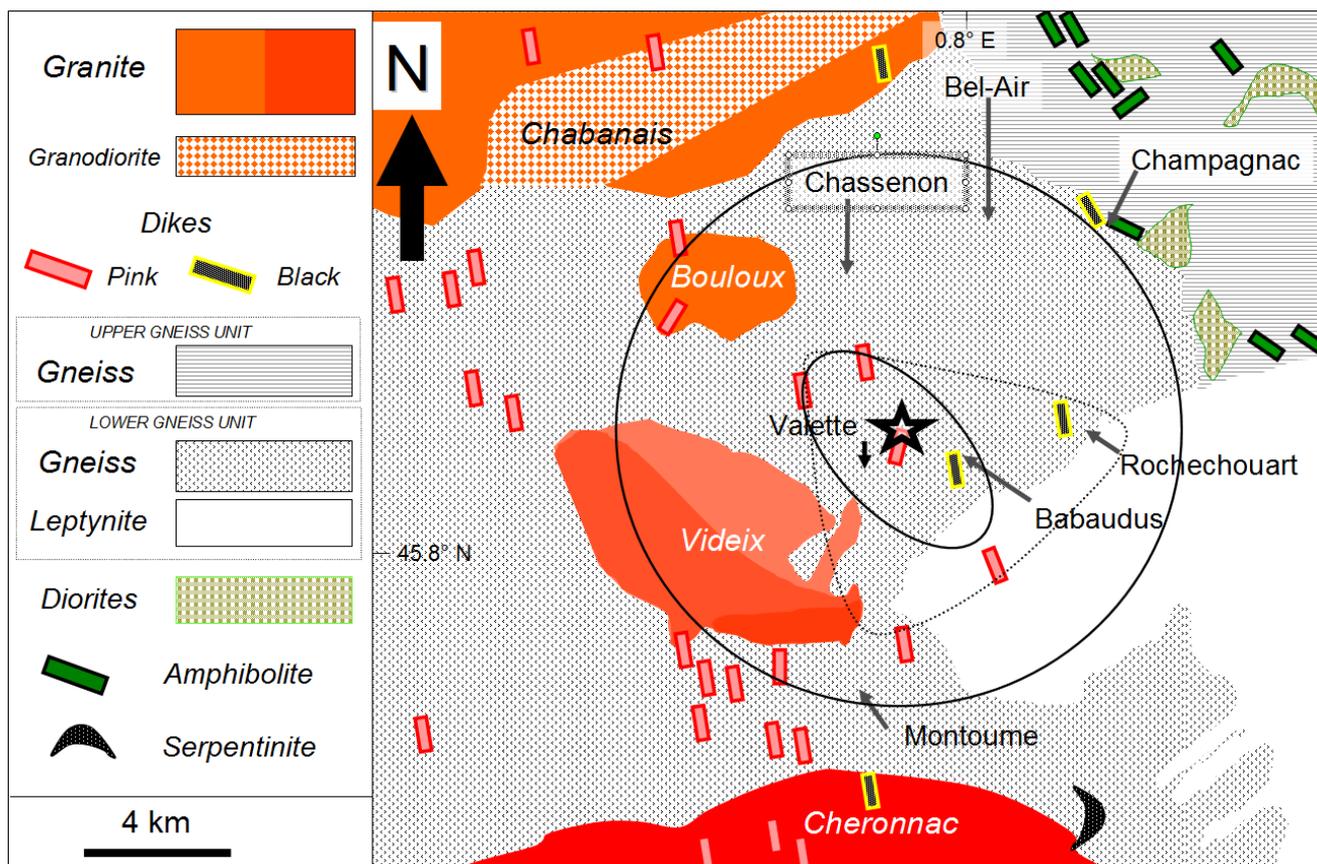


Figure 4: Schematic geologic map of the framed area of Figure 3 (after Lambert, 1974, 1977a and Chevremont et al., 1996). Target formations as exposed today at the level of the crater floor are represented. Impact deposits and surface deposits (including alluvial deposits) are omitted.

The Upper Gneiss Unit (UGU) crops out at the northern edge of the impact area (Figure 4). It is represented by gray gneisses consisting of quartz, plagioclase (oligoclase), and one or two mica minerals, and by a bimodal assemblage of more or less mafic gneisses, referred as the “leptynite-amphibolite sequence” (Floc’h, 1983; Faure et al., 2007). Such a sequence is exemplified at the large active quarry at Champagnac 7.5 km north of the center of the structure. Here, both darker amphibolite lenses and lighter orthogneisses are intercalated.

The amphibolite intercalations become significant in the northeastern quadrant of the area at a distance of 8 km from the center of the structure and beyond. Precursors of both the leptynites and the amphibolites are related to the above-mentioned Cambro-Ordovician intracrustal rifting episode predating the Variscan orogeny (Faure et al. 2008).

Both the LGU and the UGU experienced a Barrovian-type metamorphism dated around 360-350 Ma (Faure et al., 2007). This metamorphism is associated with the second major ductile deformation

event of the history of the Massif, characterized by a northwest-southeast trending lineation that is clearly expressed in the Rochechouart metamorphic rocks. The Late Visean time (ca 340 Ma) corresponds to the onset of syn-orogenic extension characterized by huge crustal melting. The NW-SE spreading of the inner part of the Massif Central was partly accommodated by ductile wrench faulting along the SW edge of the Massif Central (South Limousin (SL) fault - Figure 3) and the SW edge of the Massif Armoricain (SA, on Figure 3) which is also part of the Variscan belt. The Rochechouart structure is located in the axis of this major fault system.

The metamorphic rocks of the Rochechouart area are crosscut by plutonic intrusions which occur predominantly in the western half of the impacted zone (Figure 2A). They correspond to the southern edge of the Chabanais intrusion and to the northern edge of the Cheronnac intrusions. Small granitoid bodies (Bouloux and Saint Gervais-Videix bodies) occur in-between (Figure 4). The Cheronnac granite is closely related to the main Saint Mathieu leucogranite intrusion outcropping further to the south (Figure 3). It is characterized by light color and bears orthoclase, muscovite and biotite, and only differs from the Saint Mathieu main intrusion by an oriented fabric. Both intrusions formed by crustal melting at 325-300 Ma.

The Chabanais intrusion is a gray-pink calc-alkaline granite-granodiorite with quartz, K-feldspar, plagioclase and biotite. The small, regionally-occurring granitoid bodies (Bouloux and Saint Gervais-Videix bodies) vary in composition between that of the Cheronnac and Chabanais intrusions. The eastern part of the Chabanais intrusion locally includes meter to decameter intercalations of dark gray biotite- and amphibole-bearing granodiorite and diorite (Figure 4). To the northeast and east of the structure, small diorite intrusions containing hornblende, biotite, plagioclase (An_{40-50}), and small xenomorphic quartz occur in the Saint Junien area (Figure 3). The largest body (ca 8 km²) lies 12 to 20 km from the center of the structure.

Smaller bodies (ca 1 km² and less) crop out in the Champagnac area, 8-15 km from the center of the structure (Figure 4). Although the intrusive character of the diorite is ambiguous in places, the occurrence of amphibolite lenses supports their intrusion into the leptynite-amphibolite assemblage of the host UGU at most locations.

The former is seen in the northeastern corner of Figure 4 where meter to decameter thick intercalations of diorite and gneiss with graded contacts occur. In all the diorites, including those forming definite intrusions such as the largest body 20 km east of the center of the structure, plagioclase is more or less sericitized and locally calcitized. A complex array of fractures pervades the diorite, and these fractures are filled by secondary phases, especially adularia. Significant hydrothermal alteration is observed in the host diorite at the contact with these filled fractures with almost complete pseudomorphism of plagioclase by white mica and of biotite by chlorite (Chevremont et al., 1996).

The metamorphic units and the granites are transected by meter- to decameter-thick, fine-grained dikes of predominantly north-south orientation (Figure 4). These dikes account for less than 1% of the target material but contain most of the known shatter cone locations in the Rochechouart impact structure. Two main types - pink and black - are distinguished, both carrying millimeter- to centimeter-sized phenocrysts in a fine-grained groundmass. Pink dikes are granitic-granodioritic in composition and have been referred to as microgranites. These contain quartz and feldspar phenocrysts.

The black dikes have been referred to as "lamprophyres" and are more mafic (diorite/gabbro). In the Rochechouart structure they are referred as microdiorite (μ diorite). These dikes are relatively more abundant in the eastern part of the target, whereas microgranites occur more frequently on the western side (Figure 4). They have been dated at ca 300 Ma (Chevremont et al., 1996) and formed during the last stage of the Variscan orogeny and relate to the collapse of the whole belt.

Dikes are oriented mostly NS, in the same direction as major wrench faults (the Sillon Houiller (SH on Figure 3) and Argentat fault (FA on Figure 3)) appearing further east. These wrench faults are interpreted as transfer faults (Burg et al., 1991). An extensional regime is well recorded by the tectonic setting of intra-mountain Stephanian coal basins similarly oriented North-South in the French Massif Central among which the Saint-Étienne coal basin is the most famous (Faure et al., 2007 and references therein), as it corresponds to the para-stratotype of the Stephanian stage (304-299 Ma).

Apart from the recent (sub-contemporary) volcanism in the Auvergne region, no confirmed sign of magmatic activity is recorded in the French Massif Central after the Stephanian post-orogenic extension. A 265 Ma Rb/Sr age has been obtained by Reimold et al. (1987) on pegmatitic granitic rocks sampled near pseudotachylitic breccia veins in the Champagnac quarry. This suggests post-Variscan magmatic activity. But this age and a late post-Variscan magmatic episode in this part of France remain to be confirmed. The Rb/Sr method is known to yield too young ages as illustrated by recent measures in granites near the Rochechoourt area (Alexandrov et al., 2000).

In the immediate vicinity of the impact deposits there are no traces of younger formations except for alluvial deposits and surface formations. The latter form a quasi-continuous cover over the whole area. Alluvial deposits overlie the northern part of the impact structure in a broad east-west zone centered on the Vienne River.

Several levels of alluvial deposits have been recognized as a function of their relative altitudes with respect to the level of the Vienne River. The lower age limit for the emplacement of the oldest alluvial deposit is poorly constrained to the Oligocene (ca 30 Ma). The upper boundary is constrained from the traces of flora typical of tropical climate which ended at ca 5-3 Ma in France (Chevremont et al., 1996).

Occurrence of large and highly rounded pebbles (up to 20 cm in diameter) has been tentatively interpreted as indirect evidence for a coastal conglomerate having covered the area during the Mesozoic (Chevremont et al., 1996).

Mesozoic sediments overlie the western margin of the Massif Central (Figure 3). The basal unit consists of a 5-30 meter thick sandstone deposited horizontally and exposed at Mazières and Montbron, only 16-17 km west and 24 km southwest of the center of the structure, respectively (Figure 3).

Similar fossil poor thin formation is known at various places in the Aquitaine Basin.

It occupies the same stratigraphic position directly above basement as near Rochechoourt. Attributed to the Rhaetian on the basis of rare fossils by the 19th and early 20th field geologists (see for instance Glangeaud, 1901) it was appearing as such on the geological maps of Aquitaine Basin until the 1970's.

The latest editions of the geological maps of the area (released from 1980-1990) are now placing this sandstone unit at the base of Hettangian without justifying the change (comparison of the notices and sheets of the old 1/80000 geologic maps of Rochechoourt with the recent 1/50000 maps of La Rochefoucault, Montbon, Mazières and Angoulême).

The age of the basal sandstones is in fact poorly constrained and no recent paleontological study has been found for the region. The Aquitaine Basin is essentially missing the Trias record and the absence of significant tracks of the material eroded away from the nearby Variscan Mountains remains puzzling. Close to Rochechoourt (near Mazières and Montbron) the basal sandstone layer is covered by a 4-30 meter thick dolomitised limestone alternating with oolitic limestone. The latter delivers fossils attributed to Hettangian by Glangeaud (1910).

Geochemistry

Table 1 summarizes the major elements analyses of Lambert (1977b-c) for the three most important rock types of the Rochechoourt target (gneiss, granite and leptynite) and for a selection of minor rock types. These datas set the basis for the correlation fields in a total alkali element-Fe-Mg ternary diagram and a Quartz-Albite-Orthoclase (Qz-Ab-Or) ternary diagram seen in Figure 5.

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O ₃	K ₂ O	TiO ₂	P ₂ O ₅
Gneiss (17)	66.19 (σ=3.0)	16.21 (σ=1.6)	5.79 (σ=0.9)	2.76 (σ=0.5)	1.84 (σ=0.9)	2.94 (σ=1.0)	3.28 (σ=1.6)	0.82 (σ=0.2)	0.16 (σ=0.02)
Leptynites (8)	75.18 (σ=3.5)	13.58 (σ=1.3)	2.09 (σ=0.6)	0.56 (σ=0.3)	1.28 (σ=0.9)	3.56 (σ=0.6)	3.56 (σ=1.3)	0.03 (σ=0.02)	0.03 (σ=0.02)
Granite (7)	72.94 (σ=3.0)	14.90 (σ=1.0)	1.40 (σ=1.1)	0.74 (σ=0.8)	0.79 (σ=0.5)	3.19 (σ=0.9)	5.65 (σ=1.4)	0.16 (σ=0.2)	0.22 (σ=0.12)
Diorite	59.37	18.57	6.86	4.08	1.79	3.01	5.23	0.83	0.27
Black microdiorite (3)	60.47	16.77	7.74	5.97	1.45	1.95	4.59	1.00	0.11
Amphibolite	44.50	18.68	12.82	8.71	9.55	1.95	1.88	1.75	0.16
Serpentinite	47.45	1.12	7.96	43.44	0.01	0.01	0.01	0.01	n.m.
Leptynite n°70	75.60	12.85	1.72	0.20	1.42	3.28	4.15	0.11	0.1
Monomict leptynite breccia (dyke n°70)	75.69	13.82	1.26	0.32	0.19	2.98	5.77	0.11	n.m.
Aphanitic core (dyke n°70)	75.46	14.12	0.63	0.30	0.14	1.82	7.44	0.10	n.m.
Impact melt rocks (45)	66.60 (σ=4.2)	16.24 (σ=2.4)	4.22 (σ=2.2)	1.29 (σ=1.1)	0.25 (σ=0.2)	0.34 (σ=0.3)	10.19 (σ=1.8)	0.76 (σ=0.1)	0.09 (σ=0.06)
Impactoclastite (3)	73.24	12.65	3.03	1.00	0.46	1.38	6.12	0.63	n.m.

Table 1: Chemical composition of the main Rochechouart lithologies. All data in wt%. (): Number of analyses. Leptynite, monomict breccia dike and aphanitic core of the breccia dike from locality n°70 (cf. Figure 7). MnO measured but not reported (all data below 0.1 wt%); n.m. = not measured. XRF and wet chemical analyses after Lambert (1977a); (Measurements performed in the mid 1970's by BRGM-French Geological Survey, Orléans, France. Uncertainty of individual analyses in % of the measured wt% oxide values as follows: Al-Fe: 0.5; Si-Mg-Ca: 1; Na-K: 2; Ti: 2.5; P: 5).

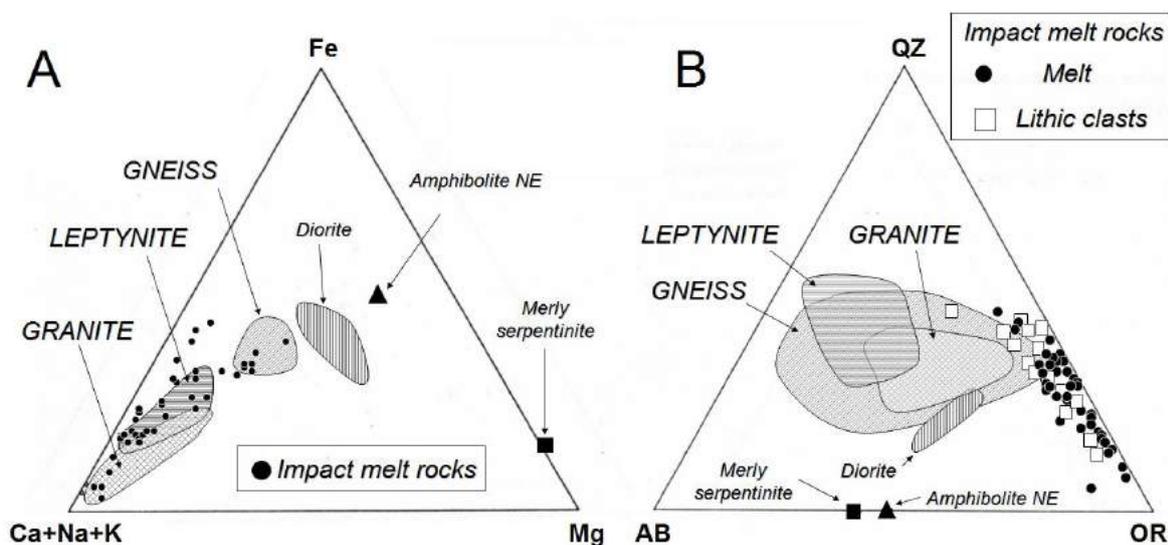


Figure 5: A: Plots of the composition of the main target formations and impact melt rocks in the total alkali elements-Fe-Mg ternary diagram. B: Plots of the composition of the main target formations, impact melt rocks, and lithic clasts in impact melt rocks in the Quartz-Orthoclase-Albite ternary diagram.

A larger set of chemical analyses has been obtained by atomic absorption spectrometry (AAS) for selected elements (Lambert 1977b). It covers the spectrum of lithologies observed in the Rochechouart basement. The complete set is shown on a Fe-Mg diagram as Figure 6A.

The results are summarized in Figure 6B which only shows correlation fields. The three main target formations plot together around the geometrical center of the Qz-Ab-Or diagram, which is

consistent with their common granitic character (Figure 5B).

Granites, leptynites and pink microgranite are characterized by high SiO₂ content and low Fe-Mg values, and plot together forming the granitic field represented next to the origin on the Fe-Mg

diagram (Figure 6B). In detail, pink microgranites appear relatively more mafic than granite, as seen in Figure 6B. Leptynites are slightly richer in SiO₂ and FeO than granites as seen from the partial overlap of what in the ternary diagrams (Figure 5) and in the Fe-Mg diagram (Figure 6B).

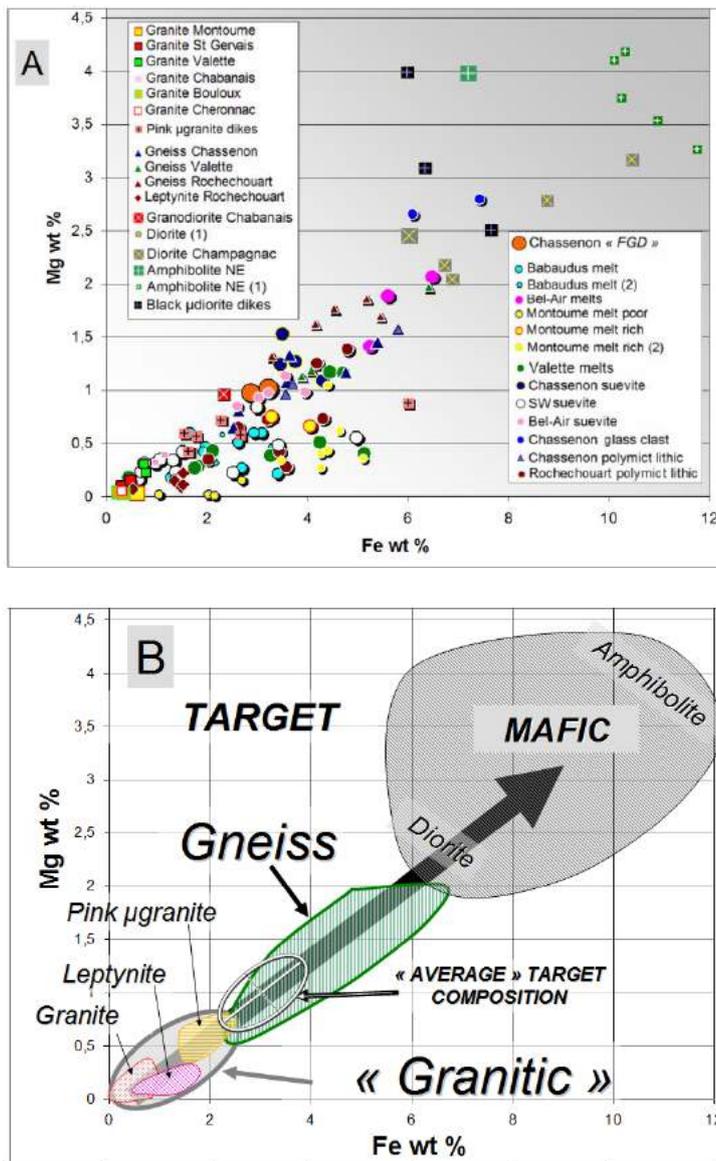


Figure 6: Fe-Mg plots for the target and impact deposits at Rochechouart after Lambert (1977a).

A: Data for 73 samples from the target and 243 impactites, impact deposits and selected clasts from suevite and impact melt rocks ((Measurements performed in the mid 1970's by BRGM-French Geological Survey, Orléans, France. Uncertainty of individual analyses: 1 to 5 % of the measured wt%). (1) Data from Chevremont et al., 1996. (2) Data from Tagle et al., 2009. « FGD » = Impactoclastites (fine-grained deposit); μ granite = microgranite; μ diorite = microdiorite.

B: Correlation plots for the main target formations. Ellipsoids represent the correlation fields for the various basement rocks exposed in the Rochechouart area. The "average" target composition field mixes the composition of the various basement rocks according to their relative proportion of exposure in the Rochechouart area (ca 50% granite + leptynite and 50% gneiss). Black solid arrow: symmetry axis of the correlation field common to all target formations

Ferromagnesian content in the granites increases from the Cheronnac granite and the Bouloux granitoid to the Saint Gervais granitoid, the granitoid of the Valette area and, finally, the Chabanais Granite. The Fe-Mg composition of the granite in the Montoume area is comparable to that of the nearby Saint Gervais granite, except for a slightly higher Fe content.

Gneisses plot separately from the granites in both the total alkali-Fe-Mg ternary (Figure 5A) and the Fe-Mg (Figure 4B) diagrams. The spread of gneiss compositions is larger than that for granites, as shown on Figures 5 and 6B. Differences of composition are also noted between gneisses from different localities. Gneiss near Rochechouart appears relatively more mafic than that near Chassenon. Gneisses near Valette tend to fall in between these groupings.

The granodiorite in the Chabanais granite gives a composition close to that of the nearby Chassenon gneiss.

Diorites plot separately from gneiss in both the total alkali-Fe-Mg ternary diagram (Figure 5A) and the Fe-Mg diagram (Figure 6B). Diorite spans from a composition close to that of the mafic gneisses of the area up to almost that of the amphibolites (Figures 5 and 6B) which crop out in the same area (in the northeast, Figure 4). The composition of the black dykes fits that of the diorites (Table 1). The amphibolites represent the mafic pole of the sequence of basement rocks exposed in the area of the impact deposits. Amphibolites are characterized by a low SiO₂ content and high Fe-Mg and CaO contents (Table 1).

Although the Merly serpentinite plots near the amphibolite on the Qz-Ab-Or diagram (Figure 5B), it forms a separate type characterized by very low CaO and Al₂O₃ contents and very high MgO content (Table 1). It is also characterized by high Ni-Cr contents (both in the 2000-2500 ppm range), contrasting with a relatively low abundance of Rare Earth Elements (all essentially below 2 ppm) (Chevremont et al., 1996).



Figure 7: Rochechouart church, characterized by unique octahedral and helocoidal bell tower. Like the Nordlingen church in the Ries, the Rochechaourt church is made of impactite. Most of the building is made of polymict lithic breccia occurring immediately beneath the site. The porch and other architectonic items are made of Chassenon suevites.

Morphometry of the crater floor

One unique characteristic of the Rochechouart structure is the wide exposure of the crater floor/wall, i.e. the boundary between the impact breccia deposit and the more or less impact-damaged bedrock.

Although the contact is generally masked by vegetation and soil cover, it is cut by a dense network of small rivers over a ca 110 km² area corresponding to the extent of the crater deposits (Figures 8-9).

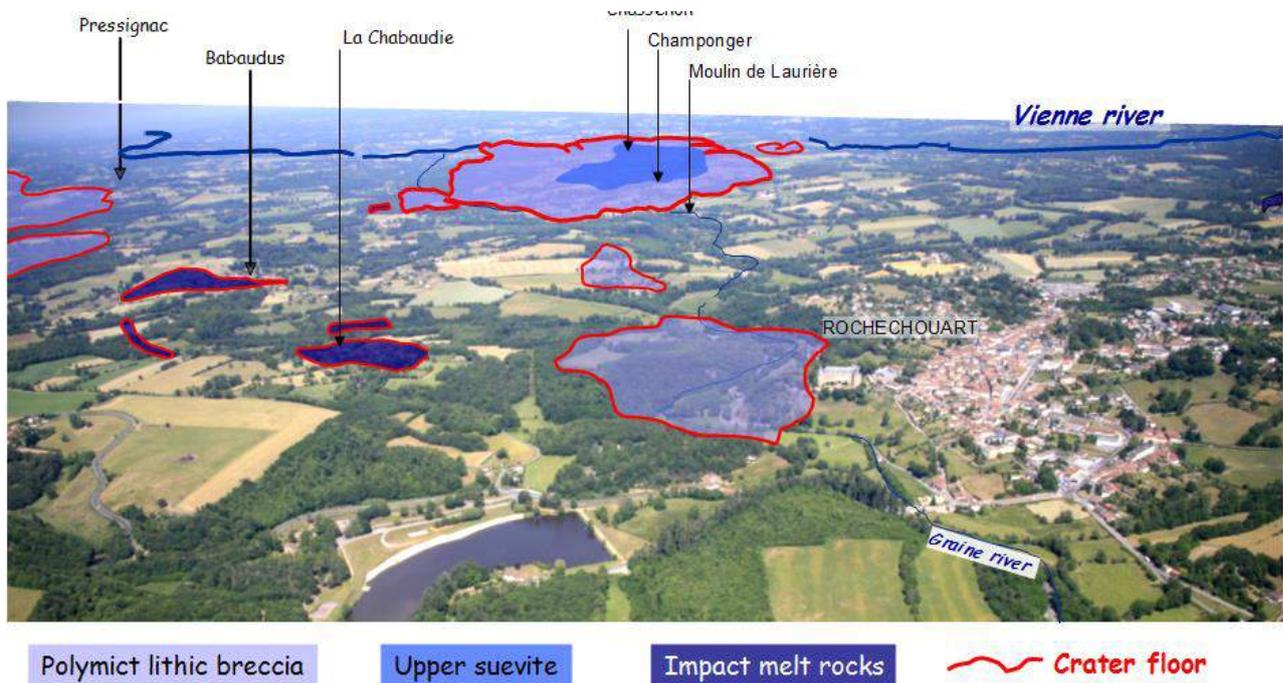


Figure 8: Aerial view of a W-NW traverse of the Rochechouart impact structure and approximate positioning of the main crater fill deposits. Note the abundant vegetation cover and the lack of topographic expression of the crater.

Where it is exposed, the boundary is complex, changing from horizontal to vertical attitudes at the decimeter to decameter scale (Figure 10). At the hectometer scale, the elevation of the crater floor displays variations up to 50 m, such as seen across the Graine River west of Rochechouart.

At the scale of the entire structure, these irregularities in the crater floor are smoothed out and the overall contact plane appears rather flat (Kraut and French, 1972, Lambert, 1974, 1977a–c). The contact on the eastern and

western sectors of the structure lies at similar elevations of 200 to 250 m; at Montoume on the southern edge of the impact breccia deposits, it lies at ca 290 m elevation, whereas north of Chassenon it is at about 175 m (Figures 10-11). This indicates a marginal inclination of 0.6° north for the deposit. There is no marked raise of the crater floor elevation at the center of the structure. At most, specific traverses (Figure 11) reveal a 3-4 km wide central “high” in the vicinity of Babaudus rising up to ~ 50 m above a 4-5 km wide topographic “low” in the area of Chassenon.

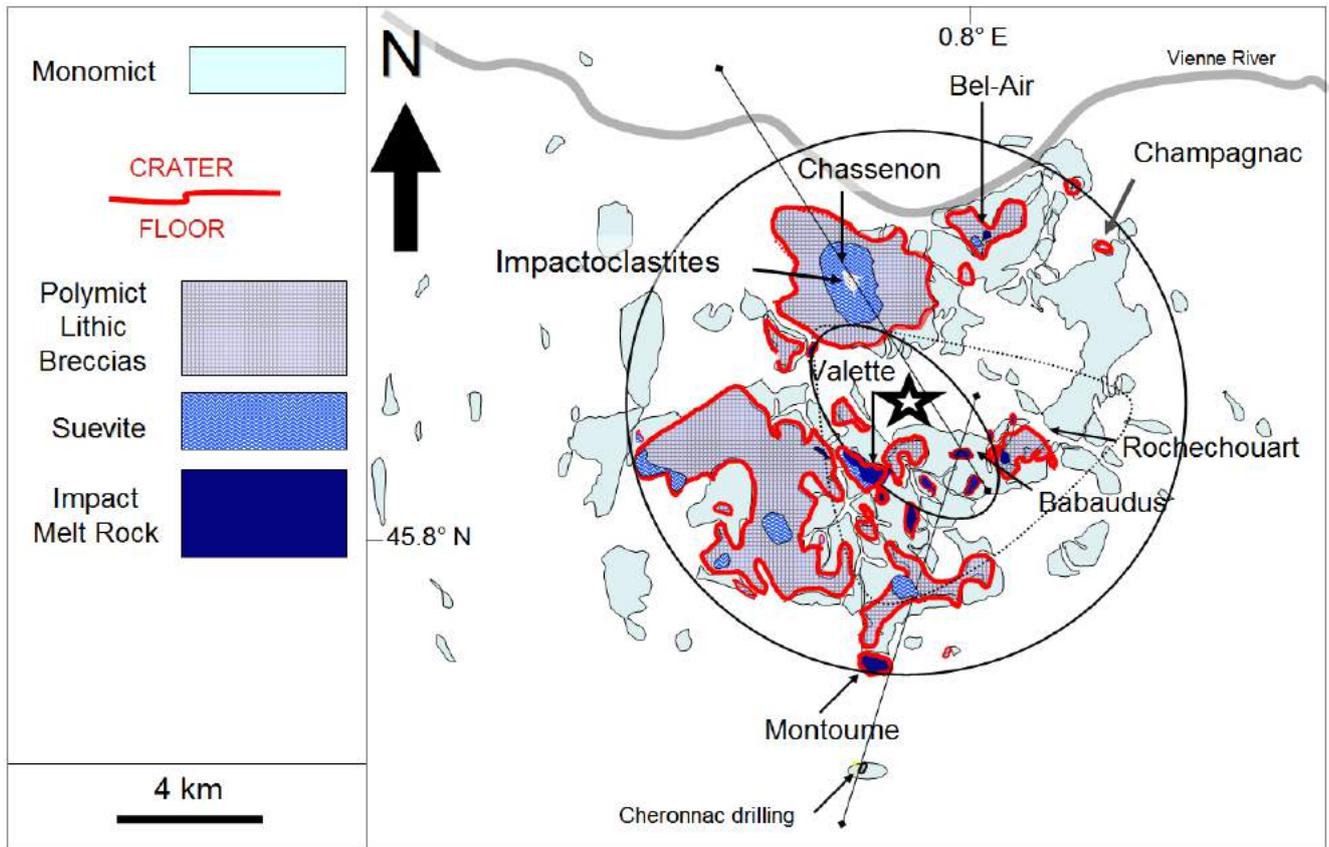


Figure 9: Schematic geologic map of the framed area of Figure 1 (after Lambert, 1974, 1977a and Chevremont et al., 1996). Rochechouart impactites. Target formations and surface deposits (including alluvial deposits) omitted. Dotted line: Spatial distribution of shatter cone localities (80% occurring within the ellipse). Lines: Positions of the two branches of the cross section shown in Figure 10. Impactoclastites: fine grained deposit and dikes (surface occupied on the map is exaggerated compared to reality in the field).

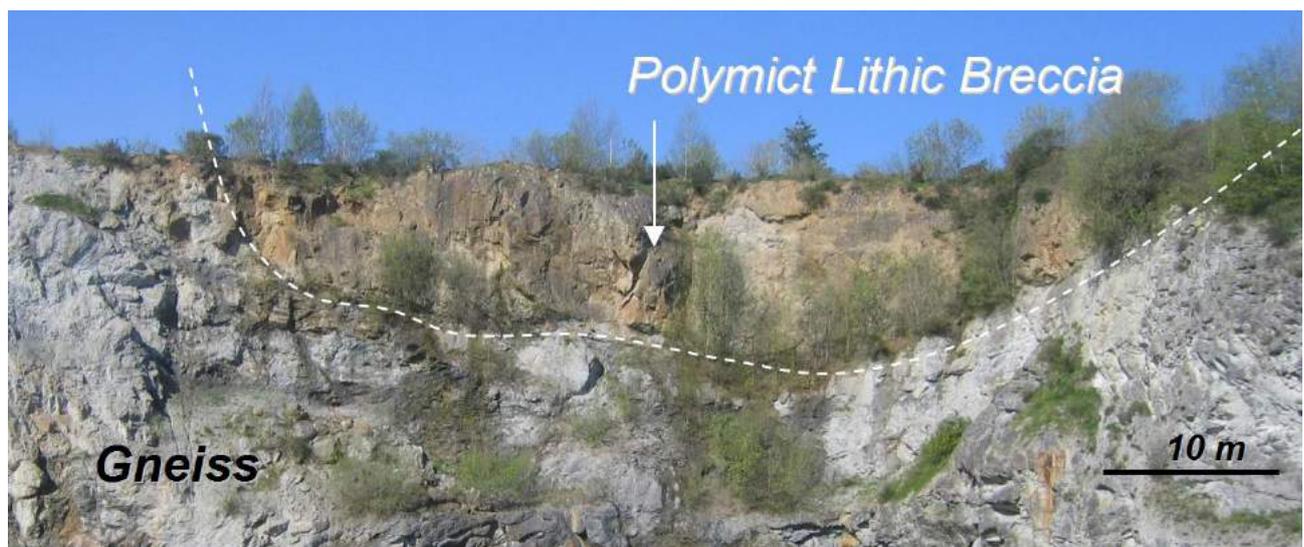


Figure 10: Field view showing the contact between a similar polymict lithic breccia and gneiss at Champagnac quarry 7.5 km NE of the center of the structure. Complex geometry of the boundary at the decameter scale. Fracturing and local brecciation of the target (photo courtesy of Claude Marchat, 2002).

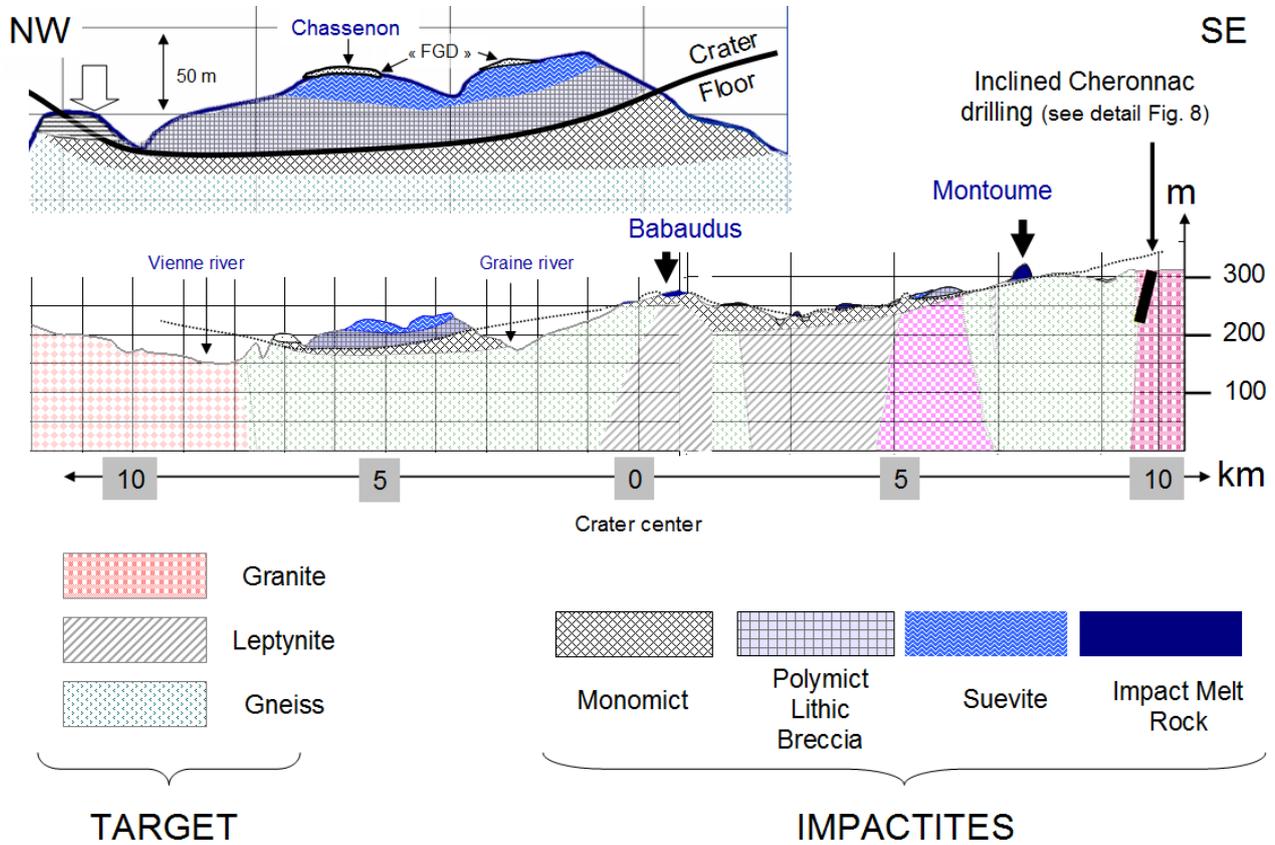


Figure 11: Schematic cross-section of the Rochechouart impact structure. Position of the cross-section shown in Figure 9. Top view: Close-up of the Chassenon deposit. Vertical exaggeration $\times 10$. FGD: Impactoclastites (fine-grained deposit and dikes: both vertical and lateral extent exaggerated for better visualisation) (after Lambert, 1974, 1977a and Chevremont et al., 1996). Open arrow: Alluvial terrace of the Vienne River.



Figure 12: Ground view from the east side of the structure, looking west showing the flat topography of the crater deposits which locally forms the top of the hills in the background.

AUTOCHTHONOUS AND sub-AUTOCHTHONOUS IMPACTITES

The close correlation between the topographic surface and the original crater floor ensures that abundant exposures of the impactite-to-basement transition are exposed. Several types of impactite are distinguished according to macroscopic texture and/or petrological characteristics:

Shocked rocks with no macroscopic fracturing or fragmentation

Basement rocks near the center of the structure in the Valette area and at significant distances from the center of the structure such as near Bel-Air, or near Videix, respectively 4.5 km north-northeast and 6 km south-southwest of the center (Figure 9) lack extensive fracturing or brecciation at the macroscopic scale but display evidence of severe shock metamorphism under the microscope.

Most feldspars recrystallized after in situ melting, micas are thermally decomposed and/or melted, and quartz is more or less completely recrystallized from diaplectic glass and in patches shows remnants of multiple sets of planar deformation features (PDF). Chemical analysis (Lambert, 1977a) indicates a strong enrichment in K_2O and a strong depletion in Na_2O and CaO of these highly shocked autochthonous or parautochthonous basement rocks.

Precise mapping of these impactites is prevented by limited outcrop. Yet they are likely to be local and limited in lateral extent ("pockets").

Shatter cones

Shatter cones are best displayed in the fine grained and massive microgranite dikes. Conversely they are poorly represented in the granite. They are also rare in gneiss, where striated irregular surfaces are more common (Lambert, 1974, 1977a). Petrographic study indicates that shatter coned rocks essentially bear no or little shock metamorphic evidence at the mineral scale, with at most some PDF in quartz and more generally only fracturing (Lambert, 1977a). The 30 sites reported by Lambert (1977a) lie in a ca 60° arc extending up to 7 km from the center towards the southeast (dashed line in Figure 4). Some 80 % of these sites fall into an elliptical area within the northwest corner of the aforementioned sector and extending in the same southeasterly orientation. This elliptical zone, ca 6 km long and 3 km wide, is centered near Valette (Figure 4). Two sites reported by Kraut and Becker (1975) at ca 7 km from the center of the structure (one in the east and the other in the west) have been searched but no shatter cones were found. Out of the 30 sites only 4 yielded a significant population of striated surfaces of sufficient quality to enable statistical measurement of cone orientation (Sorel et al., 1977).

These localities are all situated near the center of the structure. At each location both striated surfaces and striations fit onto the same virtual master cone. Master cone orientations are different from site to site. At the two closest locations ca 1.5 km from the center of the structure the measured master cones plunge steeply toward the center of the structure at $73-76^\circ$ (Sorel et al., 1977). At the two outermost locations (ca 3 km from the center) the master cones point up near-vertically (Sorel et al., 1977).



Figure 13: Shatter cones at Champonger quarry, below the Chassenon deposit. View field ca 1.5 meter wide. Picture taken in the early 1990. Photo courtesy of Association Pierre de Lune.

Monomict lithic impact breccias

These breccias comprise highly fractured and fragmented bedrock (Figure 13) in which fragments are rotated and displaced and lie in a fine-grained clastic matrix usually representing less than ca 20 vol% of the rock.

Fragment sizes are generally between 1 and 100 millimeters. The clasts are highly irregular

and angular. Most of the minerals in these rocks display no or only weak shock metamorphism, corresponding to stages 0 and 1a in the IUGS nomenclature (Stöffler and Grieve (2007).

It is missing in the central part of the structure, over a 1 to 3 km wide - 8 km long zone oriented east-west (Figure 2B) where the basement shows only local occurrences of monomict lithic breccia dikes and more rarely polymict lithic breccia dike and pseudotachylite-like dikes (see next section).

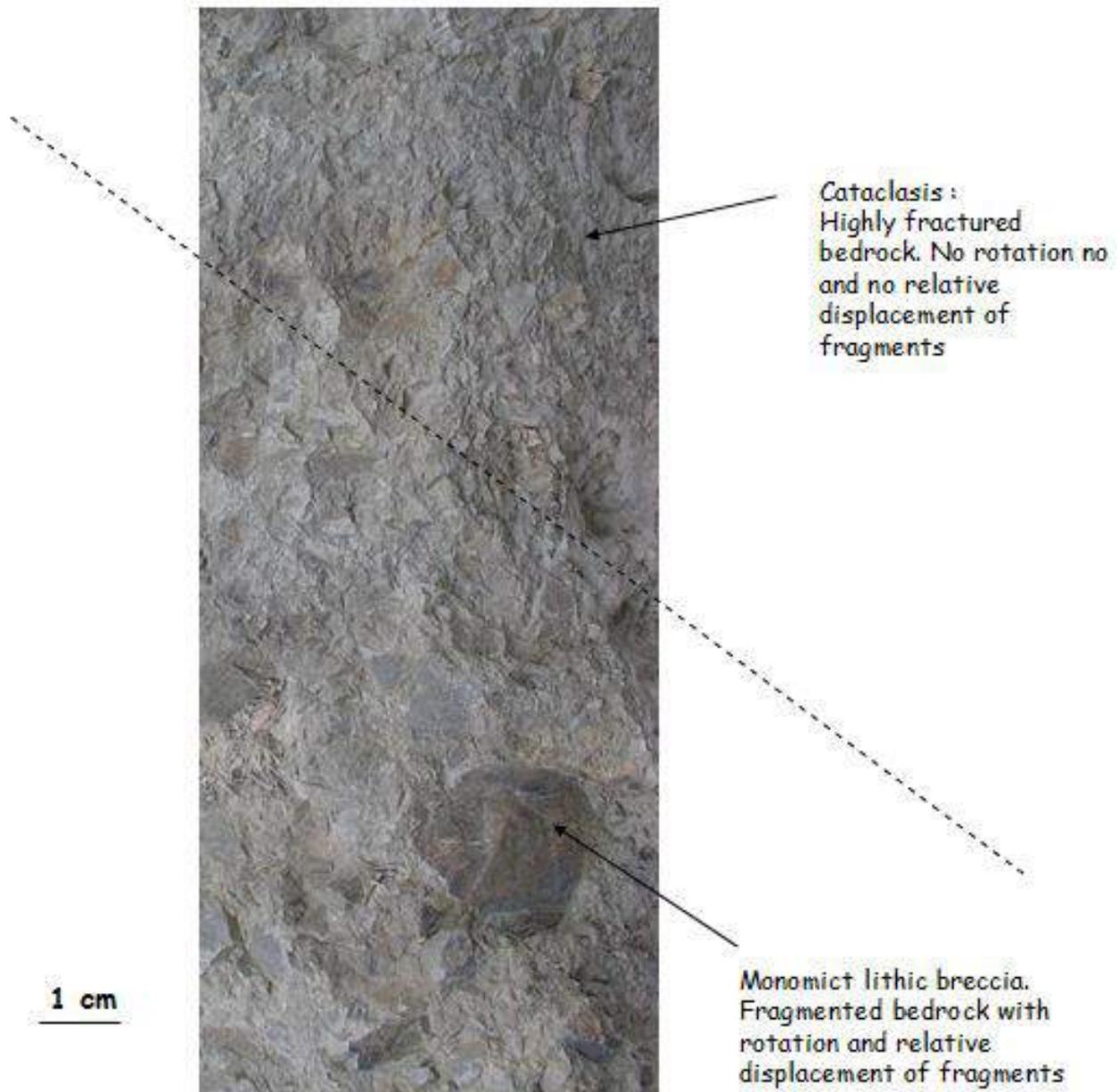


Figure 13: Highly fractured orthogneiss at Champgnac quarry. Cataclasis and progressive grading into a monomict lithic breccia.

Field observations indicate a close relationship between monomict lithic impact breccias and fragmented rock lacking displacement of the fragments (Figure 13). These are mapped as a single monomict impactite unit in Figures 9 and 11.

As shown in Figure 9, the monomict impactite is better exposed in the 15 km diameter inner zone (zone of the ejecta deposits). The maximum thickness of this monomict impactite unit is ca 90-100 meters, recorded at Champgnac 7.5 km from the center of the structure.

Elsewhere is usually thin (meter to a few decameter) and very variable at the hectometer scale.

The monomict lithic impact breccia is also exposed outside the inner 15 km diameter zone (Figure 9), but it is not as extensive or abundant as the large patches that occur in the inner zone. The most remote occurrences are found ca. 12 km west of the center of the structure (Figure 9).

Geochemical analysis of granitic and gneissic monomict lithic impact breccias shows a significant difference in composition compared to the undeformed target material (Table 2). The monomict lithic impact breccias are systematically depleted in Na₂O and enriched in K₂O (Table 2). On average, there is an increase by a factor of 2 in the K₂O/Na₂O ratio in the monomict breccias compared to non-brecciated basement.

			K ₂ O/Na ₂ O	K ₂ O/CaO
BEDROCKS (unshocked)		Gneiss (42)	1.2	1.8
		Leptynite (26)	1.3	2.8
		Granite (21)	1.6	7.2
IMPACTITES	MONOMICT BRECCIAS	Gneiss (17)	3.4	n.m.
		Leptynite (2)	4.0	n.m.
		Granite (10)	3.0	n.m.
	POLYMICT BRECCIAS	Lithic (86)	6.9	n.m.
		Suevite (99)	9.1	n.m.
		Impact melt rocks (95)	21.6	40.7
		Lithic in melt (18)	15.8	n.m.
	IMPACTOCLASTIC DEPOSIT			18

Table 2: Summary of the K₂O/Na₂O and K₂O/CaO ratios of the main Rochechouart lithologies (including the distinction between unshocked basement rocks and brecciated ones). (.): Number of analyses. n.m. = not measured. AAS, XRF and wet chemical analyses after Lambert (1977a).

Breccia dikes

A variety of breccia dikes is exposed in the Rochechouart basement. It includes i) monomict lithic impact breccias resembling the monomict lithic breccia forming the monomict unit described above, ii) polymict lithic breccias (examples at Figures 14-15) resembling the polymict lithic breccia observed above the crater floor in the crater deposits (see allochthonous impactite section next) and iii) impact pseudotachylite and impact pseudotachylite-like breccias forming complex networks of

millimeter- to decimeter-sized veins characterized by a prominent fine-grained matrix unresolved under the optical microscope, where evidence of a glass origin for the matrix is verified in the former type (such as at Champagnac site, Reimold et al., 1987) and is not in the latter (various sites reported in Lambert, 1977a, 1981).

Materials matching the textural characteristics of the suevite, the impact melt rocks and the impactoclastites (see description in the next section) in the crater deposit are not observed in the dikes and veins cross-cutting the Rochechouart basement formations.

Shock features are observed in rock and mineral clasts of all the types of breccia dikes (Lambert, 1981). On average, the level of shock recorded by the lithic fragments in the various types of dikes in the Rochechouart target remains low - stage 1b at most (in reference to IUGS nomenclature of Stöffler and Grieve, 2007) - and most clasts do not display shock deformation. The basement rocks crosscut by these dikes commonly lack any other macroscopic evidence of shock damage but can display a fractured-fragmented texture. Another noticeable and common characteristic of these breccia dikes is the lithologic compositions of the clast populations that match the wall rock

lithologies. No clasts of sedimentary material have been observed so far in any of the Rochechouart breccia dikes.

The width of the monomict and polymict lithic impact breccia dikes at Rochechouart varies from ca 10 cm to several meters (as exemplified in the Champagnac quarry). Like the massive monomict and polymict lithic impact breccias found, respectively, below and above the crater floor, these dikes display a large proportion of more or less angular rock clasts embedded in a matrix of fine debris.

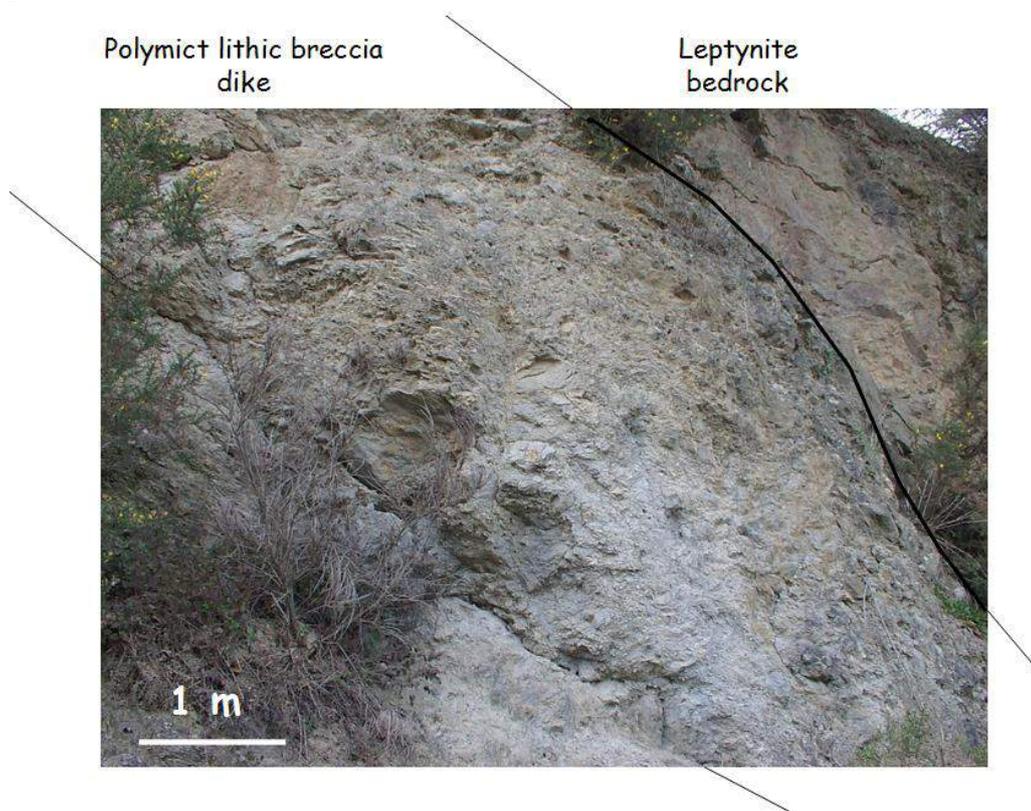


Figure 14: Polymict lithic breccia dike at Champagnac quarry. Vertical distance to the crater floor is estimated < 100 m

The only difference between the monomict and polymict lithic impact breccias in the dikes and those forming massive units concerns the grain size and the shape of the clasts. The average diameter of clasts obtained by image analysis of sections of polymict lithic breccia occurring as a dike in the bedrock at Cheronnac

is ca 3 millimeters, whereas it is 12 millimeters for a massive polymict lithic breccia deposited near Rochechouart (Table 3). The difference in the aspect ratio of clasts is not as marked as the difference of grain size (1.5 in the breccia dike, against 1.6 in the massive deposit measured by image analysis on the material in Table 3) yet it

indicates clasts in the dikes tend to be more spherical than in the massive deposit. A similar trend, but more pronounced (aspect ratio at 1.4), characterizes the clasts of the impact pseudotachylite/impact pseudotachylite-like material (measured by image analysis of a

micrographs from Puyjoyeux and Cheronnac samples. The latter are characterized by an average grain size of clasts 2-3 orders of magnitude below that measured for the clasts of the polymict lithic breccia and suevite in the crater deposits (Table 3).

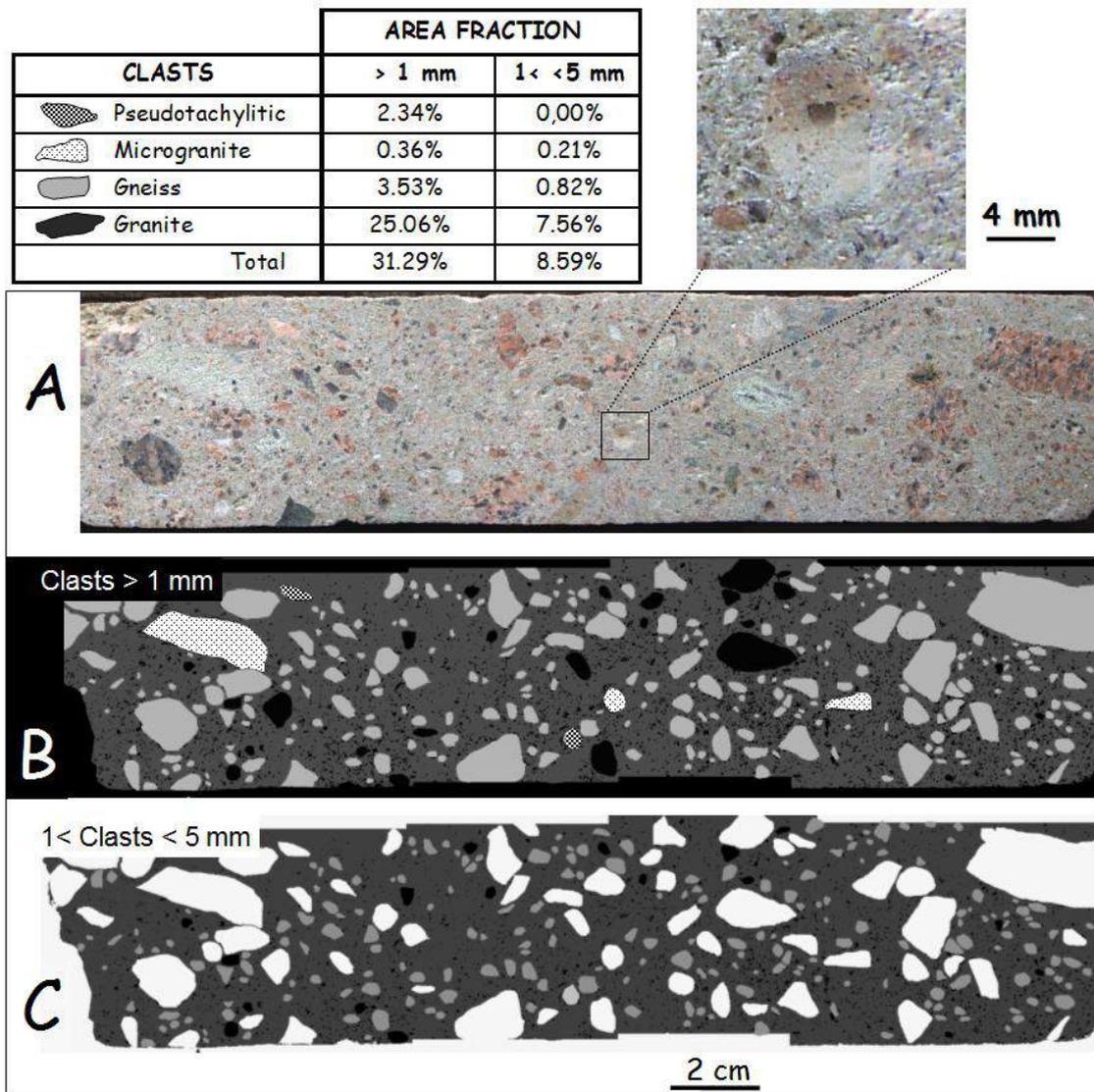


Figure 15: Polymict lithic breccia at 93 m in the 5 cm diameter drill core at Cheronnac, 10 km south of the center of the structure (see location on the map at Figure 9 and location on the drill core log at Figure 18). A- Macroscopic view of the axial cross section plane showing a large contribution from local granite with a mix of very rounded and isometric clasts significant of abrasion related to friction during transportation and very angular clasts indicating no or very limited transportation. Insert in the upper right corresponding to a close up view of a light colored banded and fined grained clast of pseudotachylite. B- Segmented false color images of the Figure 7a distinguishing different phases in the clasts population > 1 mm in length. Phases identified at the table on the upper left corner giving the proportion of the phase according to relative surface area measured by image analysis. C- Idem B fort clasts comprised between 1 and 5 mm in length. Larger clasts (not measured at the table) appear in white.

		Volume %				
	Diameter in mm	Average	> 5	>1	>0.3	>0.05
Massive Deposit	Lithic breccia and suevite	>10	29	>50	n.d.	n.d.
	Impactoclastite	<0.05	0	0	0.2	5
Dike	Lithic breccia	3	29	32	n.d.	n.d.
	Impact pseudotachylite	<0.05	0	<1	<1	8
	Impactoclastite layer 1	<0.05	0	0	0.4	12
	Impactoclastite layer 2	0.9	0	4	13	n.d.
	Impactoclastite layer 3	0.8	0	4	6	n.d.

Table 3: Average diameter of particles and volume% as function of particle size, from statistical measurements by image analysis on polished macro- and micro-sections. n.d. = not determined. (Sample locations: Cheronnac drill core for lithic breccia dikes, Rochechouart and Chassenon for the massive breccia deposit; Chassenon for the impactoclastic deposit and dikes (layers detailed in Figure 19 and 20)).

The best exposure of various types of breccia dikes and their complex time-space relationships is in the active quarry of Champagnac (Figures 4 and 10). Both impact-generated lithologies and basement are exposed at a quarry-face that is currently ca 1500 m long and 80 m high (Figure 16).

The basement rock displays a complex network of breccia dykes. Multiple sets of fractures intersect each other, including low-angle faults, which have been studied in detail by Kenkmann and Ivanov (1999) and Kenkmann et al. (2000) (Figure 16).

Although not as spectacular as those at Champagnac, breccia dikes are common in all basement rock types at other sites as well. Examples of breccia dikes in gneiss are exposed at the center of the structure in small, old quarries along the Graine River.

Figure 17 illustrates an interesting example, now lost, as the site was utilized for landfill in the late 1970s. Located near Puyjoyeux 5 km from the center of the structure, 2 km southeast of Rochechouart, the site displays a 20-50 cm thick dike characterized by a complex dike-in-

dike breccia texture. The centimeter-thick core (denoted 3 in Figure 17A) displays a distinct white color and is made of an optically unresolved very fine-grained material embedding a few small sized rounded clasts.

Flow features, vortex-like features and crude sorting are observed. The core grades into a highly fractured-brecciated leptynite (denoted 2 in Figure 17A). At the edge of the dike, the contact with the leptynite wall displays millimeter-thick breccia veins bearing the same very fine-grained matrix material as that in the core. A few thin veins also branch into the wall (denoted 4 in Figure 17B).

Table 1 reports the major element compositions of the leptynite wallrock and the core and margin of the monomict breccia. SiO₂ contents are exactly the same for the three samples, but the breccia is relatively depleted in Na, more significantly depleted in Ca, and strongly enriched in K. The same trend is observed for the core but the differences of compositions compared to that of the host rock are more pronounced in the core sample than in the peripheral monomict breccia (Table 1).



Figure 16: Top: General overview of part of the Champagnac quarry located 7.5 km NE of the center of the structure. Bottom: Detail of the framed zone showing the complex network of fractures and dikes crosscutting the bedrock. Arrows: major faults and breccia dikes.

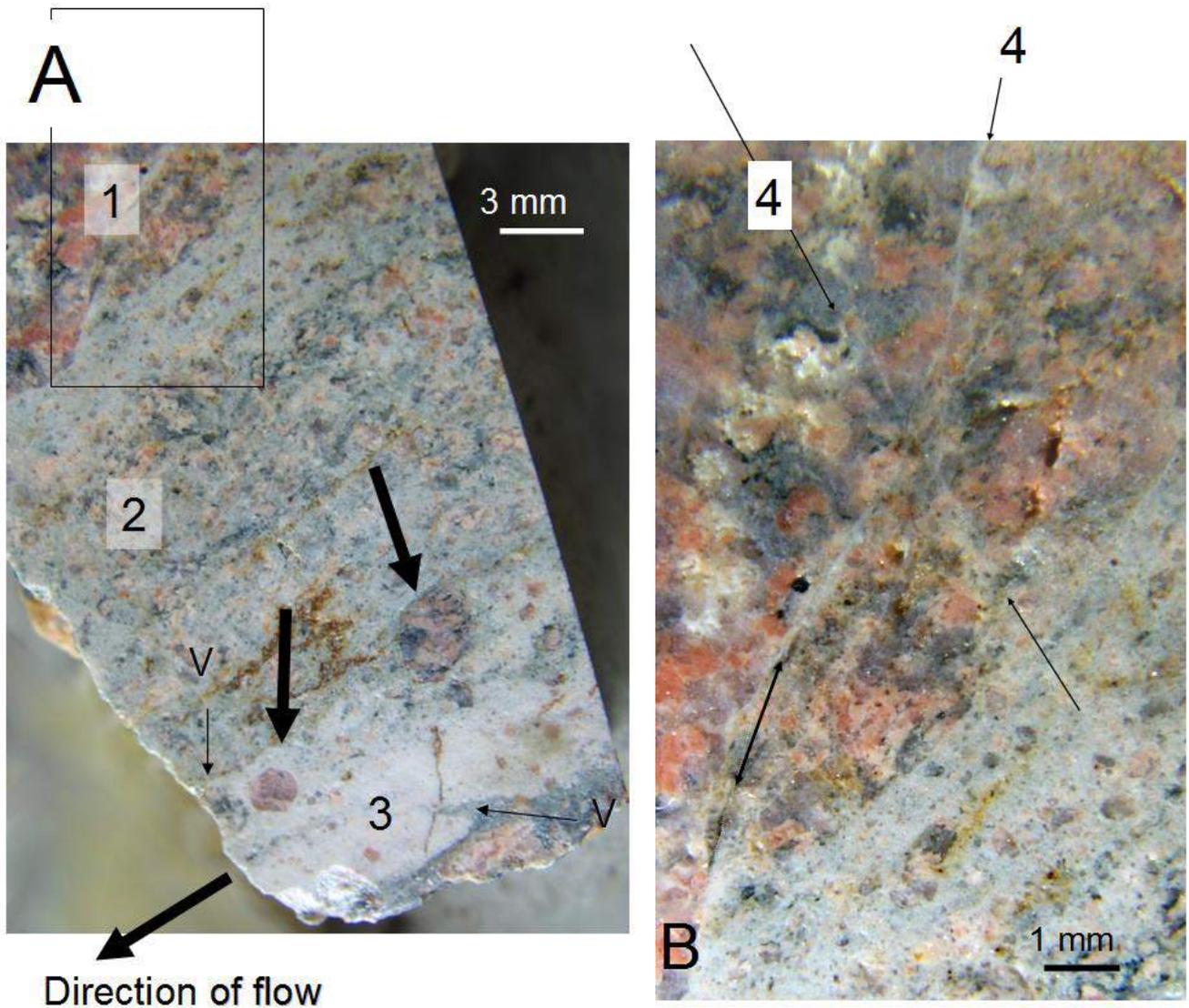


Figure 17: Complex breccia dike crosscutting leptynite at « Puyjoyeux » quarry, 2 km SE of Rochechouart, ca 6 km from the center of the structure. A-Detail of the zone at the contact of the dike and the leptynite displaying a progressive passage from bedrock (denoted 1) to monomict lithic breccia (denoted 2), and then to a very fine-grained material forming the core of the dike (denoted 3). The latter is characterized by flow features and a few small, rounded clasts (black arrows). Chemical analyses for the 3 materials given in Table 1. The zone at the contact with the bedrock (plain white arrow) displays millimeter thick breccia veins bearing the same very fine-grained matrix material as that in the core. B: Close up view of the leptynite wall and the contact with the breccia dike (framed zone in A). Note the thin intersecting veins branching in the wall (denoted 4).

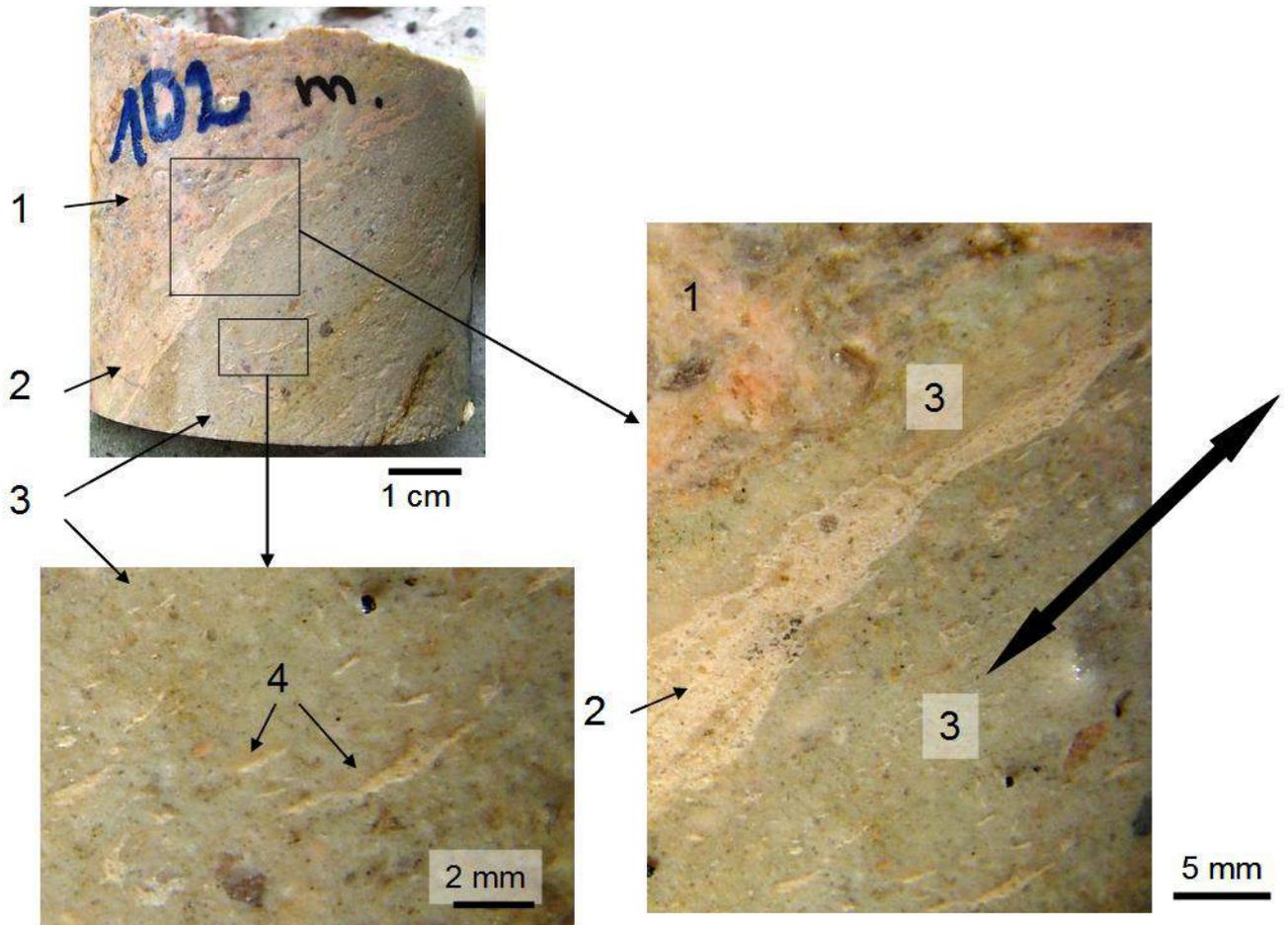


Figure 18: Complex breccia dike at 102 m depth in the Cheronnac drill core, 10 km S of the center of the structure. 1: Brecciated granite belonging to a 4 meter wide monomict breccia dike. 2: Centimeter thick vein forming the core of the dyke displaying an aphanitic and locally fluidal texture, surrounded by 3: a different color breccia also characterized by the prominence of an optically unresolved very fine-grained matrix embedding clast of the core material. 4: Close up view showing elongated and schlierig debris of the aphanitic core breccia in the aphanitic peripheral breccia. Black double arrow: Preferred orientation of clasts in the aphanitic peripheral breccia and direction of flow features in the aphanitic core breccia.

Another example of a multi-layered breccia dike is illustrated at Figure 18. It is observed in the 131 m long, 45° inclined drill core near Cheronnac, 10 km south of the center of the structure (Figure 18). The section cuts through ca. 90 m of granite and 40 m of gneiss. The granite is intersected by 1 to 5 m thick microgranite dikes (Figure 19). Two impact pseudotachylite-like dikes each about 10 cm thick are found at 56 and 102 m depth.

Figure 18 shows the particular multi-layered texture of a complex dike-in-dike breccia dike centered at 102 m in the drill core. As at

Puyjoyeux the core of the dike is formed by an optically unresolved very fine-grained translucent material (denoted 2 at Figure 18) embedding a few small sized clasts. Some clasts are rounded and some are strongly elongated and schlieric in the direction of the dike, suggesting near-melting conditions. This core material is interpreted as the remnant of an impact pseudotachylite which has been reprocessed by a second generation of fracturing along the dike as it is surrounded by a darker material (denoted 3 at Figure 18), also characterized by an optically unresolved very fine-grained material, where clasts (still rare) are dominated by elongated and schlierig debris of the

layer 1 material (denoted 4 at Figure 18). This complex dike forms the core of a 4 m wide monomict breccia dike (Figure 19).

Two relatively thick (up to 4.3 m) intercalations of polymict lithic breccia are also encountered in the Cheronnac drill core

respectively at 60 and 93 m depth. Their clast fraction is dominated by fragments derived from the local granite (Figure 19), with minor contributions from gneiss, microgranite and pseudotachylitic material similar to that encountered at 102 m.

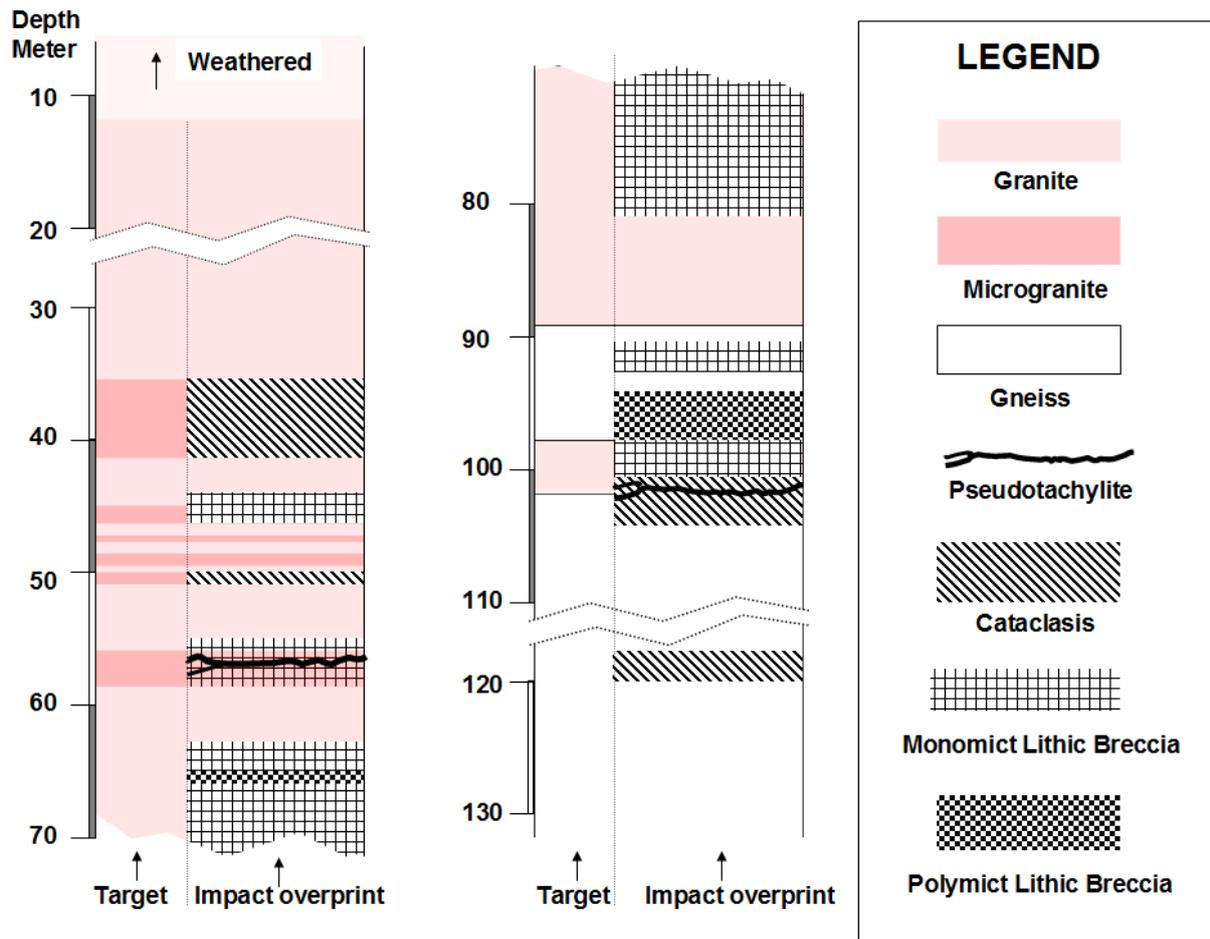


Figure 19: Schematic log of the 45° inclined- 5 cm diameter drill core from Cheronnac 10 km south of the center of the structure (see location on Figure 2B). Target lithologies are represented with the impact overprint indicated on the right side (20-30 m and 110-120 m intervals interrupted for graphic purposes).

Eight monomict lithic breccia dikes were intersected by drilling at Cheronnac (Figure 19). The largest dike is 13 m thick and developed in granite. The deepest dike is 2.3 m thick and occurs in gneiss at ca. 120 m (Figure 19).

Breccia dikes similar to those encountered in the Rochechouart bedrocks are known from direct exposures and from drilling below the crater floor at many other terrestrial impact structures.

The various breccia intercalations found in the inclined drilling at Cheronnac compare to those encountered in the basement of the Ries crater below the suevite deposit, as exposed by the Nördlingen 1973 deep drilling (Engelhardt and Graup, 1977; Stöffler et al., 1977).

The Nördlingen 1973 deep drilling record shows that up to c.a. 8 m wide polymict lithic breccia dikes below the suevite deposit are constrained to the upper section (the first 100 m) below the floor of the crater (Engelhardt and Graup, 1977). The emplacement of these dikes is related to the movement of large blocks of basement rock mobilized during crater floor readjustment (Stöffler et al., 1977). The thick polymict breccia dikes cut by the inclined Cheronnac drilling down compare in both position and texture to those at Ries and their origin is interpreted in a similar way. The Cheronnac breccia dikes delimit large blocks of basement rock mobilized during crater floor readjustment and landmark the upper section of the bedrock just below the crater floor level.

Ries and Rochechouart structures being comparable in size, it is deduced from the position of the 4.3 m thick polymict lithic breccia dike found at 70 m below the surface at Cheronnac (positioned at 93-98 m on the inclined drilling: see Figure 8) that the level of the crater floor is less than a few ten's of meters above the present ground surface at this particular site (10 km away from the center). As the crater deposits is dipping 0.6° N and the presumed elevation of the floor at Cheronnac is at the same level as observed in the field at Montoume located 2 km north of Cheronnac (see Figures 9 and 11) once the whole structure is tilted back to a horizontal position.

The cross-section through the upper section of the crater floor at Champagnac active quarry is currently (and temporarily) displaying a double set of low-angle over thrust faults marking the limit of two highly fractured locally brecciated gneiss megablocks overlapping each other and

overlapping a non brecciated diorite (see further detail at stop 19 in part 2).

ALLOCHTHONOUS IMPACTITES

Allochthonous rocks in the Rochechouart area are polymict breccias that display variable degrees of alteration. All display definite evidence of shock metamorphic effects. Together, these breccias appear to have once represented a single, continuous, horizontal stratigraphic unit over the entire extent of the 15 km diameter inner zone of the structure. However, the present topographic effects have imparted a patchy character (Figure 9), with the current remnants of the impact deposits being exposed in the topographic "highs" of the area.

The highest local high of the Rochechouart area is 323 m in elevation, at the position of the Montoume impact melt body at the southern edge of the 15 km diameter inner zone (Figures 9 and 11).

The thickest occurrence of what remains of the initial impact deposits is generally less than 70 m thick. It forms a ca 14 km² patch at Chassenon (Figures 9, 11). The deposits are better preserved in the western and southern parts of the structure than in the eastern and northern parts (Figure 9). In the north, the deposits have been strongly eroded by the west-flowing Vienne River (Figures 9, 11) resulting in low topography (150 m elevation).

The Rochechouart structure displays the three classical lithologies of impact deposits encountered at terrestrial impact structures, namely polymict lithic breccia, suevite, and impact melt rocks. In addition, however, a distinct, fine-grained material is found, which is characterized here separately from the other impact breccia types.

Rochechouart allochthonous impact breccia deposits.

The largest clasts observed in polymict lithic breccia, suevite, and impact melt rock are a few decimeters in size and nowhere do they exceed one meter. The overwhelming proportion of clasts is less than 10 centimeter in size, and a large proportion is of centimeter size, or smaller. No sorting or preferred orientation of clasts is observed in any of these impactites.

So far, only fragments of the same metamorphic and plutonic rocks that are currently exposed in the Rochechouart basement have been found in the impactites. This includes diorite and amphibolite in the northernmost part of the impact area, however, no clasts of serpentinite have been observed. With the exception of a single carbonate clast recently reported in a thin section of lithic impact breccia (Sapers et al., 2009), no other sedimentary rock fragments have been found.

The level of shock metamorphism recorded by clasts in these breccias is highly variable and covers the full range of shock metamorphic effects known for granitic material (see classification of Stöffler, 1971 and Stöffler and Grieve, 2007), with the exception, so far, of high-pressure polymorphs of quartz which have

not been observed despite an extensive search (Lambert, 1977a).

Shock damage ranges from brittle deformation (fracture), plastic deformation (deformation bands and kinks), phase transition (planar deformation features related to plastic deformation of the low pressure phase), to phase change (partial melting, decomposition, recrystallization). More details on shock metamorphism at Rochechouart have been given in Kraut and French (1971), Lambert (1977a-b), Ferrière and Koeberl (2007), and Trepmann (2008).

Despite the abovementioned variability of shock levels of clasts for all types of Rochechouart impactite, statistical measurement of shock degrees in individual clasts shows that, on average, the shock recorded by lithic clasts in impact melt rock is higher than that in clasts in the suevite, which is in turn higher than that in clasts in polymict lithic breccia (Lambert, 1977a).

All Rochechouart allochthonous impact breccias display evidence of post-impact alteration. Melts and glasses are devitrified, recrystallized, chloritized and/or sericitized (Kraut and French, 1971; Lambert, 1974; 1977a-b; Reimold et al., 1987; Sapers et al., 2009) (Figures 20-21).

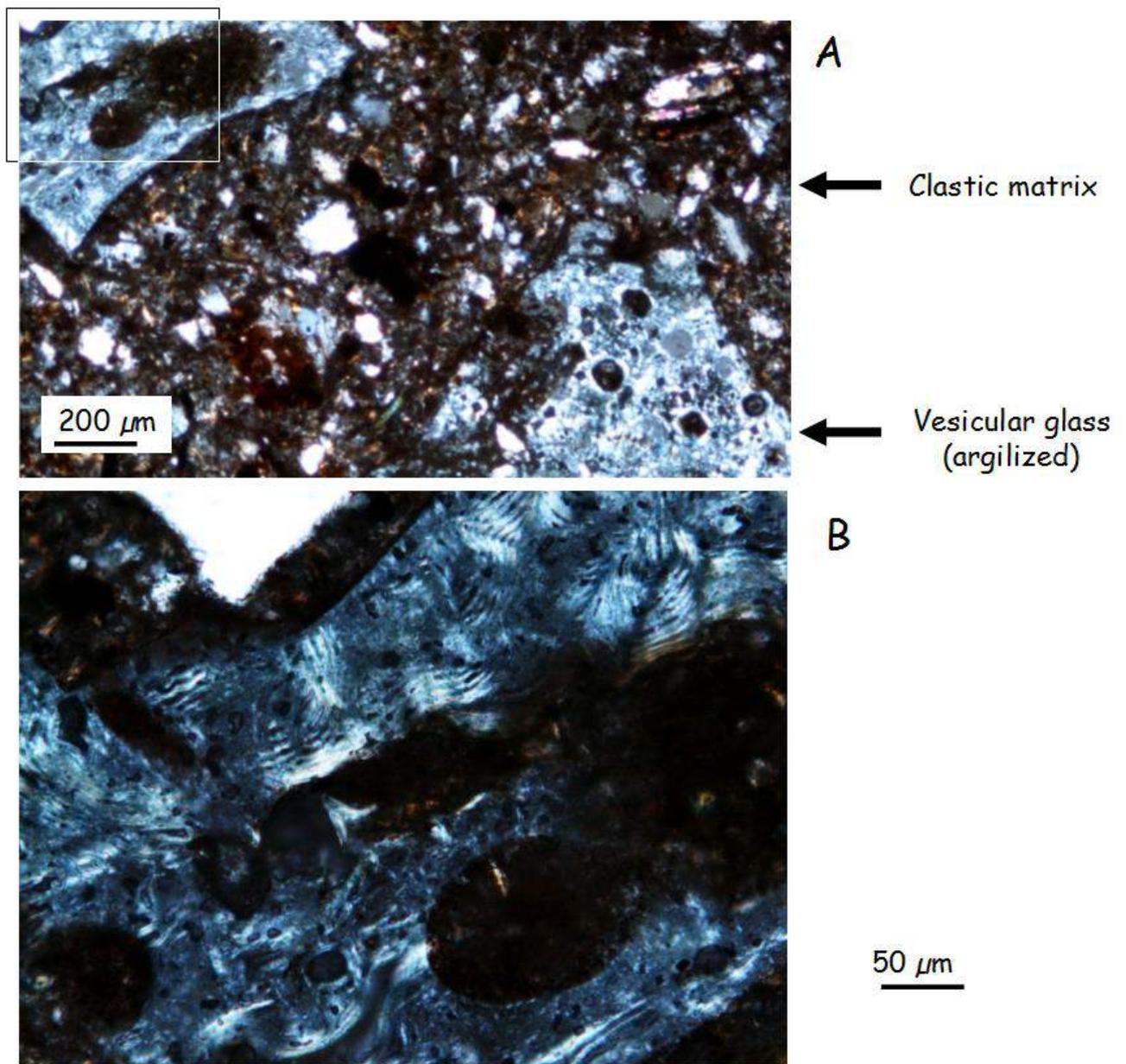
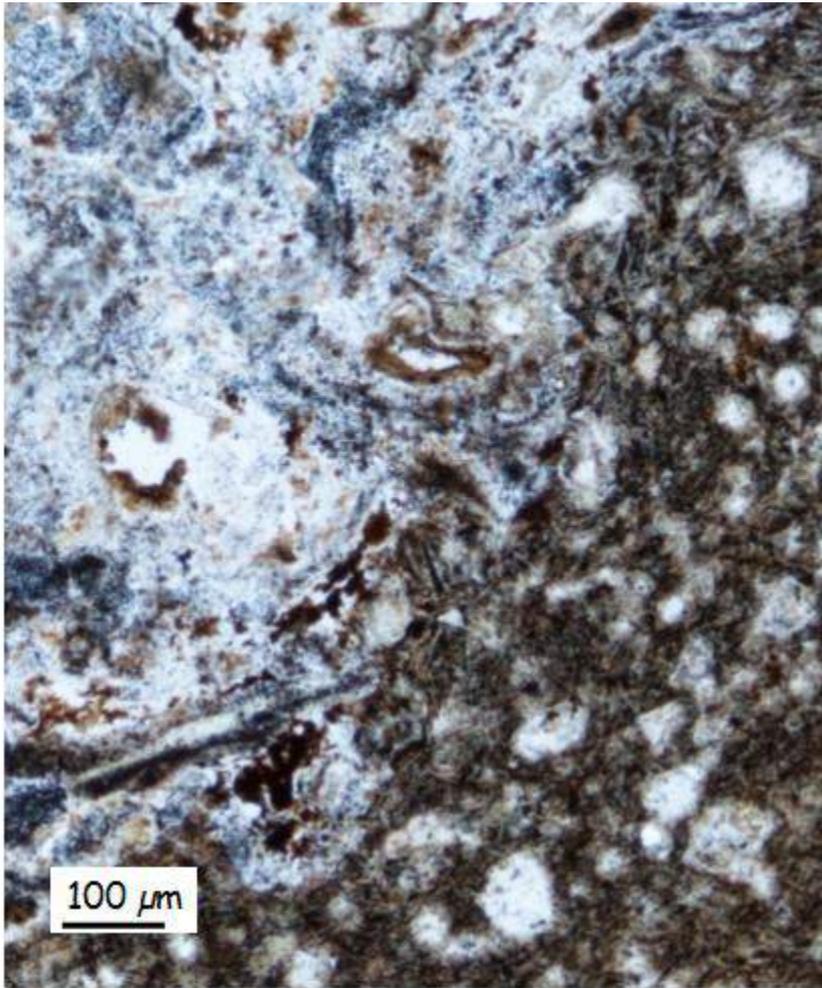
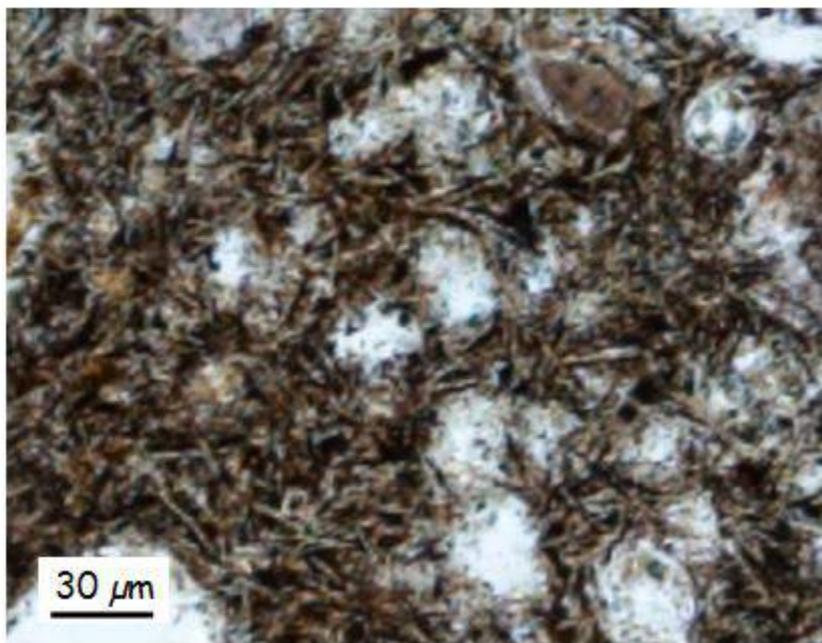


Figure 20: Petrographic details seen by optical microscope in plane polarized light of a double-polished thin section of a sample of the Chassenon suevite. Clastic matrix and vesicular glass clast (argilised).



A

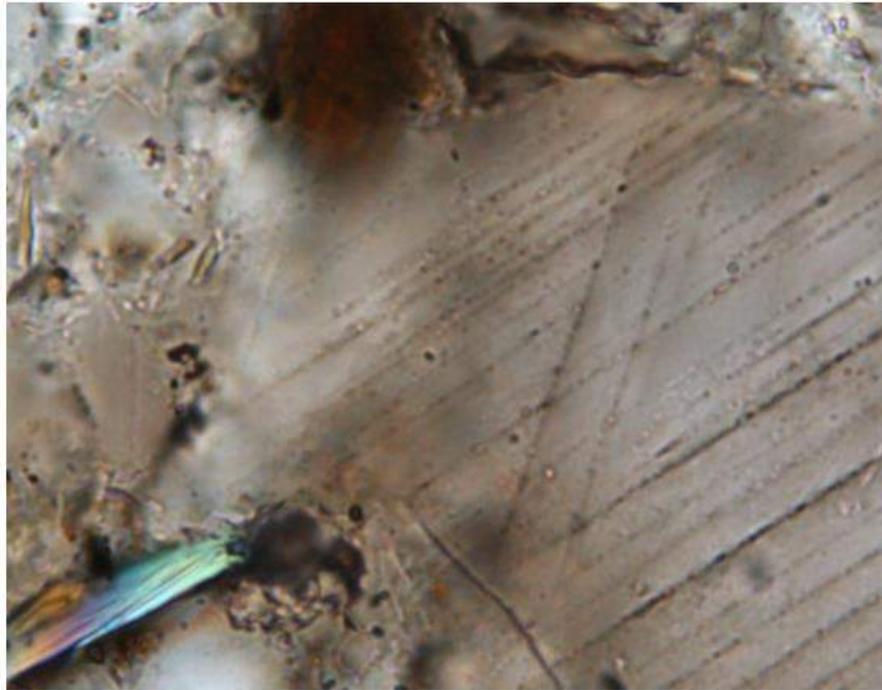
Figure 21: Optical microscope view in plane polarized light of a thin section of a clast-poor, vesicular impact melt rock from Babaudus. Boundary between the vesicular melt matrix (entirely recrystallised: detail in B) and a vesicle-free melt clast (also entirely recrystallised) of quartzofeldspathic composition.



B

More generally there is no (or only trace) of glass left as glass in any of the melt bearing impactites at Rochechouart. All tectosilicates shocked to stage 1b and higher in the lithic clasts of all the Rochechouart

allochthonous impact breccias are altered and/or recrystallized (Lambert, 1977a). PDFs in quartz and feldspars are systematically decorated by fluid inclusions (Lambert, 1977 a).



4 μ m

Figure 22: Optical microscope view in plane polarized light of a thin section of polymict lithic breccia near Rochechouart. Quartz with PDF decorated by fluid inclusions

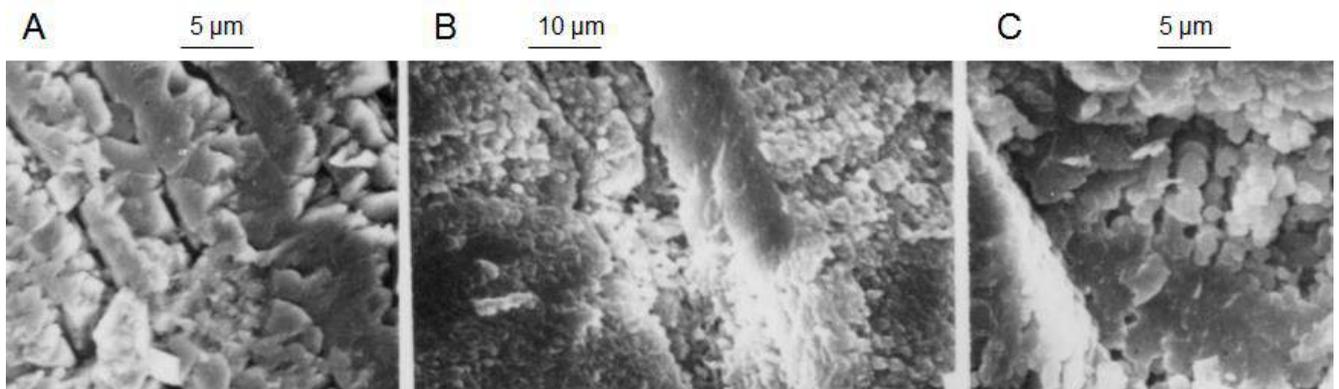


Figure 23: SEM view of quartz with PDF in A: shocked gneiss near Le Bouchet near the center of the structure. B-C: Lithic clasts in polymict lithic breccia from the same locality as A. Note the micro-crystalline character of the quartz. All the crystallites are sharing the same orientation and the quartz grain appears monocristaline under the optical microscope.

Feldspars in the highly shocked lithic clasts are largely replaced by argillic assemblages. These argillic assemblages are also developed in the clastic matrix of the polymict lithic breccias and the suevite. The size of these phases and their intricate relationship with the fine debris in the matrix make mineral identification difficult and sometimes hampers the identification of impactite type.

The following review of the specific features of the various types of Rochechouart allochthonous impact breccias deposit distinguishes between polymict lithic impact breccias, suevite, and impact melt rocks according to the nomenclature proposed by Stöffler and Grieve (2007).

Polymict Lithic Impact Breccias

Polymict lithic breccia is by far the most abundant impactite unit preserved in the Rochechouart structure. It covers ca 41 km² and is found near the center of the structure between Babaudus and Valette and up ca 7 km away near La Chassagne and Videix (Figure 9). Polymict lithic breccia typically occurs directly above the target bedrock. The maximum thickness of the currently exposed unit is ca 40 m, recorded in Rochechouart town and measures (Figure 9). Based on the lateral extension and thickness of the polymict lithic breccias at the various locations as observed in the field, the total volume of polymict lithic breccia remaining in the Rochechouart crater is calculated at about 1 km³ (Table 4).

EXPOSED TODAY	Area km ²	Thickness (m)		Vol. km ³	Melt	
		Average	Max		Fraction	Vol. km ³
Polymict lithic breccias	40.9	26	40	1.1	0%	0
Suevite	4.9	15	20	0.07	1-38%	0.01
Impact melt rocks	1.9	7	20	0.01	50-95%	0.01

Table 4: Field based estimates of the area, thickness and volume for the main impactite deposits in the Rochechouart crater as exposed today.

Despite its clearly polymict character, there is evidence for a relatively local origin for the clasts in the polymict lithic breccia. Clasts are characterized by angular to sub-rounded shapes and are embedded in a fine-grained clastic matrix. Morphometric measurements by image analysis on thin sections indicate that 30 % of the clasts are 5 mm and larger, and 50 % are > 1 mm (Table 3).

Locally, slight apparent stratification is observed in the polymict lithic breccia unit, for example in the cliff below Rochechouart castle. The faint bedding extends parallel to the exposed crater floor, which here dips 20-30° to the south (Figure 24).

As seen in Figure 25, geochemical analysis for the Rochechouart and Chassenon polymict lithic breccia gives elongated data fields that only partially overlap. The Chassenon polymict lithic breccia is more mafic than the “average” target and plots into the area of the gneiss field (Figure 25). The Rochechouart polymict lithic breccia is centered on the “average target” and extends over the lower portion of the gneiss field and the upper portion of the granite field. As seen in Figure 4B, the long axis of the Fe-Mg field for both the Chassenon and Rochechouart polymict lithic breccias is parallel to that of the target (granite+gneiss) but it is slightly shifted towards higher Fe.

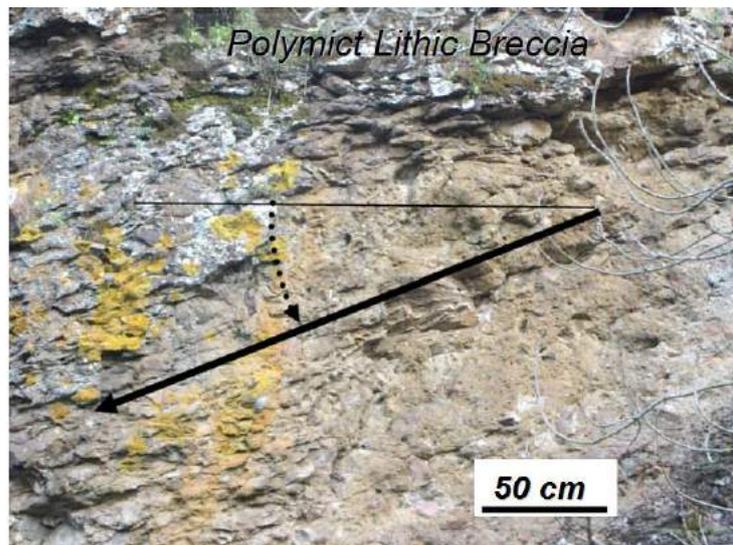


Figure 24: Field view of polymict lithic breccia at Rochechouart. Faint apparent inclined stratification

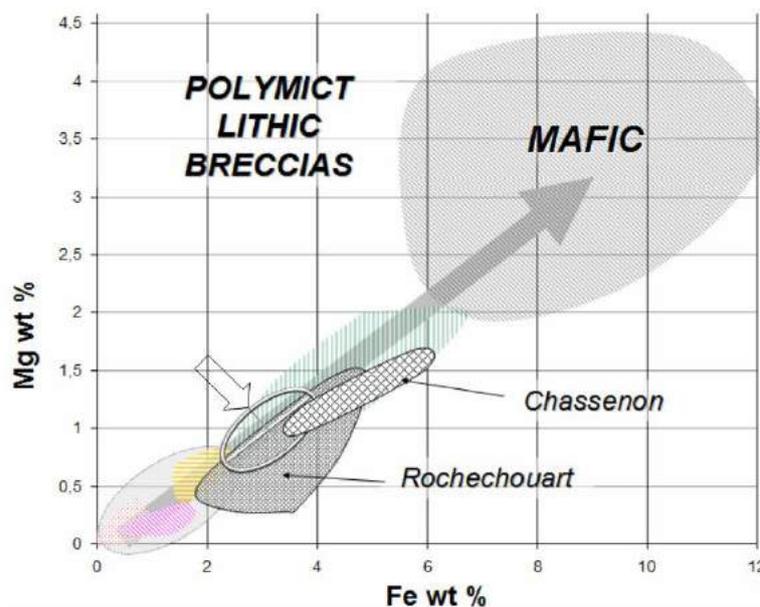


Figure 25: Fe-Mg plots for the main polymict lithic breccias exposed in the Rochechouart structure, near Rochechouart and near Chassenon respectively. Background: plots of the granite (lower left) and gneiss (Figure 6B). Ellipsoid (open arrow): “average” target composition field mixes the composition of the various basement rocks according to their relative proportion of exposure in the Rochechouart area (ca 50% granite + leptynite and 50% gneiss).

Suevites

The material termed suevite in the Rochechouart structure is granulometrically and texturally very similar to the polymict lithic impact breccia. The only difference is the

occurrence of melt (altered and/or crystallized) fragments in the suevites. Melt is observed both in the matrix and in the clast fractions of suevite (Figure 26). Quantitative analysis of the melted fraction in suevite by combined macroscopic and microscopic image analysis on polished sections (Lambert 1977a) indicates that the majority of

melt occurs as particles >5 mm in size, especially where the overall proportion of melt is high (> 15 vol%). The total amount of melt in the suevite is highly variable, from 0.1 to 38 vol%. On average, it is 12 vol% or less (Lambert 1977a).

The maximum thickness of the suevite is ca 20 m as deduced from field data at Chassenon. The area of exposure of suevite comprises approximately 4.9 km², 12% of that of the polymict lithic breccia. According to lateral extent and thickness of the patches, the total volume of suevite left in the structure is estimated at ca. 0.07 km³ (Table 4), or about 5% of that of the polymict lithic breccia.

From estimates of the melt fraction at the various suevite localities from Lambert (1977a) and the volumetric estimates for the various suevites, the total volume of melt in the suevite actually exposed in the Rochechouart structure is estimated at about 0.01 km³ (Table 4).

Two main types of suevites are reported, which are distinct in setting and texture, namely, the upper suevite forming the largest suevite unit and corresponding to the usual definition of suevite and the bottom melt-rich suevites.

Upper Suevite (or suevite sensu stricto): This suevite occurs directly overlying polymict lithic breccia. It forms small isolated patches close to the periphery of the impactite deposits in the southwestern part of the structure (Figure 9); however, it is absent from the center of the structure. As in the case of polymict lithic breccia, a faint ondulose to sub planar

stratification is observed locally in the suevite (Figures 9-10).

The largest and most famous suevite occurrence is in the Chassenon area. It forms a continuous horizontal sheet up to 20-30 m thick, 2 km long, and 1.2 km wide (Figures 9 and 11). It accounts for 90 % of the total volume of suevite left in the crater structure.

The Chassenon suevite is deposited on top of 30-40 m of polymict lithic breccia (Figure 11) as deduced from stratigraphy accessible in the field and confirmed by shallow seismic profiling done in the context of ongoing archaeological investigation of the Chassenon site (Bobee et al., 2005).

Referred to for over 15 decades as volcanic material in the French geological literature (Manes, 1833; Kraut, 1935), the Chassenon suevite was actively quarried for building purposes up to the early 20th century (Figures 27-28). It was used extensively from the 1st to 4th centuries for Roman constructions, including baths, a temple, an arena, and villas at "Cassinomagnus," which was more important in Roman times than today's village of Chassenon.

The Chassenon suevite has been instrumental in the recognition of the Rochechouart impact structure, after delegates of the international scientific community were taken by F. Kraut in the late 1960s to the remnant of the last active quarry in Chassenon village. This quarry and its unique, finely stratified deposit have unfortunately disappeared in the 1980s after local municipalities used the quarry for landfill purposes and then covered it.

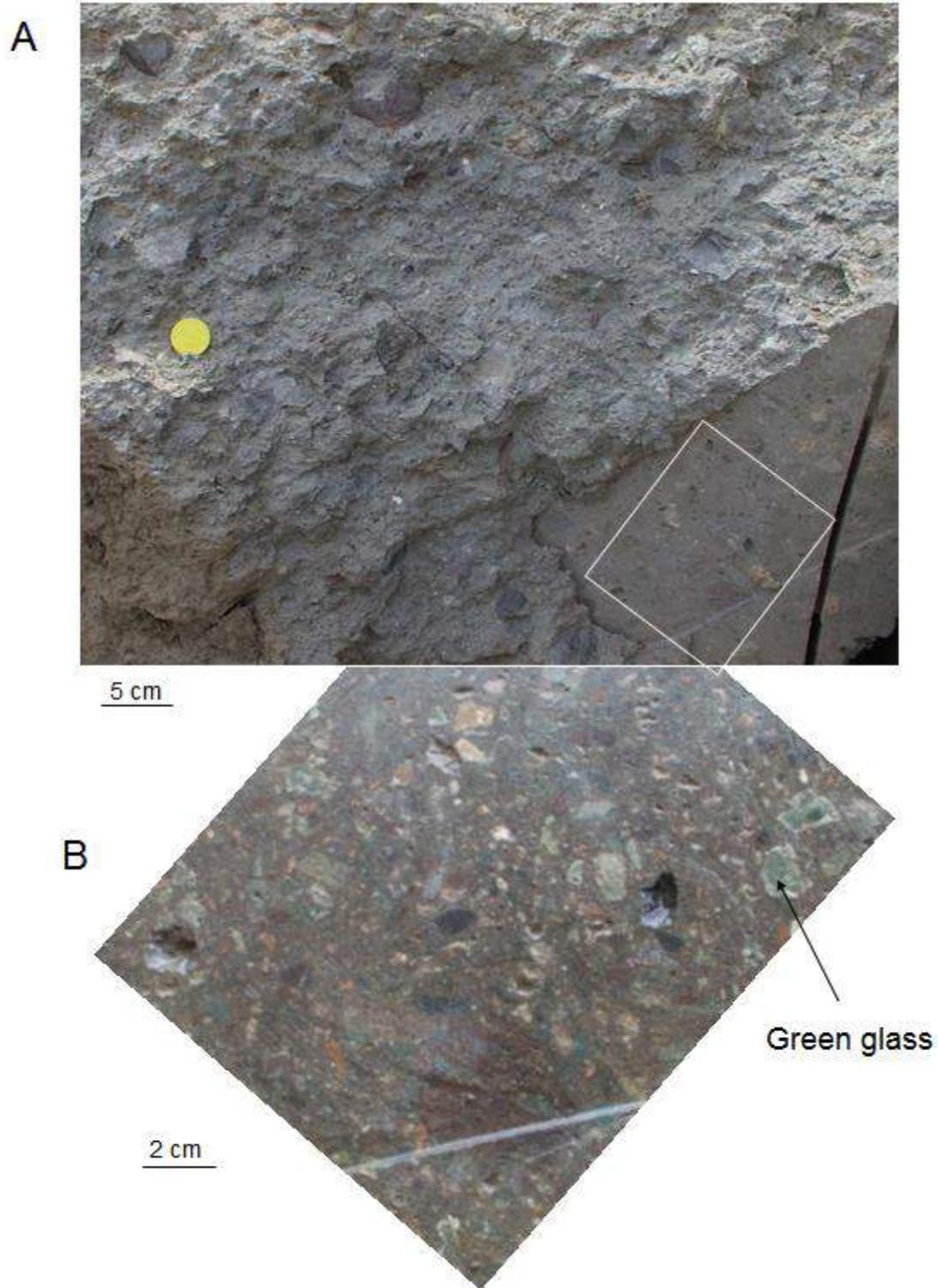


Figure 26: Field view of the upper suevite (suevite sensu stricto) at "Grosse Piece" quarry near Chassenon.

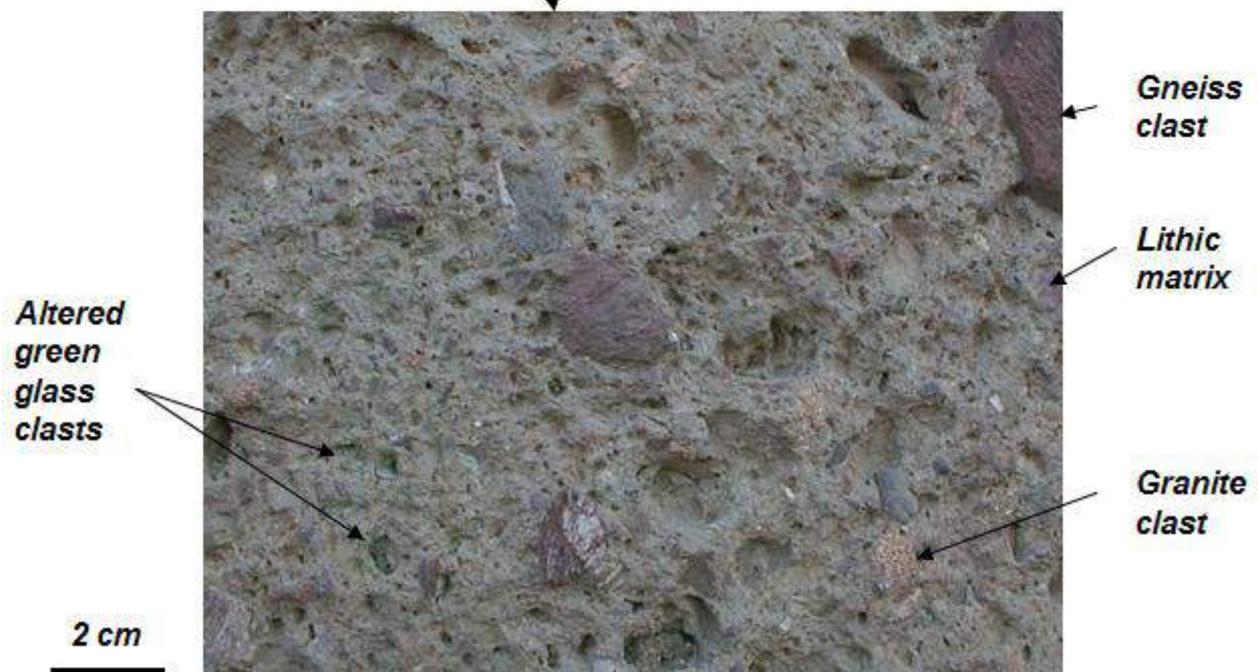


Figure 27: Chassenon Roman church built in suevite (suevite sensu stricto) and close up view of the wall

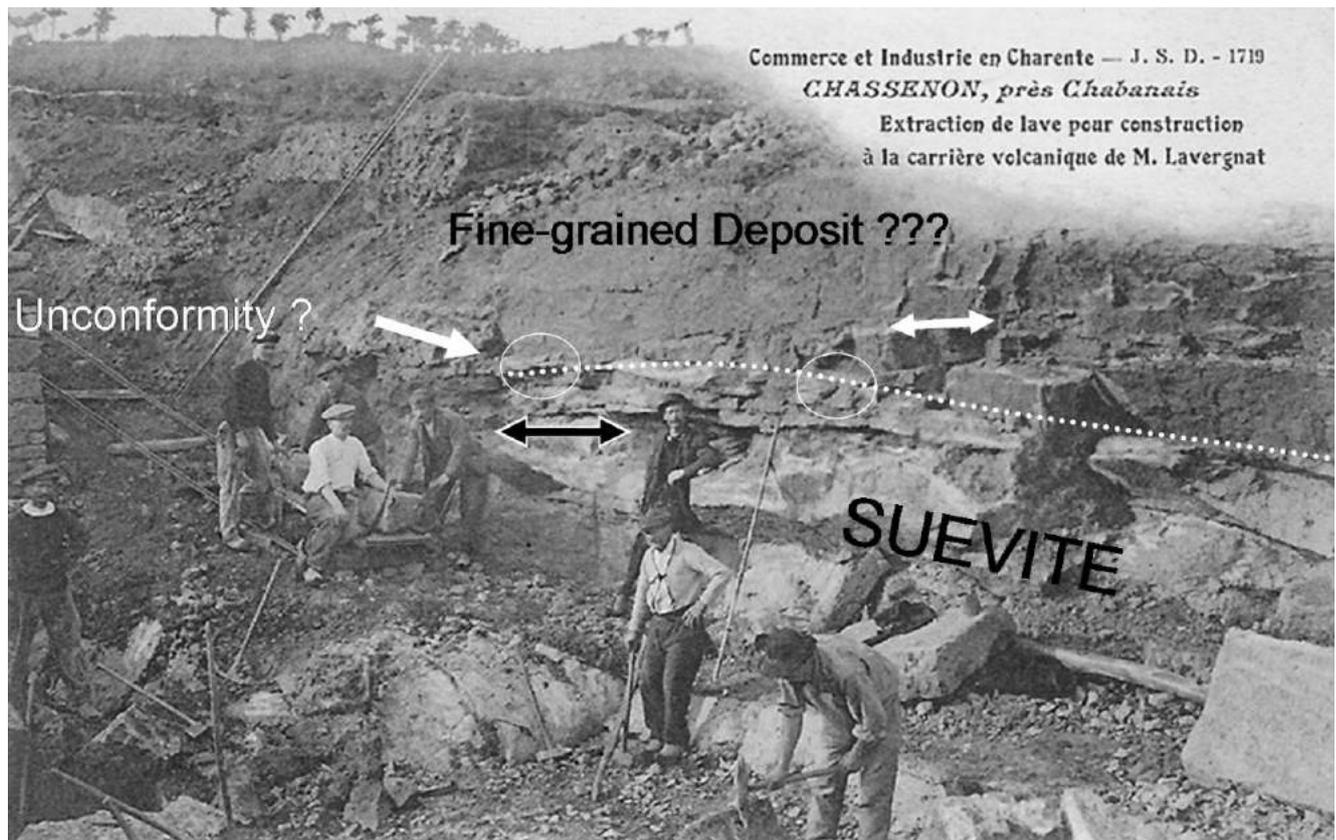


Figure 28: Top of the suevite at the « Volcanic » quarry of Chassenon as seen on a postcard dated to the early 1900's (also known as *Carrière des Arènes*). The quarry's exploitation for construction material ended in the 1930's and the remnant of the quarry finally disappeared in the early 1980's after having been filled in. The top deposit seen on the picture appears massive. It displays a slightly curved stratification (white double arrow) resembling cross-bedding that seems to intersect the underlying suevite at low angle (unconformity?: dotted line). This top unit is supposed to correspond to the impactoclastic deposit which was sampled at the remnant of this quarry in the early 1970's (see text). The underlying suevite displays a faint stratification roughly parallel to the horizontal (black double arrow).

Smaller outcrops of the same suevite deposit are still exposed along road cuts and at various remnants of Roman quarries in the nearby woods. The typical Chassenon suevite is a polymict breccia with angular to subrounded clasts typically of mm to cm size (Figures 26-27). Clasts are formed by target rock fragments and glass (altered glass) particles, including highly vesicular debris resulting from partial shock melting of lithic material. Shape and size of glass particles essentially compare to that of lithic clasts. Contorted, twisted shapes are rare among the Chassenon glass particles (Figure 26).

The suevites in the Chassenon area are characterized by a uniform texture and color

(gray-green). They also display a narrow field of compositional variations compared to the other impactites as seen on the Fe-Mg diagram (Figure 29). Chassenon suevites plot close to the “average” target and generally match the composition of the local gneiss (comparing Figures 6B and 29).

Melt-rich suevite (melt-poor impact breccias): These breccias are characterized by highly variable colors and textures. They are only found directly overlying the bedrock. They are observed in the vicinity of impact melt rocks. They bear a clastic matrix, which incorporates a relatively large proportion (20-50 vol%) of melt clasts (example at Figure 30).

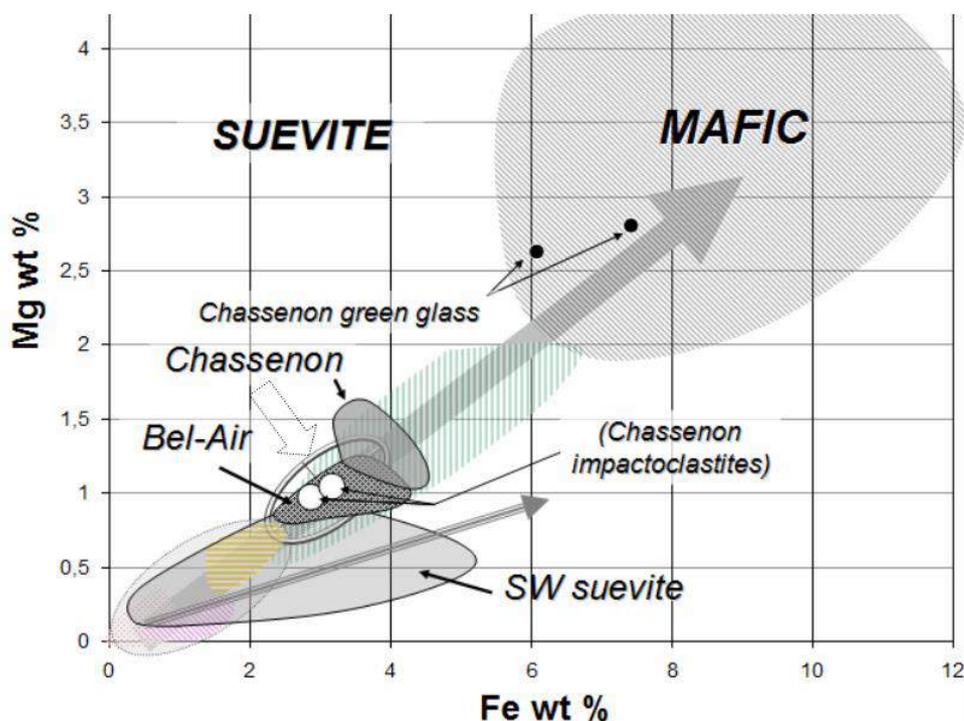


Figure 29: Fe-Mg plots for the suevites. Background: plots of the granite (lower left) and gneiss (Figure 6B). Ellipsoid (open arrow): “average” target composition field mixes the composition of the various basement rocks according to their relative proportion of exposure in the Rochechouart area (ca 50% granite + leptynite and 50% gneiss).

Unlike melts in the Chassenon suevite which usually displays a homogeneous texture (glass (altered) + vesicles), melt bearing clasts in the melt rich suevite are characterized by a complex and heterogeneous texture where lithic debris clasts and/or clast of partially melted lithic debris are incorporated in the melt (Figures 30-31).

This material is not observed around the center of the structure, only from a distance of 2-3 km from the center. A small patch occurs in the Bel-Air area, here it is characterized by a yellow color. Most melt-rich suevites are observed in the south-southwest part of the impact deposit (between Valette-Montoume-Videix), where the breccias are predominantly pink, maroon, and red. These melt-rich suevites plots separately on the Fe-Mg diagram (Figure 29), and their Fe-Mg content is also distinct from that of the Chassenon suevite.

The southwestern melt-rich suevites show the broadest variations, the compositions of which spread over the granitic field, whereas the Bel-Air melt-rich suevite plots at higher Fe-Mg values in the lower part of the gneiss field (Figure 29). The southwestern melt rich suevites crop out in a region of the target where granites are dominant (Figures 4 and 9), whereas the Bel-Air suevites overlie gneisses.

The Fe-Mg plot for the southwestern suevite compositions matches that of the impact melts occurring in the same region (from Valette to Montoume: see Figure 40 next section). As seen in Figure 29, the long axis of the Fe-Mg correlation field for the southwestern suevites is not parallel to that of the target (granite+gneiss). It is shifted towards higher Fe, as observed also for Babaudus, the Montoume and the Valette impact melt rocks (see Figure 40 next section).

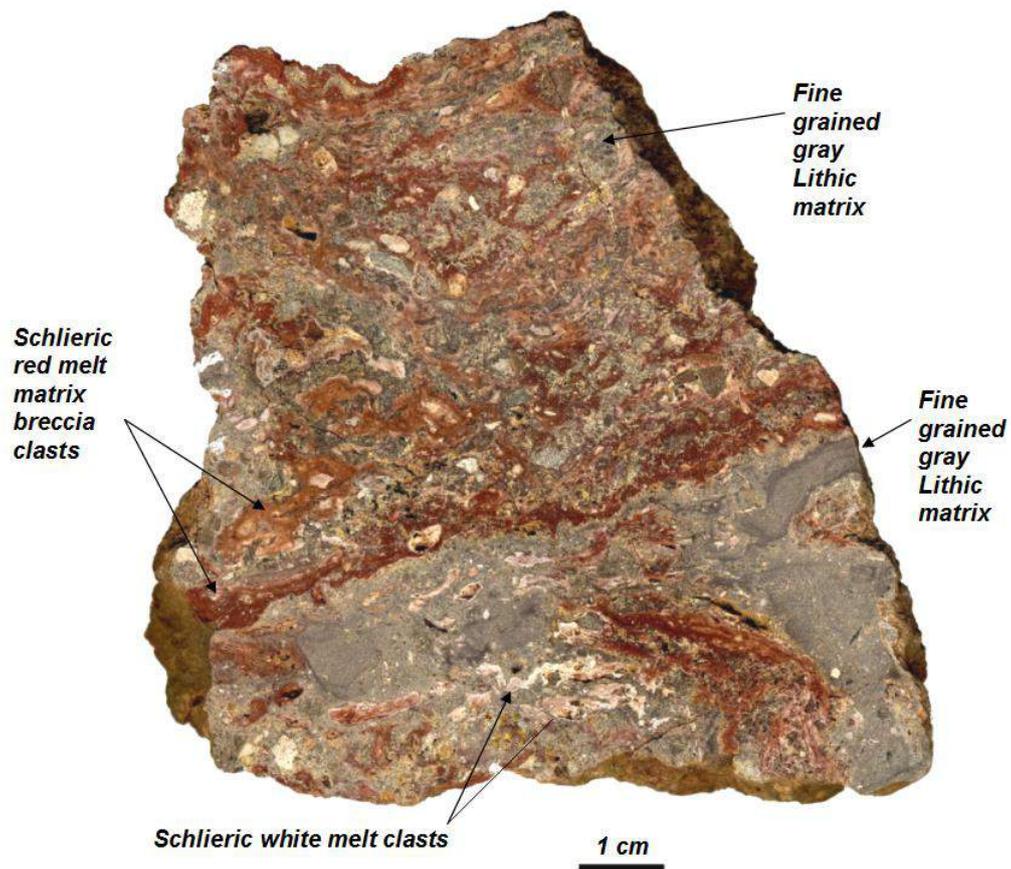


Figure 30: Melt rich basal suevite near Valette 2 km SW of the center of the structure (photo courtesy of Martin Schmieder).

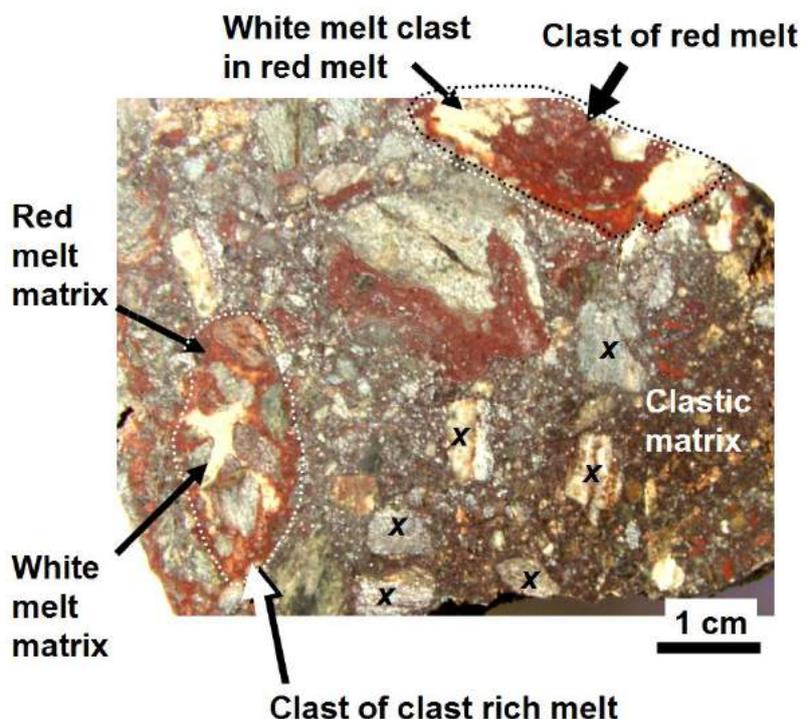


Figure 31: Cross-sections of a basal suevite occurring at the immediate contact with bedrock and outcropping at the edge of the Valette impact melt sheet 2.5 km SW of the center of the structure. Lithic clasts are essentially all derived from the same gneiss (« x »: gneissic fabrics clearly preserved and sharp edges of lithic clasts). Note large rounded « clasts » of red melt matrix breccia including- either as clasts or as matrix- a white melt matrix material. Note the diffuse contour between the two melts.

The variability of textures and the compositional differences observed in the Rochechouart suevite, together with their specific settings, suggest different origin. The upper suevite layer, forming most of the suevite at Rochechouart and lying on top of the polymict lithic breccia, is apparently distinct from the melt rich suevite observed at the contact with the basement. The latter is clearly tied to the presence of impact melt rocks. The narrow field of Fe-Mg composition for the upper suevite (Chassenon suevite) (Figure 29) seems to indicate greater homogenization of the upper suevite relative to the basal suevites and impact melts rocks, which are much more varied in composition. This may also reflect the relative importance of “slow and late” conduction melting mechanisms (as opposed to rapid and early shock melting) of more or less shocked but unmelted clast introduced and mixed in a hot environment. This mechanism requires the proximity a significant heat source i.e. the proximity of an impact melt body as observed in the field. This mechanism probably accounts for a significant part of the melt observed in the melt rich basal suevite.

The relative abundance of homogenized glass and the relative lack of heterogeneous melts in the top suevite compared to the basal suevite may not only reflect their variation from different shock regimes in the crater but also different post-depositional metamorphic processes mechanism. The top suevite is interpreted as the product of thorough dispersion and mixing of melt and cold lithic debris during ejection and fall back, resulting in a rapid cooling of the melts to glass and preventing late thermal melting of lithic clasts in contact and or in the vicinity of the impact melt sheet. The basal suevite on the other hand is the result of heterogeneous and local mixing conditions between the impact melt and ground-surge deposits at the contact with bedrock near the center of the structure. The relatively high shock level recorded on average by the lithic clasts originating at the bottom of the crater in the center of the crater, plus the heat provided by the overlying melt sheet would have aided further partial melting and incomplete assimilation of melted lithic clasts in the basal suevite.

Impact melt rocks

The currently exposed Rochechouart impact melt rocks are all in direct contact with bedrock. They display a large variety of textures related to the nature, proportion,

orientation and granulometry of clasts that may even vary at the hand specimen scale (Figures 32-33). These rocks are characterized by a matrix made entirely of melt which is recrystallised (see detail at Figure 33).

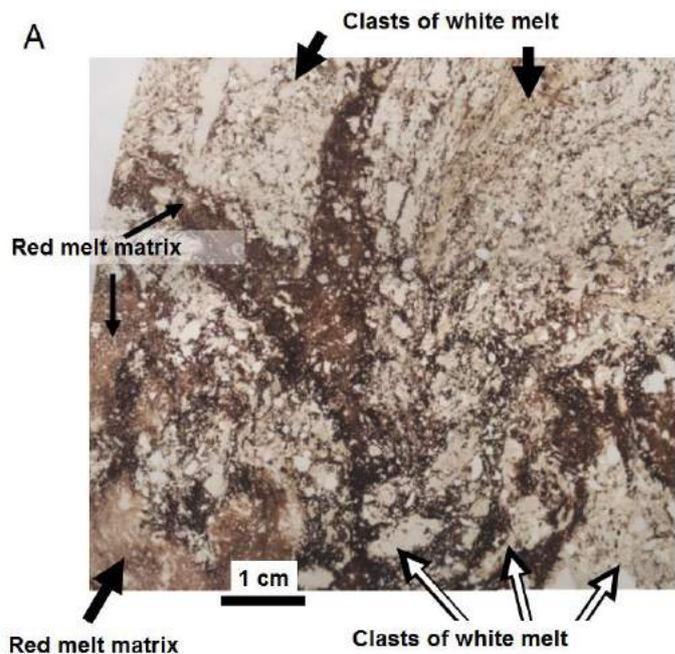
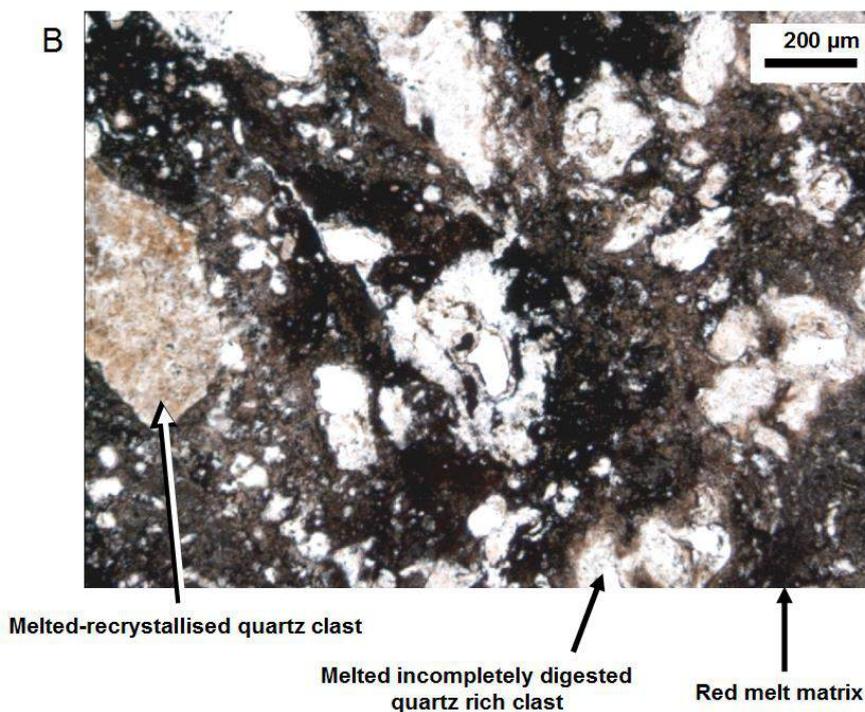


Figure 32: A: Optical view of a thin section under plane polarized light of a massive and vesicle-free 99 vol % melt impact melt rock near Valette (2km SW of the center of the structure) with equal proportion of two different melts (both recrystallised) showing both contorted flow features. The white melt bears the remnant of the original lithic fabric (trace of the gneiss foliation) and reflects incomplete assimilation by the red melt. B: Close up view of A under plane polarized light.



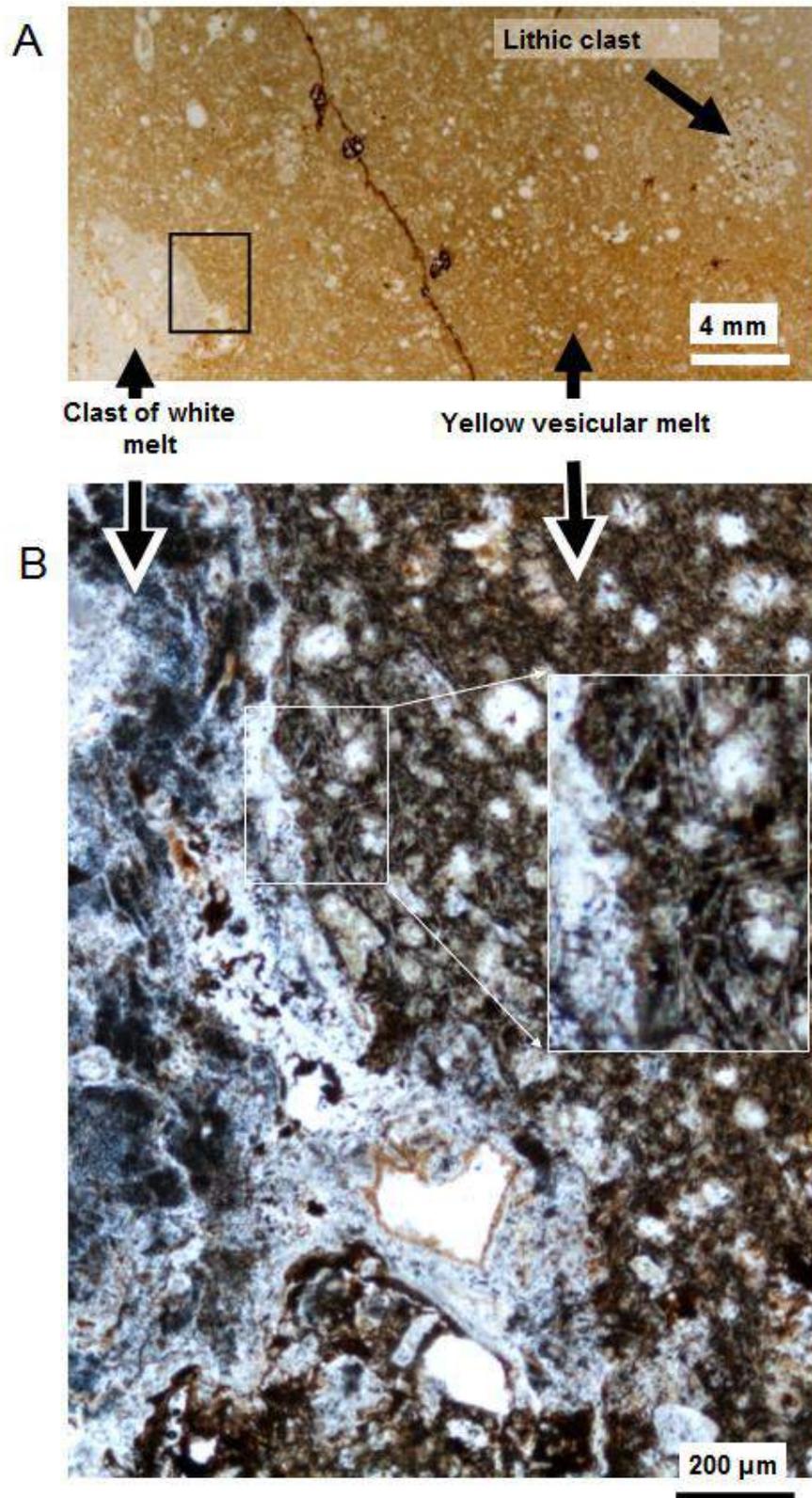


Figure 33: *A: Optical microscope view in plane polarized light of a thin section of a clast-poor, vesicular impact melt rock from Babaudus (1.5 km from the center of the structure). (Black rectangle: field of the micrograph shown in B). B: Detail of the boundary between the vesicular melt matrix (entirely recrystallised) and a vesicle-free melt clast (also entirely recrystallised) of quartzofeldspathic composition. Enlarged block: detail showing the crystalline state of the melt matrix.*

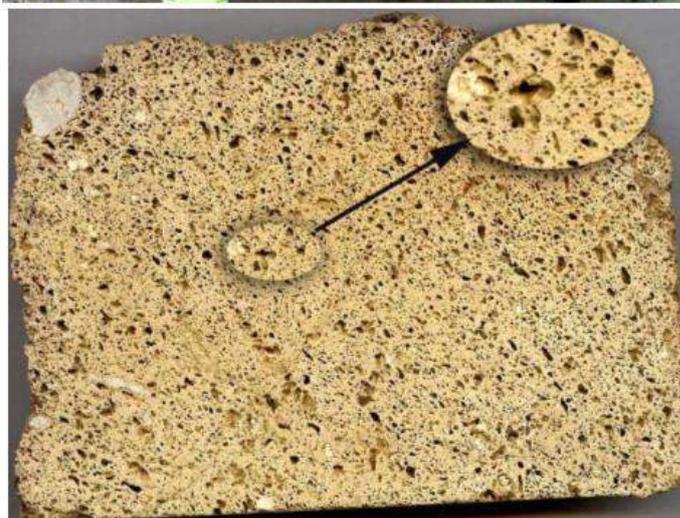
Quantitative analysis by combined macroscopic and microscopic image analysis on polished sections indicates a variable amount of melt ranging from 47 to 99 vol% (Lambert 1977a).

Proportions of melt over 90 vol% are rare. About 75% of the studied Rochechouart impact melt rocks contain more than 10 vol% lithic clasts. Clasts generally display fluidal textures indicative of plastic deformation – likely due to thermal softening. They show complex contacts with the matrix, indicating partial assimilation and digestion in the matrix (Figures 32-33).

Rochechouart impact melt rocks form small isolated patches mostly limited to the central 4 km diameter region of the structure. However, small patches of impact melt rocks have been reported up to 7.5 km from the center of the structure (Figure 9). Vesicular impact melt rocks are observed mainly in the central part of the structure at distances of 2-3 km from the center and less (Figure 34). Vesicles are commonly non-symmetrical. They are elongated horizontally at Babaudus and Fontceverane (Figure 35). The impact melt rocks occurring at distances of 4 km or more from the center of the structure do not contain vesicles.



Figure 34: Impact melt rock at Babaudus (1.5 km SE of the center of the structure). Top: “fresh” cut. B: Same material but more weathered (stone from the wall of a farm at Babaudus). Very few lithic clasts. Small spherical vesicles enlarged by weathering (B).



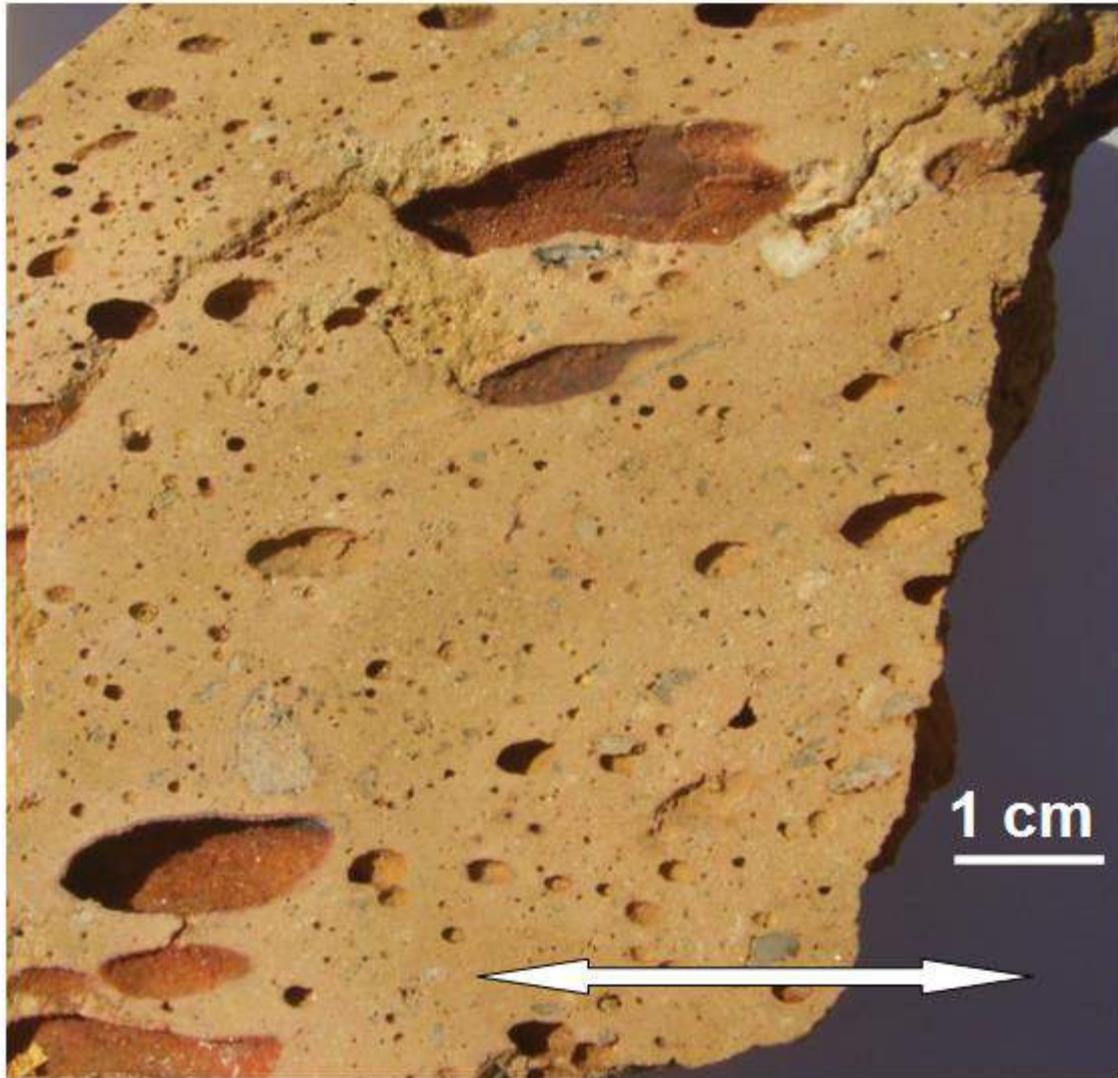


Figure 35: Saw-cut of an impact melt rock sampled near Fontceverane 2 km SW of the center of the structure. Double arrow: Trace of the horizontal plane at the sample locality. Note bubbles elongated in the horizontal plane indicating the melt was still in motion at the time of quenching. It also implies that the crater floor, observed immediately beneath the melt rocks at that particular locality, acquired the horizontal profile as observed today prior to quenching.

The largest exposure of impact melt rock currently known at Rochechouart is a 1.6 km long, 0.7 km wide vesicular body covering 0.3 km² between Valette and Fontceverane, ca. 2 km southwest of the center of the structure (Figure 9). It is only a few meters thick and its volume is about 0.007 km³. Bearing 80 vol% of melt, on average, as measured in thin sections, this unit accounts for ca. 0.005 km³ of melt

representing about half of the total volume of melt residing in the impact melt rocks currently exposed at Rochechouart. The other occurrences form smaller bodies, such as that at Babaudus (Figure 9), which is a few hundred meters wide and one or two meters thick. The smallest bodies such as that near Bel-Air are only a few meters wide and meter thick (Figure 36).

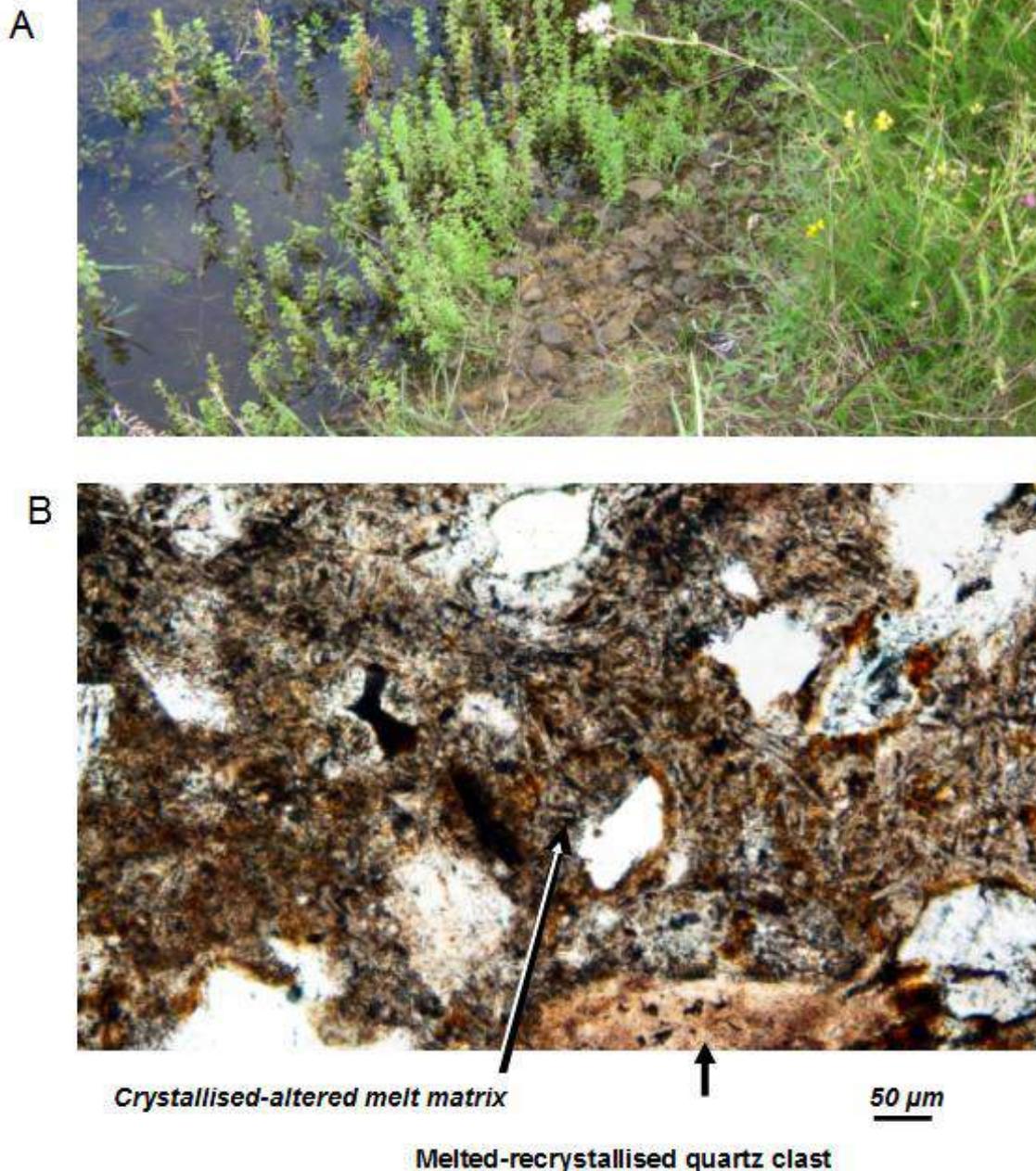


Figure 36: Impact melt rocks at Bel-Air located ca 5.5 km N-NE of the center of the structure. A: Field view ca 3 meters wide) showing the poor conditions of outcropping. B: View under the optical microscope in plane polarized light of a thin section of a typical Bel-Air sample.

The thickest body is also the most remote from the center of the structure (7.5 km). It forms a 900 m long and 600 m wide hill near Mountoume village at the southern edge of the impact deposit zone (Figure 9). The maximum thickness deduced from the intersection with

topography is ca 25 m. The contact with underlying granitoid bedrock dips at 2° to the north (Figure 11). This unit was initially distinguished from suevite and from impact melt rocks and described as “Mountoume red welded breccia” (Kraut and French, 1971).

It appears as a suevite on the current 1:50 000 geologic map (Chevremont et al., 1996); however, this material more closely resembles a clast-rich impact melt rock than a suevite and has been referred to and mapped as impact melt

rocks in Lambert's works (1977a,b) and more recently by Sapers et al. (2009).

The Montoume breccia is massive structure, lacks vesicles, and displays columnar jointing (Figure 37).

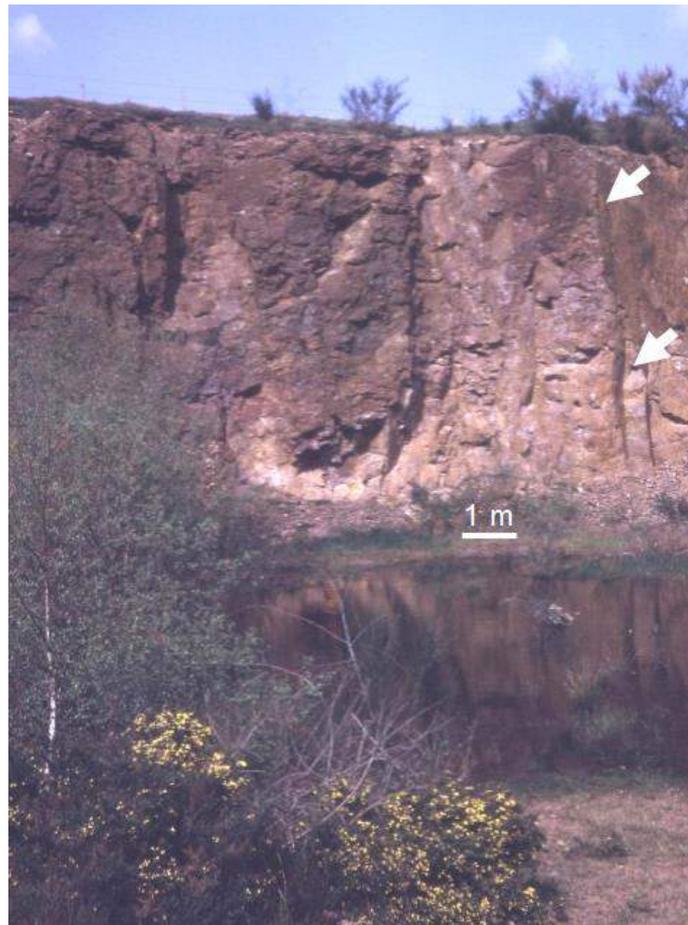


Figure 37: Clast-rich impact melt rock from Montoume 7.5 km S of the center of the structure. Old view (1970's) of the Montoume quarry displaying large columnar joints (arrows).

Its texture is complex and variable at the meter scale (Figure 38). The proportion of lithic clasts >0.5 mm varies between ca. 25 and 40 vol% as measured by Lambert (1977a). The proportion of undoubtedly lithic clasts <0.5 mm in the matrix varies between 3 and 12 vol% and the proportion of matrix thus varies between 50 and 70 vol%.

The matrix is crystalline; it locally displays flow features. Flow features are seemingly

related to local sorting of small lithic clasts and to elongation of partially digested schlierig clasts (as demonstrated for instance by the wavy contour of the periphery of the lithic clasts on Figure 38B). There is no preferred orientation of these flows at the scale of the unit. From the geological setting and the relative proportion of clasts measured in the melt it is deduced that the total amount of melt contained in the Montoume area comprises between 0.002 and 0.004 km³.

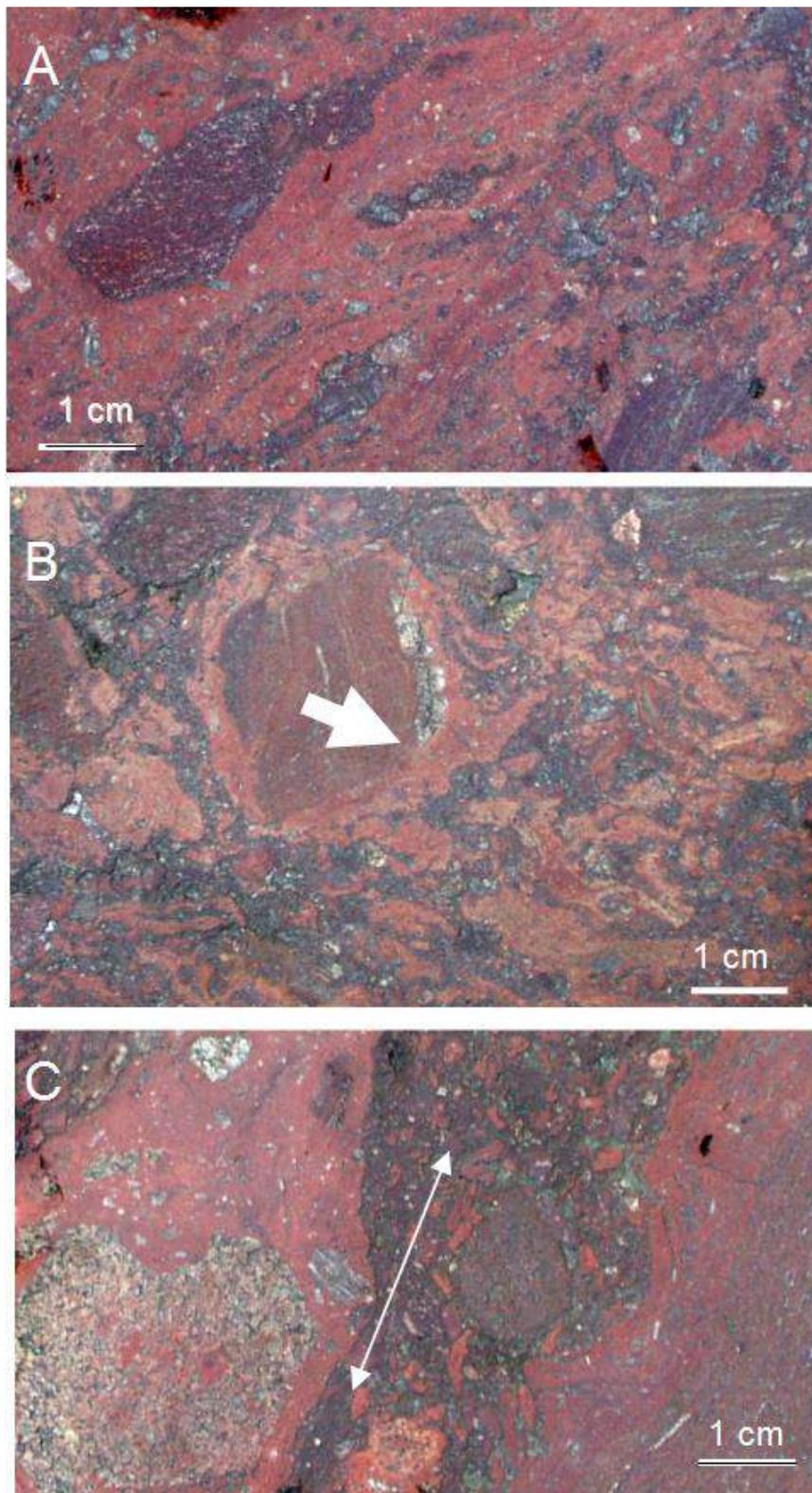


Figure 38: Polished slabs of clast-rich impact melt rock from Montoume 6 km S of the center of the structure. **A:** Highly fluidal melt with partially digested clasts elongated in the direction of the flow (arrow). **B:** Oriented and schlierig fluidal felsic melt clasts with more or less diffuse edges locally coating a lithic clast (arrow) embedded in a darker melt matrix. **C:** Assemblage of 3 distinct clast rich schlierig melts displaying different types, proportion and size of lithic clasts. Arrow: direction of the flow features.



Figure 39: Wall of the Montoume quarry, 6 km S of the center of the structure showing variations of color in the massive impact melt rock. At this particular spot the melt is quasi free of clast.

Although the Montoume impact melt rocks are essentially all deep red in color, limited occurrence of gray-green matrix material resembling (in color only) to Chassenon suevite is observed locally in the red breccias (Figure 39). The contact with the red matrix material is gradual. Local occurrences of clast poor fine grained matrix material are also encountered (Figure 39). All this to conclude that despite of an apparent homogeneity of the Montoume formation, the texture is complex and the relationships between the different textural declinations remain unexplored.

The occurrence of deformed and schlieric clasts of melts and melt matrix breccia clasts in the Montoume impact melt rocks may explain why this formation can be confused with a suevite. It seems worthwhile alerting the

community to these textures that do not necessarily fit in with the nomenclature.

In addition to distinct melting mechanisms (shock melting and post-depositional melting) the occurrence of impact melt breccia as clast in basal suevite as well as in melt poor impact melt rocks (such as at Montoume) imply multiple discrete source of impact melt breccia that become mixed at a latter stage. A minimum time gap that remains to be constrained is indeed required between the generation of the early impact melt breccia and the formation of the suevite or the impact melt rock in which the first generation melt breccia is occurring as clast. It also implies the first generation melt breccia has acquired a minimum strength and cohesion at the time it is processed by the second mechanism leading to the observed suevite or impact melt rock.

Non homogenized melt clasts in impact melt rocks are also constraining time and temperature conditions of cooling and mixing. The composition factor is also involved. One notes the melt clasts in impact melt rocks at Rochechouart are typically quartz rich in composition (such as those illustrated at Figure 11). This has certainly to do with the refractory character of quartz when compared to granite and gneiss.

All this will require further and more detailed investigation in order to provide full understanding and quantitative estimates of the various parameters involved.

Eventually Rochechouart impact melt rocks displays all the intermediate stages of clasts fabrics between that of a typical lithic clast and that of a completely molten, yet non digested melt clast that has lost essentially the memory

of its lithic origin, but which maintains its chemical signature. This raise the open question of where to set the boundary between clast and melt and how does this interfere with the evaluation of melt content in impactites.

The geochemical record of melt at Rochechouart.

Geochemical analysis shows that all the Rochechouart impact melt rocks bear a common granitic composition as seen in the Fe-alkali element-Mg ternary diagram (Figure 5A). Compared to the target composition, the composition of this material displays a prominent shift towards the orthoclase pole on the quartz-orthoclase-albite ternary diagram (Figure 5B).

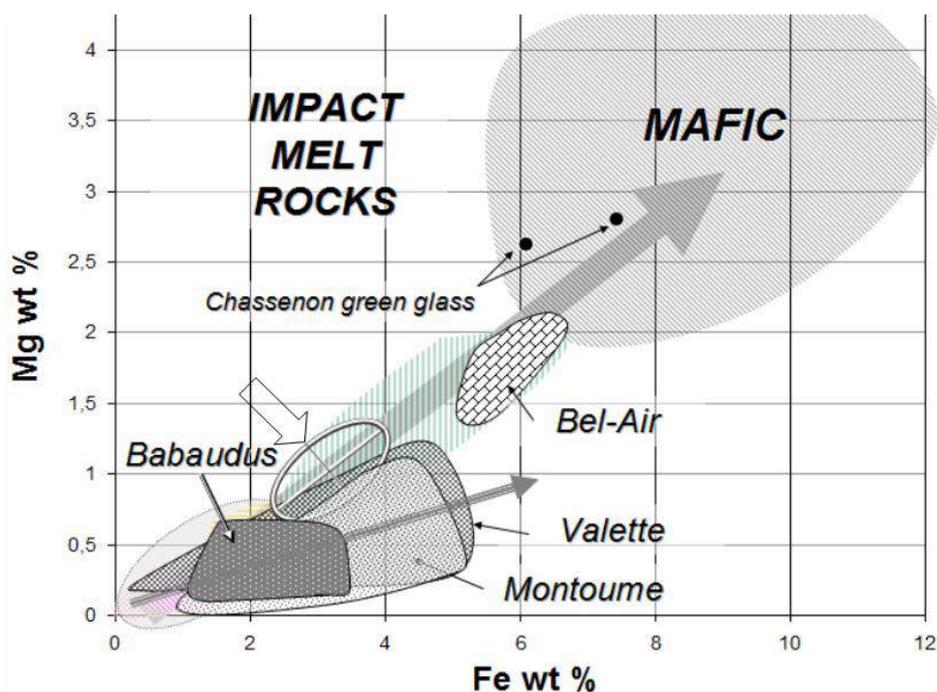


Figure 40: Correlation plots for the impact melt rocks at Bel-Air, Babaudus, Valette and Montoume. Note the same symmetry axis for the correlation fields of Montoume, Babaudus and Valette melt rocks (open arrow), which is shifted toward the Fe axis compared to that of the target formations (black solid arrow). Background: plots of the granite (lower left) and gneiss (Figure 6B). Ellipsoid (open arrow): “average” target composition field mixes the composition of the various basement rocks according to their relative proportion of exposure in the Rochechouart area (ca 50% granite + leptynite and 50% gneiss).

The same shift is observed for the lithic clasts in the impact melt rocks (Figure 5B). This shift is associated with a relative increase in K_2O and relative depletion of both Na_2O and CaO (Table 2). The K/Na ratio for impact melt rocks is ca. 15 times that of the target rocks, whereas the K/Na ratio in lithic clasts in the impact melt rocks is ca. 10 times that of the target rocks. The K/Ca ratio in impact melt rocks is ca. 10 times that of the target rocks.

Beyond the common granitic signature and the pronounced change in the K/Na ratio, the various impact melt rocks show small but significant differences in composition. They plot separately in the Fe-Mg diagram (Figure 40). The Babaudus impact melt rock plots into a narrow field that is much more felsic than the average target composition (based on presently exposed country rocks). It matches the compositional field of the leptynites. Conversely, the Bel-Air melt rock is much more mafic than the average target and plots between the most mafic gneisses and the diorite-amphibolite field (Figure 40).

The Valette melt rock compositions fall into the broadest field, which covers the granitic compositions and extends to the lower half of the gneissic field (Figure 40). Despite the specific red color of this deposit, the Montoume breccia has the same composition as the yellow Valette impact melt rocks. As seen on the Fe-Mg diagram, Montoume and Valette melt rock compositions are almost identical. Both melt rock data sets fully cover the granitic compositions and extend to the lower half of the gneissic field (Figure 40).

The relative inefficiency in homogenizing and mixing of melt at Rochechouart.

The abundance of “multi-melt breccia” textures and melt clasts in suevite and in impact melt rocks at Rochechouart reflects a

relative inefficiency in homogenizing and mixing at the scale of a hand specimen. The geochemical data suggest that this may also be true at the kilometer scale. The Montoume impact melt rocks reflect the composition of nearby granitoids, leptynite and gneiss.

The Valette and other southwestern (bottom) suevites are characterized by a granitic composition which is consistent with the local target composition dominated by granites. The composition of the Bel-Air (bottom) suevite matches that of the local gneiss. The very small Bel-Air impact melt rock patch is significantly more mafic than local suevite and local gneiss (Figure 40). It is suggested that it incorporates some contribution from a mafic lithology, which is common in this region (see Figure 4).

Such a local source of melt is also advocated for the two green glass clasts extracted from the upper suevite at Chassenon (Figure 29). Their Fe-Mg composition is completely different from that of the host suevite and corresponds to that of the diorites and microdiorite dykes which are both developed in this part of the target. These two clasts are definitely not representative of the overall melt component in the Chassenon suevite as the Fe-Mg correlation field for these rocks would otherwise expand toward the green glass plots on Figure 29. It is not the case. Instead, such a distinct chemical signature of these glass clasts compared to that of the bulk host rocks demonstrates a very local and discrete origin for the glasses in the Chassenon suevite. More generally it suggests melts in the top suevite are not derived from a unique and homogenized melt source.

The Babaudus impact melt rock has a granitic composition, suggesting a major contribution from the nearby leptynites with a minor contribution from the local gneiss. All this suggests a relatively local origin for most impactites in the Rochechouart structure, and especially but not exclusively for the melt-rich

impactites (impact melt rocks and bottom suevite). This further implies that the excavation and readjustment did not mix/or homogenize ejecta at the scale of the Rochechouart crater, a feature that is also observed at other craters such as Bosumtwi (Coney et al., 2010).

The Rochechouart Impactoclastic Deposit

An approximately 1 m thick and few meters wide outcrop of very fine-grained, horizontally multilayered gray rock occurs above suevite in the quarry of Chassenon (Lambert, 1974, 1977b). Contrasting in both color and texture with the local suevite, it superficially resembles an ignimbrite. The material is compact, despite having a tuff-like aspect (Figure 41). The contact between the fine-grained deposit and the underlying suevite is gradational over a several-centimeter-wide transition zone in which centimeter-sized clasts of the suevite are mixed into the fine-grained deposit, which then loses its regular sorting.

The fine-grained horizontal deposit at the top of the Rochechouart impactite sequence strictly complies with the definition of an impactoclastic deposit recently introduced in the impactite nomenclature (Stoffler and Grieve, 2007). The shocked minerals cast no doubt about the relationship of this material to impact. The prominence of mineral debris and the granitic composition of the debris indicate an origin by comminution of the same basement rocks from which suevite and the other impactites at Rochechouart were formed.

Data regarding the original extent and thickness of the impactoclastic deposit are extremely scarce. It is possible that it may have had a 2 to 3 m thickness in the Chassenon quarry before complete extraction. As seen on ancient photographs (Figure 28), the top of the historic Chassenon quarry at the beginning of

the 20th century displayed a ca. 2 m thick formation that is seemingly distinct from the underlying suevite and that displays a faint horizontal stratification. It appears massive and apparently shows curved bedding seemingly intersecting the underlying suevite with a low-angle unconformity (Figure 28).

This fine-grained rock was considered waste and discarded by both the Roman and latter generations of builders in the area who preferred the colorful and textured aspect of suevite for construction.

Individual components of the fine-grained deposit are not recognizable with the naked eye (Figure 41). Image analysis of photomicrographs indicates that 83 vol% of the material comprise unresolved matrix and clasts less than 25 μm in size; only 8 vol% is 50 μm in size or larger (Table 3). Particles identifiable with the optical microscope are mostly mineral debris with a small proportion (< 5 vol%) of lithic debris (Figure 43).

Unlike in suevite, no individual melt clasts could be observed macroscopically, nor among the finest particles (25-50 μm). Rounded glass particles similar to “lapilli” or “microtectites” were also not observed. There is no trace of sediment, and no evidence of diagenesis, in the matrix. The overall porosity is ca 5 %, as measured by image analysis on backscattered electron images. Clasts are mostly angular and consist of quartz, feldspars and micas, corresponding to the main mineralogical components of the target (Figures 43-49).

The matrix is made of the same detrital and porous assembly of microscopic and submicroscopic debris, including extremely thin mica laths (50-200 nm thick and a few micrometers long). Long and very thin mica laths are also common among the largest clasts. The mica clasts commonly display partial delaminating along cleavage and edges perpendicular to the cleavage may be splayed (Figure 17).

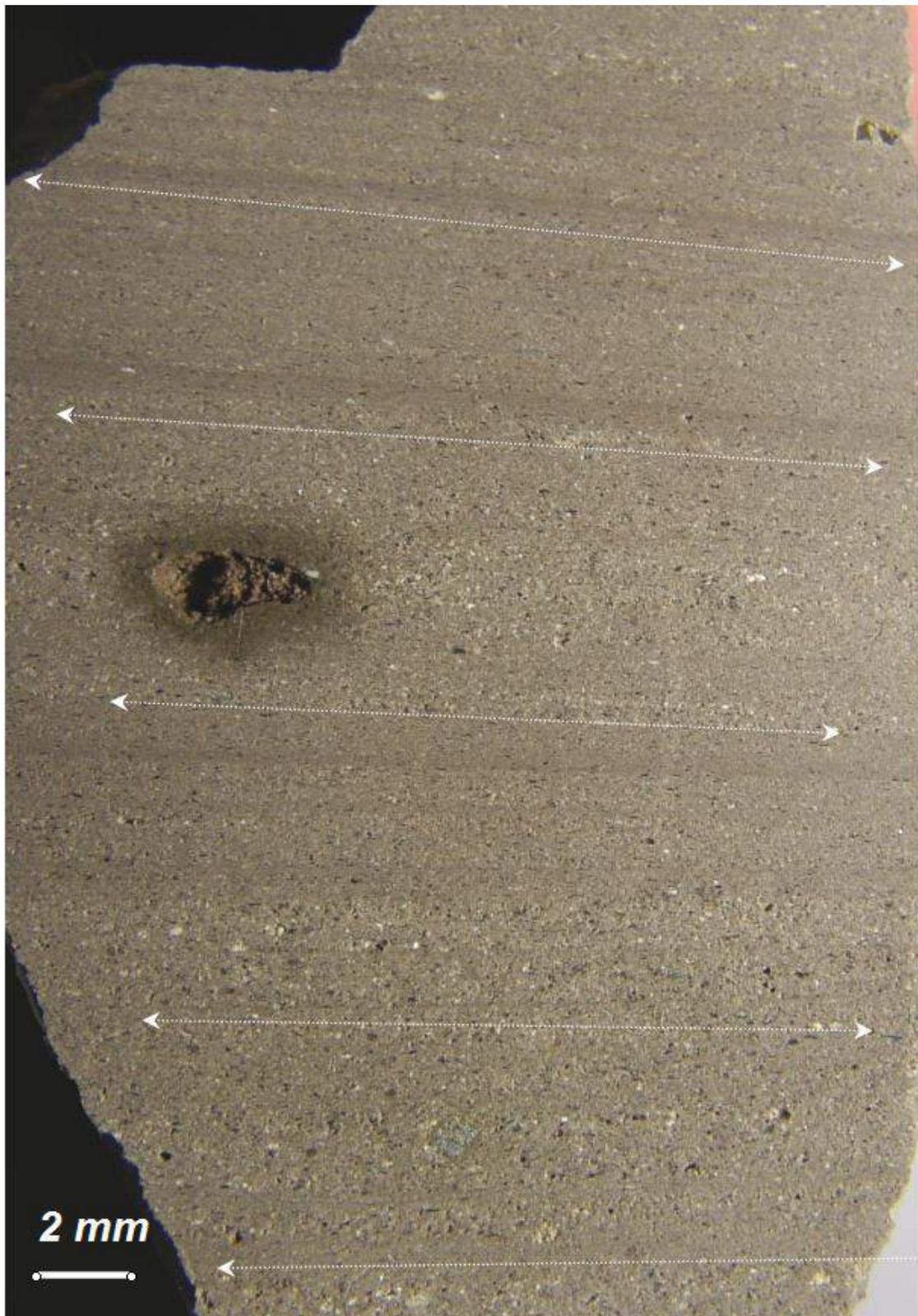


Figure 41: Impactoclastic deposit. The Chassenon fine-grained horizontal deposit sampled at the Arenes quarry at ca 4km of the center of the structure. The material is characterized by a relatively dense and massive texture and extremely regular bedding.

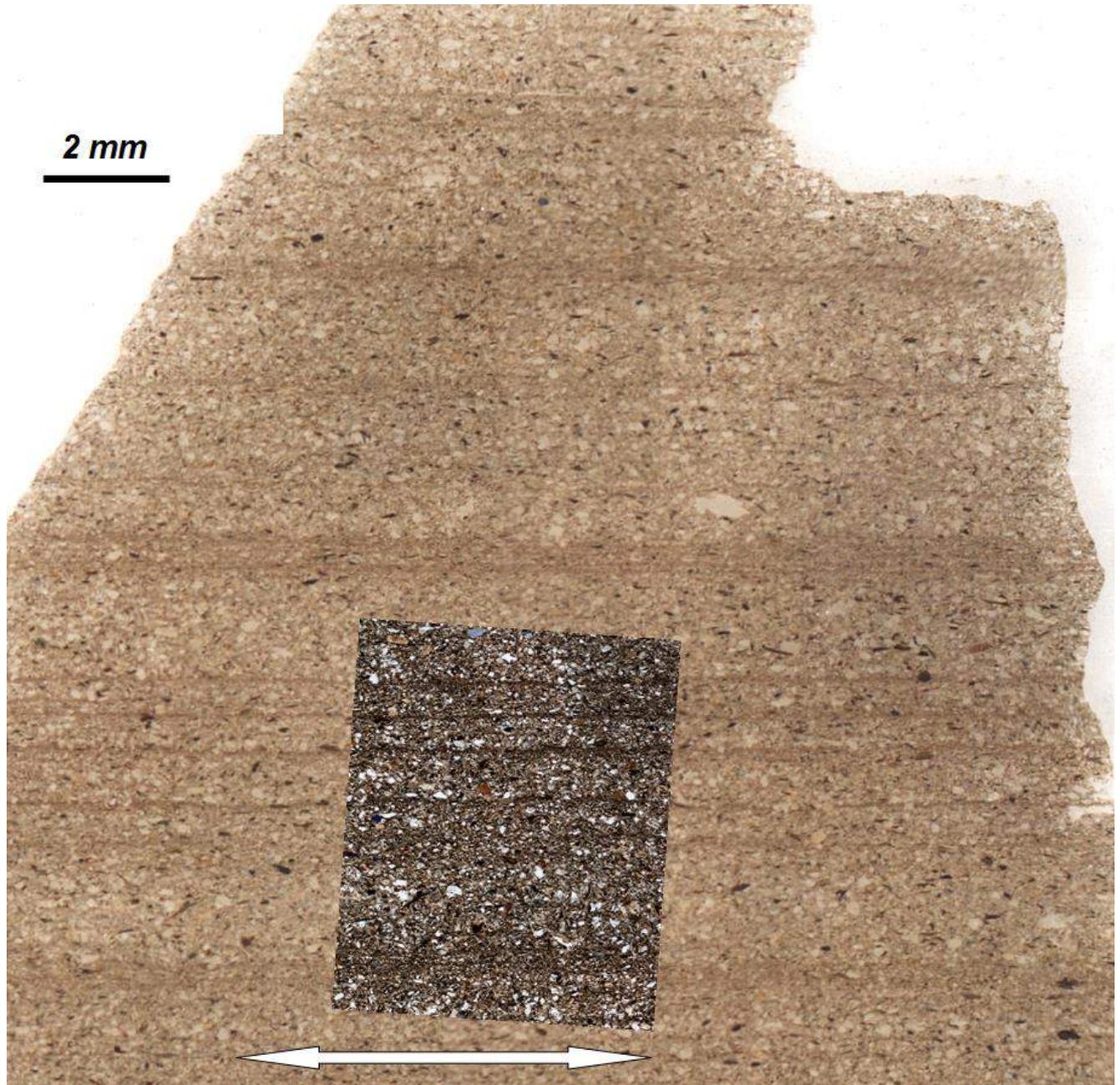


Figure 42: Impactoclastic deposit near Chassenon, 4 km of the center of the structure. Optical view of a thin section under plane polarized light of the sample of the Chassenon fine-grained horizontal deposit seen at Figure 41. Double arrow: Trace of the local horizontal plane at the sampling locality. Insert: crossed polars (see Figure 43). The material is characterized by a relatively dense and massive texture and extremely regular bedding. The stratified aspect is due to slight variation in grain size, porosity and composition (see Figures 43 and 44).

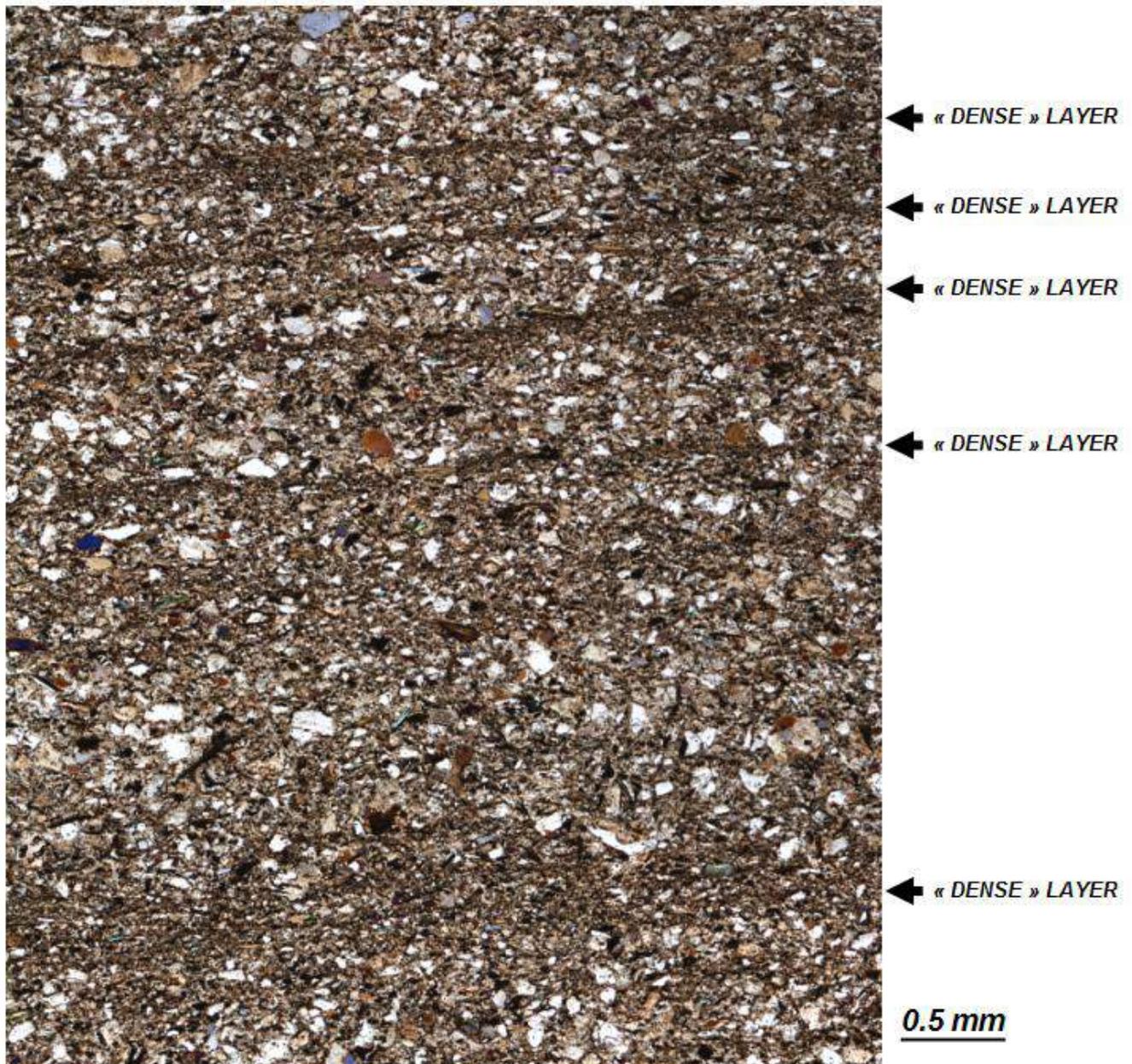


Figure 43: Impactoclastic deposit near Chassenon, 4 km of the center of the structure. Optical view of a thin section under polarized light (crossed polars) of the framed field at Figure 42.

The stratified aspect of the unit reflects slight variations in grain size and composition, and differences in porosity between the layers. The thinnest and darkest layers visible macroscopically have higher proportions of phyllosilicates and a significantly reduced porosity, both in terms of pore size and pore

volume (Figures 42-45). These bands are 10 μm to a few tens of micrometers thick. The layering is extremely planar at the micro-scale; however, it curves slightly and branches at the decimeter to meter scale (Figure 41). On average, it is horizontal.

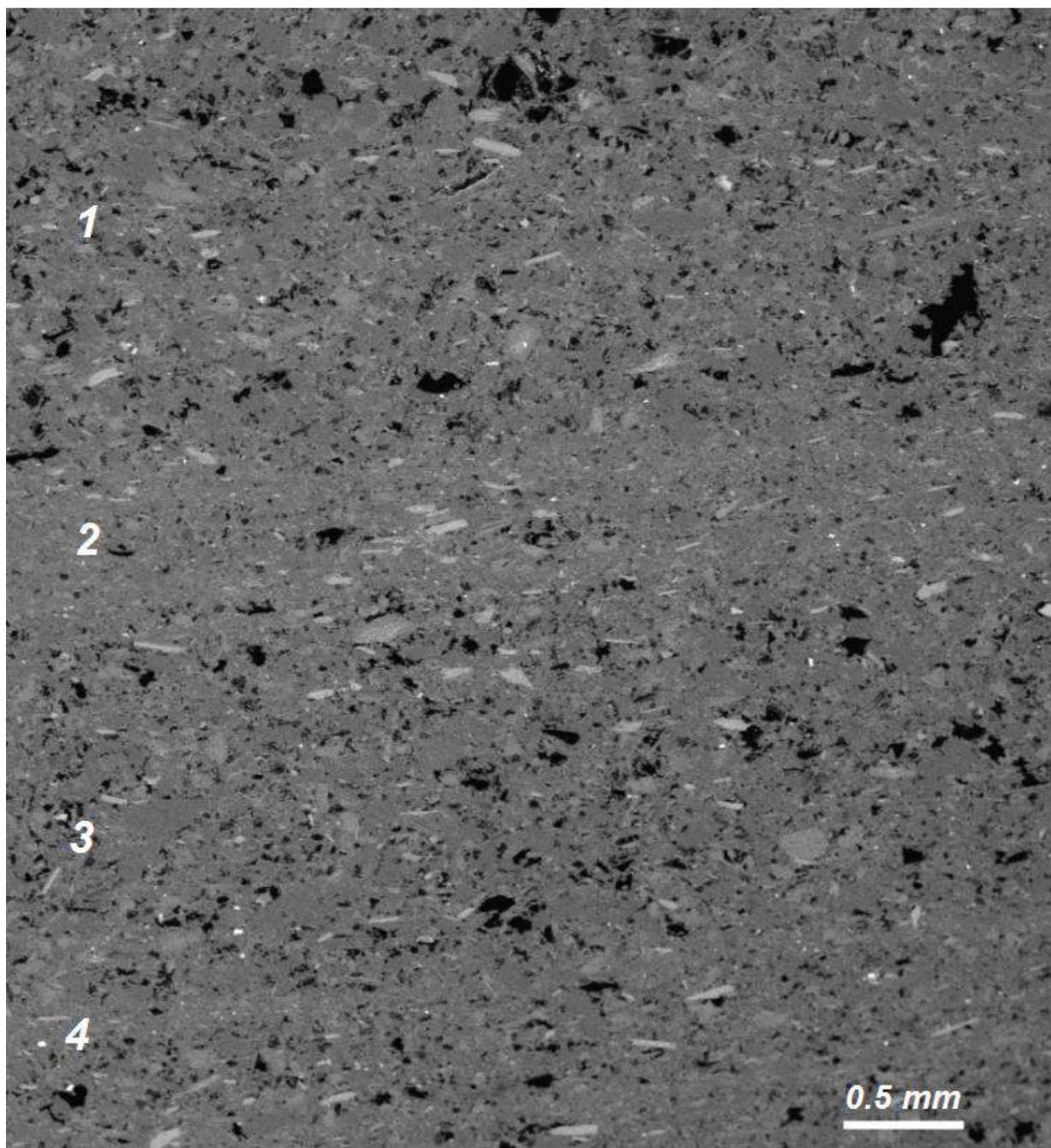


Figure 44: Impactoclastic deposit near Chassenon, 4 km of the center of the structure. SEM view (back scattered electron image) of the double polished thin section seen under polarized light at Figures 42-43 (same orientation). Note the preferred orientation of mica (lighter mineral). 1-4 sequence of alternating dense and porous layers (see detail at Figure 45).

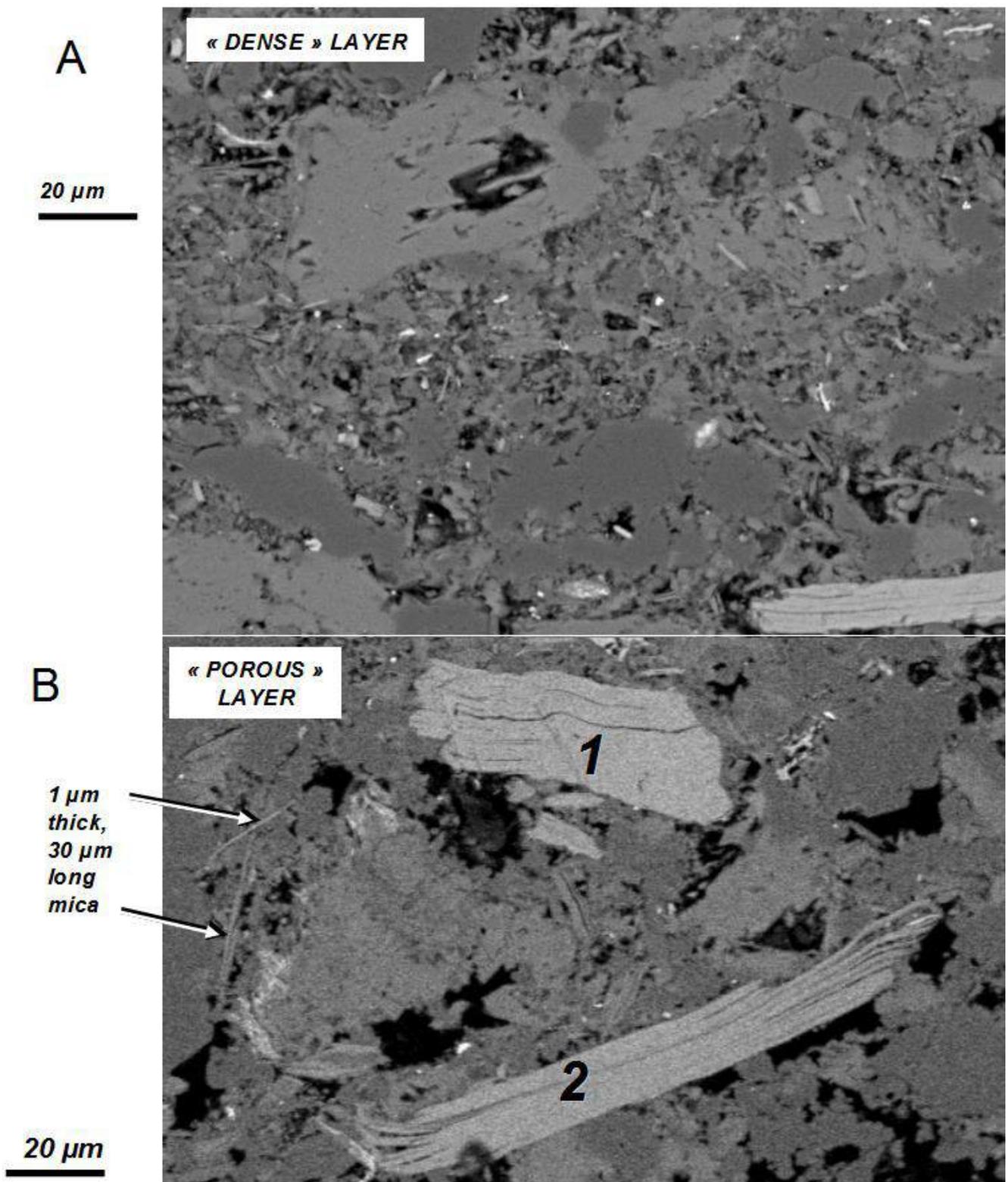


Figure 45: Impactoclastic deposit near Chassenon, 4 km of the center of the structure. Detail of the double polished section of a sample of the Chassenon fine-grained horizontal deposit seen under the SEM (back scattered electron image). A: Dense and fine particle layer (denoted 2 and 4 in Figure 43); B: Coarser layer (denoted 1 and 3 in Figure 44). Note the deformation (kinking (1)) and the splays at the end of large mica flakes (2).

The microscopic mineral debris and rock clasts display a wide range of shock metamorphic grades. Decorated planar microdeformation features in quartz and feldspars (Figures 46-47) and partial melting

and decomposition lithic debris are observed (Figures 48). Tiny automorphous crystals of quartz and feldspars 5-20 μm wide are common and decorate the pore spaces (Figures 48-49).

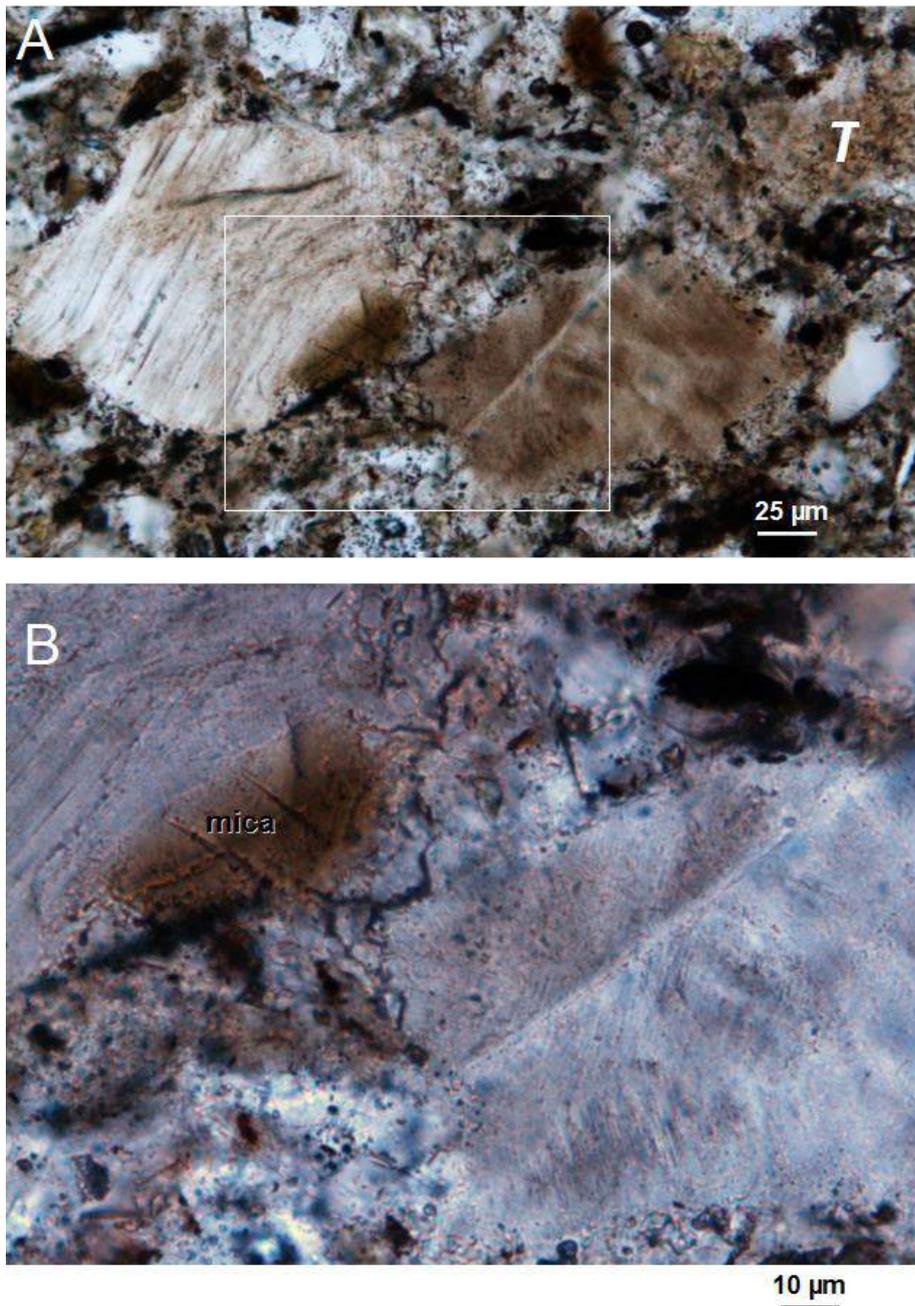


Figure 46: Petrographic details seen by optical microscope in plane polarized light of a double-polished thin section of a sample of the Chassenon impactoclastic deposit. Quartz clasts displaying a high density of planar deformation features. T: toasted quartz. Rectangle in A: field of view B.

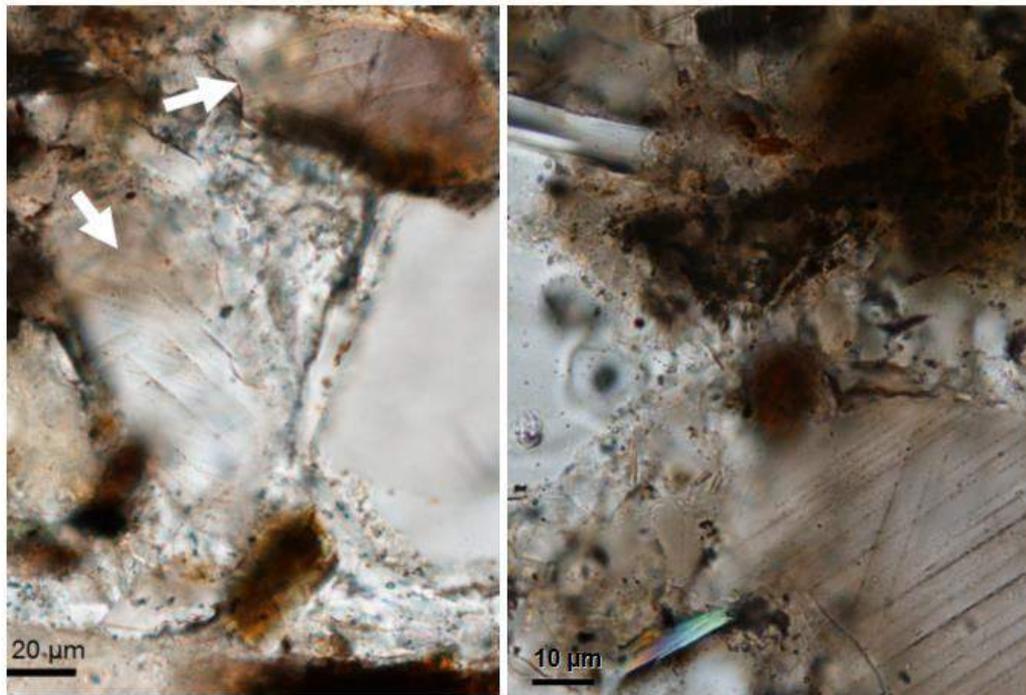


Figure 47:
Petrographic details seen by optical microscope in plane polarized light of a double-polished thin section of a sample of the Chassenon impactoclastic deposit. Quartz clasts displaying decorated planar deformation features.

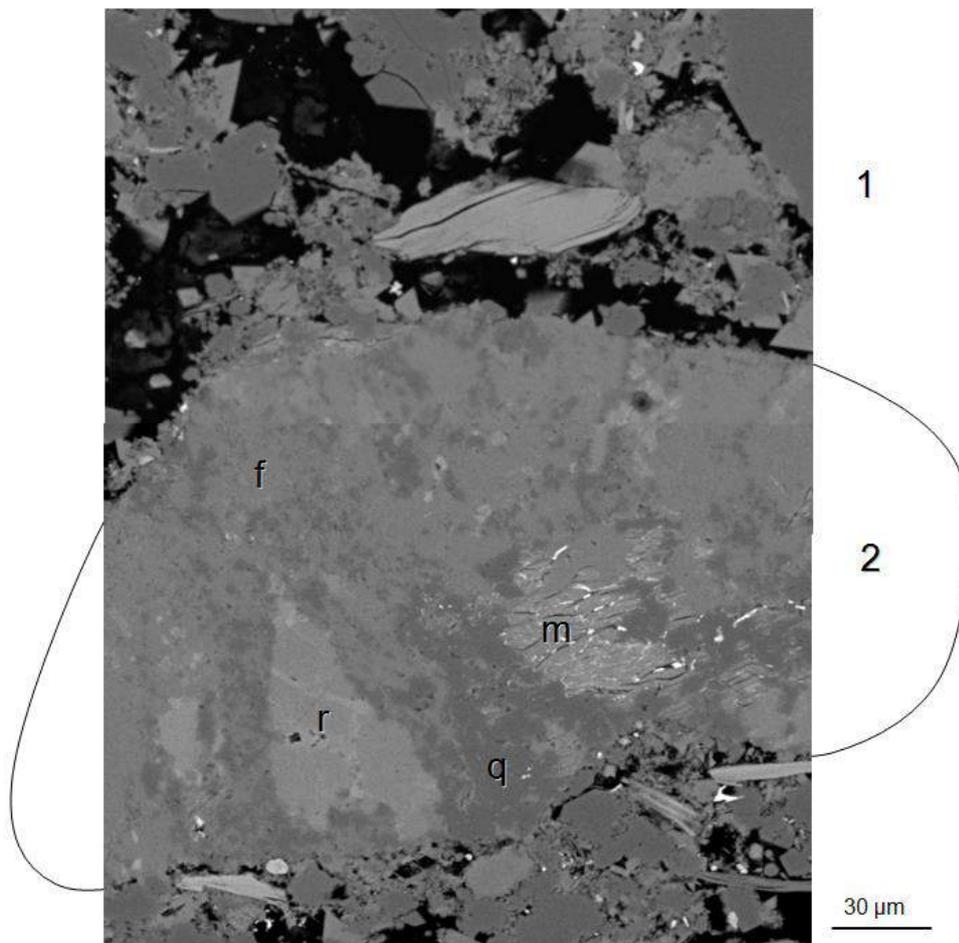


Figure 48:
Impactoclastic deposit. Detail of the double polished section of a sample of the Chassenon fine-grained horizontal deposit seen under the SEM (back scattered electron image). 1-Highly porous zone with abundant new born tectosilicate cristalites characterized by well developed crystal faces. 2- Lithic clast of granitic composition almost completely molten but not homogenized, with relicts of the original lithic material (r), relict of mica (m) in a matrix made of a diffuse assembly of quartz and feldspar (q and f).

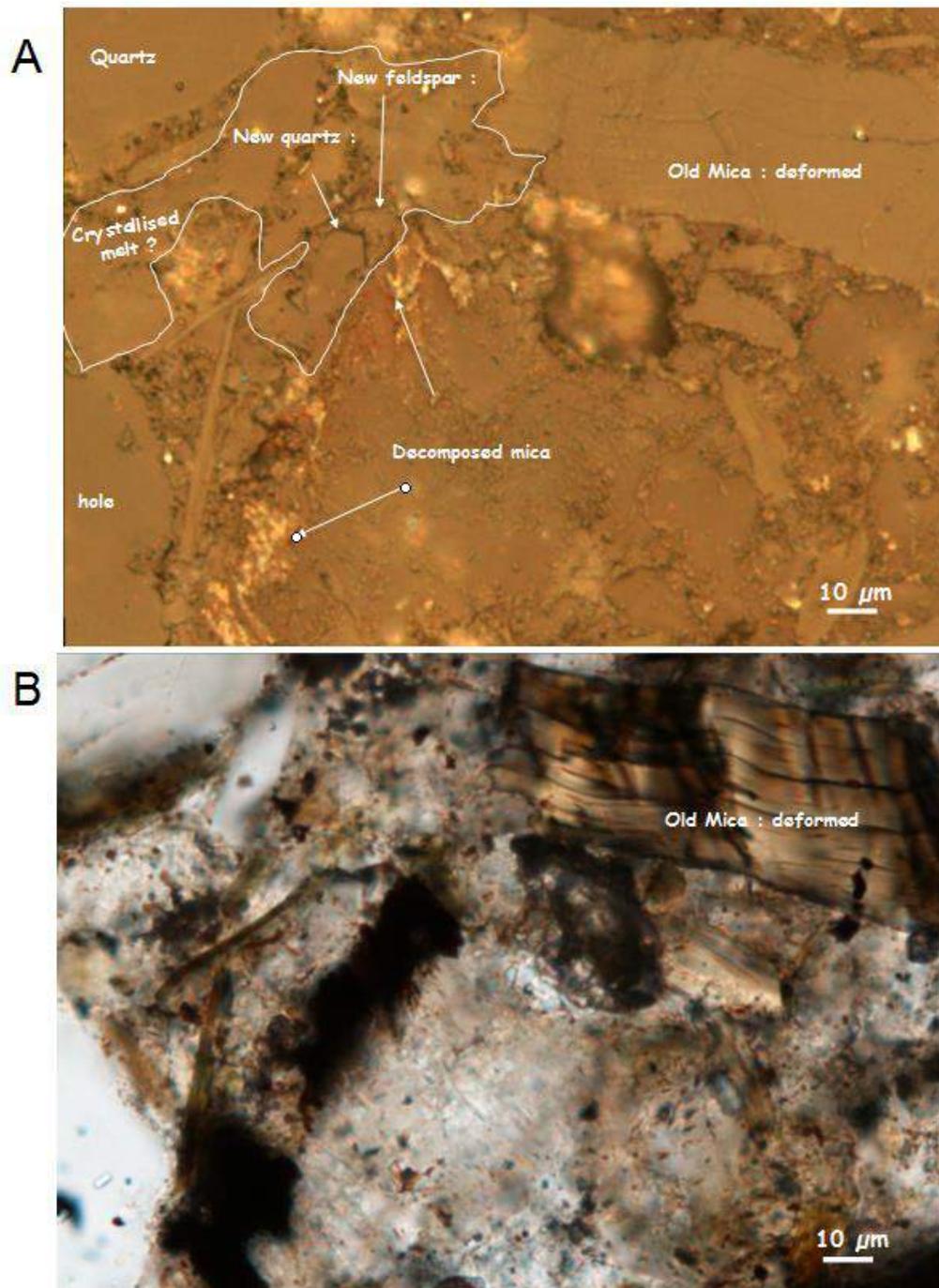


Figure 49: Petrographic details of the same field seen by optical microscope in reflected light (A) and in transmitted light (B- crossed polars) of a double-polished thin section of a sample of the Chassenon impactoclastic deposit. The framed area in A is mainly formed of a new generation of tiny crystals as deduced by clean extinction and automorphous crystal shapes.

Both thermal decomposition (Figure 49) and congruent melting of mica are observed. The later results in a highly vesicular opaque froth invading local porespace and intragranular

fractures in neighbouring tectosilicates (Figure 50). A significant proportion (20-40 %) of micas is affected by these thermal effects.

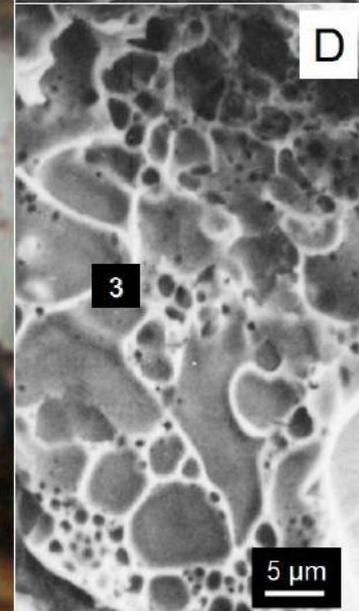
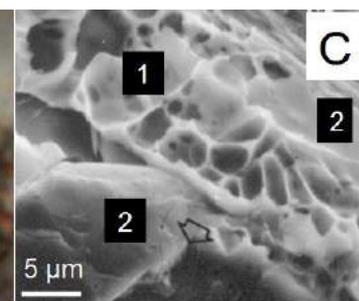
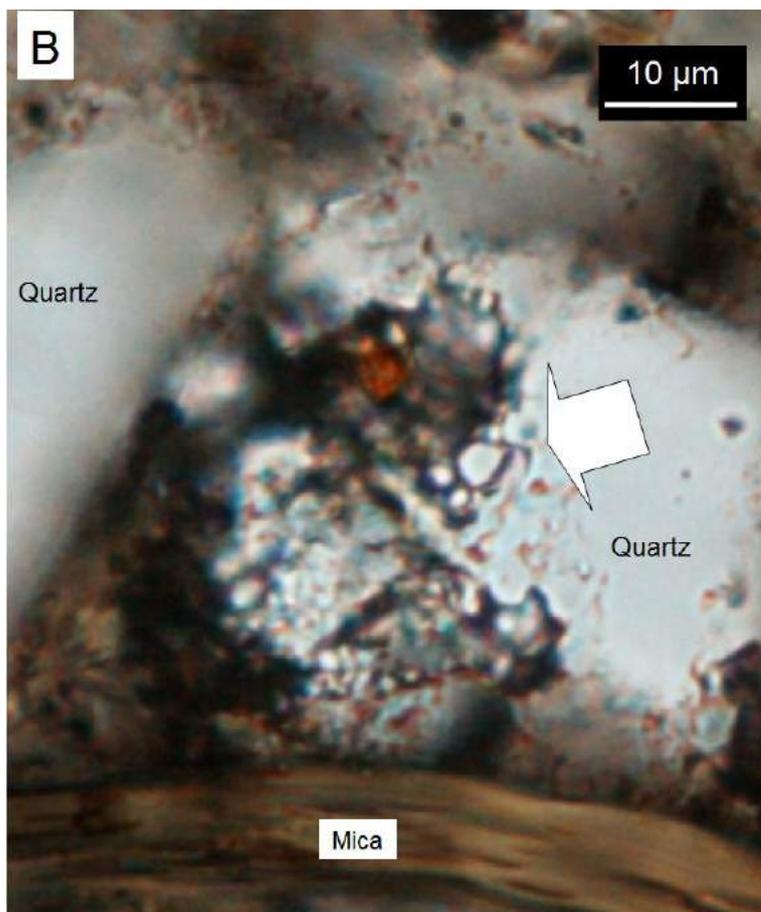
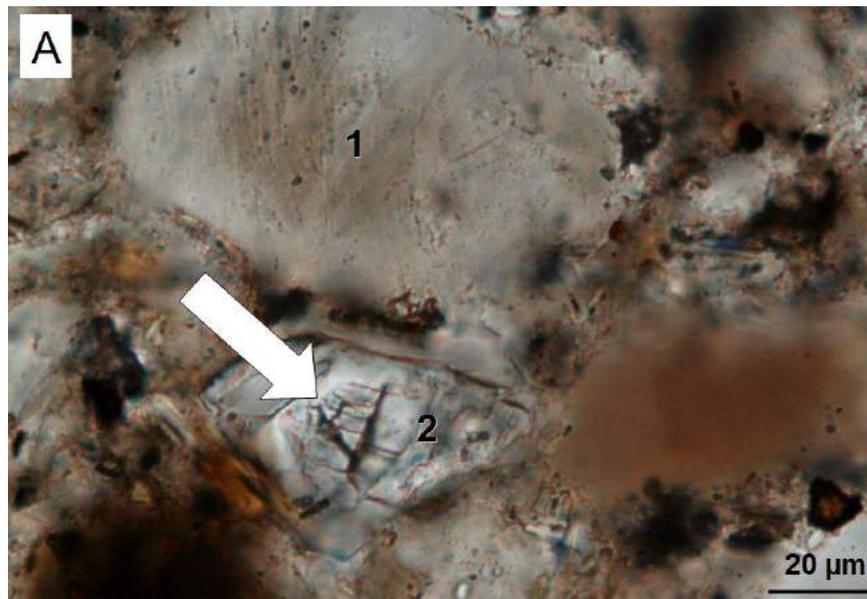


Figure 50: A-B: Detail, in the optical microscope, partially crossed polarizers, of a double-polished thin section of a sample of the Chassenon impactoclastic deposit. Arrow: black glass decorating intragranular fractures in quartz displaying flat vesicles when the fracture is seen in the plane of focus of the microscope; C-D: SEM view of a Rochechouart gneiss experimentally shocked at 35 GPa displaying highly vesicular devolatilized mica glass (1), diaplectic quartz (2) and froth of devolatilized mica glass (3) decorating the surface of a joint and an intragranular fracture in quartz after congruent melting of mica, flow and injection of the melt into local porespace driven by the expansions of volatile in the mica liquid upon pressure release (Lambert and Mackinnon, 1984).

Despite evidence for strong shock deformation in some clasts, most show no shock damage and the average shock level is relatively low (shock stage 0 and 1b).

No evidence of carbonate crystal is observed.

The major element composition of the fine-grained clastic deposit is intermediate between that of the granite and the gneiss. On the Fe-Mg diagram, it matches the composition of the average target (Figure 29). Like the other impact formations, the K_2O/Na_2O and the K_2O/CaO ratios of the fine-grained deposits are significantly increased compared to that of the target rocks. The values are similar to those of the impact melt rocks (Table 2).

Physical evidence for a fine-grained impact fallback layer at other impact structures remains rare. Such a layer has only been reported to date from drilling (core LB-5B) at the interface between impact breccia and post-impact sediments in the 10.5 km, 1.07 Ma old Bosumtwi crater (Ghana) (Koeberl et al., 2007b) and from the post-impact resurge sediment at Chesapeake Bay (Reimold et al., 2009, in press). The Bosumtwi layer comprises a large proportion of melted and highly shocked material, whereas the Chesapeake Bay layer comprises a very large proportion of sedimentary material mixed with a subordinate amount of impact-related debris during the post-impact tsunami stage of this shallow-marine impact. Unlike the reported 30 cm thick fine-grained layer in Bosumtwi core LB-5B containing accretionary lapilli and microtectite-like spherules, there is no evidence of such features in the Rochechouart impactoclastic deposit.

Interpretation and implications: Any mechanism proposed for the origin of the Rochechouart impactoclastic deposit must thus explain the comminuted nature of the impactoclastites, the prominence of overall relative weak shock levels, the absence of melt clasts and the welding.

The welding and the relative abundance of thermal alteration of micas suggest the impactoclastic deposit is not cold despite the absence of melt particles and was possibly emplaced at a relatively high temperature near thermal decomposition of micas.

The remarkable thinness and regularity of the stratification of the Rochechouart impactoclastic deposit constrain the conditions of final deposition to a calm environment. This and the horizontal setting indicate it took place after the crater adjustment had been completed, and turbulent mixing in the underlying impactites had ceased. The texture and the fragility of the extremely small and thin mica laths (as seen in Figure 45) compares to that of glass shards in pyroclastic deposits. With the exception of a lack of a glass mesostasis, all the textural characteristics of the impactoclastic deposit match those of ignimbrite supporting the interpretation it is depositing in the atmosphere. The discontinuity between the impactoclastic deposit and the suevite indicates the fine debris forming the impactoclastic deposit travelled in suspension significantly longer than the coarser glass and lithic debris forming the underlying suevite and, thus, that they were deposited separately. Yet the time hiatus must have been extremely brief compared to the time needed to erode the underlying impactites, implying the underlying sequence of deposits is complete at this particular location (Chassenon).

Impactoclastic Intercalations (dikes) in suevite

In addition to the stratified though massive impactoclastic deposit, distinct dikes occur that intersect, or are intercalated within, the uppermost section of the massive suevite deposit. The fine structure, better resolved under the optical microscope, appears more complex and multilayered than that of the material described in the previous section, and

there are some layers that contain small glass particles.

A steeply-dipping dike, tapering from ca. 1 m wide at the top of a ca. 1.5 m high wall in the historical Chassenon suevite quarry to ca. 0.5 m at the base merges into the fine-grained horizontal deposit overlying the suevite before over a transition zone of about 10 centimeters width (Lambert, 1974).

A similar dike is exposed 800 m from Chassenon at Longeas in the active archaeological excavation next to the Roman Baths. The irregular dike of ca. 50 cm width cuts through suevite (Figure 51) with a vertical to steep dip, but the attitude below the current level of exposure requires further attention (providing digging is permitted).



Figure 51: Field view of a 50 centimeter wide multi-layer impactoclastic dike in suevite near Longeas near the top of the Chassenon suevite deposit, at ca 4km of the center of the structure .

Another site is located ca 400 meters south in the remnant of opposite walls of two ancient quarries abandoned since the 4th century. Several 10 to 30 cm wide, subparallel and apparently low-angle intercalations appear there interbedded with faintly layered suevite.

The intercalations and dikes display similar characteristic features. The fine-grained texture contrasts with the breccia texture of the host suevite, and the multi-layered texture is distinct from that of the horizontal deposit described before. The characteristics are illustrated in Figure 52, which shows the

macroscopic view of a cross-section cut from one of these intercalations. The cross-section is perpendicular to the contact with the suevite. The texture is significantly different from that of the host suevite deposit. Three main “layers” are visible that are each a few centimeters wide (Figure 52).

Layer 1 at the contact with the suevite is characterized by a fine-grained flow-banded texture. It is not a breccia. It is similar in color, texture and grain size variation to the fine-grained horizontal deposit described before. This material is formed from the same mineral

debris that displays the same range of shock features as that forming the fine-grained horizontal deposit described before. Only a single glass clast was observed in layer 1 (Figure 52). The morphometric characteristics of particles as measured by image analysis (top left at Figure 52) compare to those of the particles observed in the fine-grained

horizontal deposit (Table 3). The population of objects 50 μm long and larger accounts again for 12 vol% of the material. The average diameter of particles is less than 50 μm . Particles > 0.3 mm form 0.4 vol% and no particle larger than ca. 500 μm was observed (Table 3).

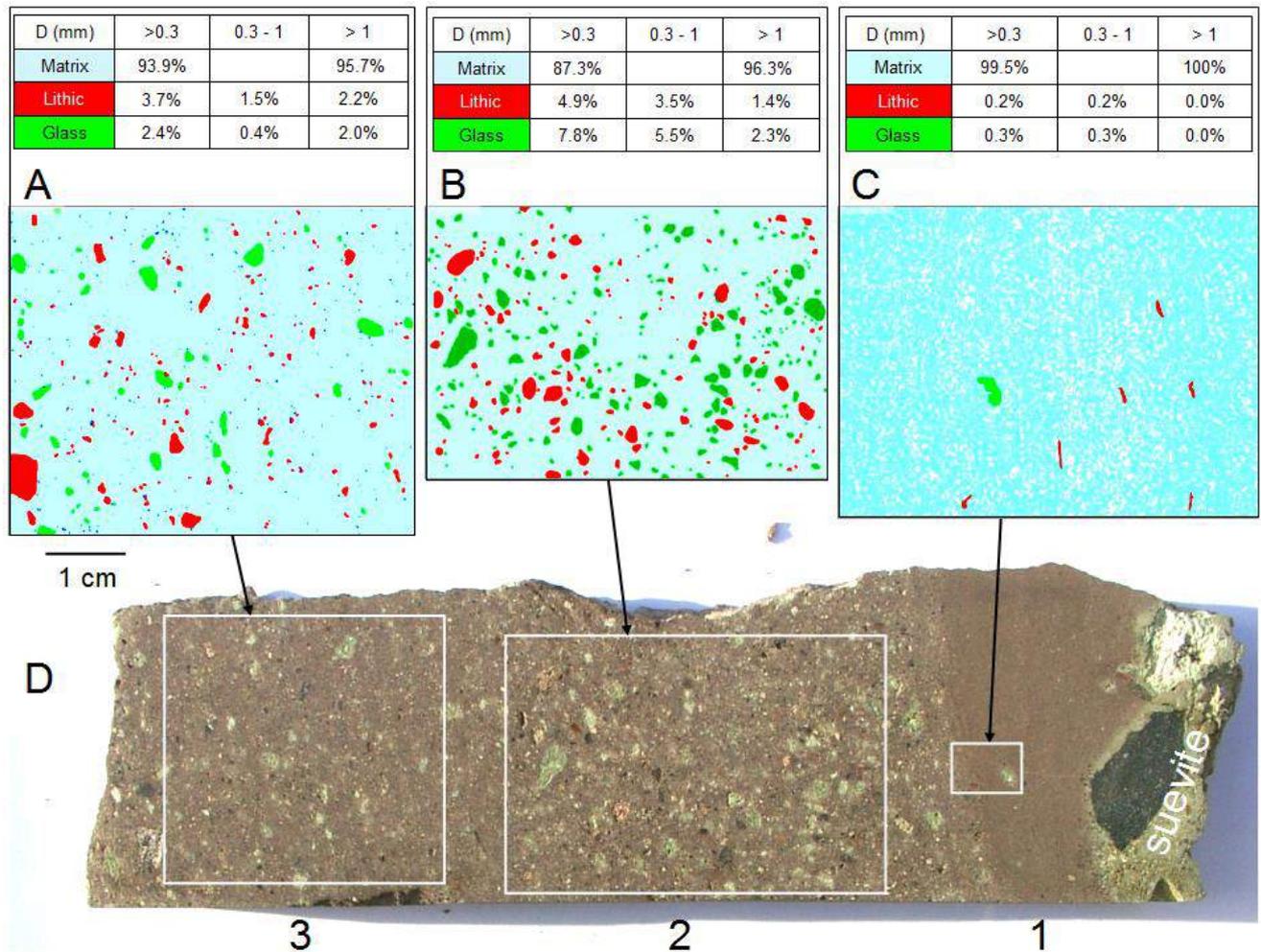


Figure 52: Impactoclastic dike. Fine-grained intercalation at the top of the Chassenon suevite deposit, at ca 4km of the center of the structure. A-C: Segmented false color images distinguishing different phases of the framed areas on a polished slab (D) and related tabulated values of relative proportions of the phases according to modal and granulometric measurements by image analysis. Red phases: Lithic clasts. Green phases: Glass. Light blue: Matrix. White phases (view C): Clasts < 0.3 mm in diameter. D: Macroscopic view of half section cut perpendicular to the wall of one of the 25 cm thick multi-layer impactoclastic intercalations in suevite near Longeas. Layer 1 is characterized by a fine-grained and flow-banded texture. It is similar in color, texture and granulometry to the fine-grained horizontal deposit. Only one glass particle was observed in this layer. Layer 2: Bearing green glass clasts, it resembles the surrounding suevite except for the grains sizes which are much smaller. Layer 3: Same texture as layer 2 but with a smaller proportion of glass clasts. Note the gradual transition between the 3 layers and suevite (on the right).

As observed for the fine-grained horizontal deposit, layer 1 is characterized by a microscopic layering related to sorting and preferred orientation of mineral debris; however, the layering is neither regular nor planar - it displays undulations and vortex-like features (Figure 53). The contact between layer

1 and the suevite is characterized by a 10 mm wide transition zone with clear evidence of turbulent flow, as shown by the loss of the regular banded texture that characterize layer 1 and by the deformation of centimeter-sized melt clasts in the neighboring suevite (Figure 53).

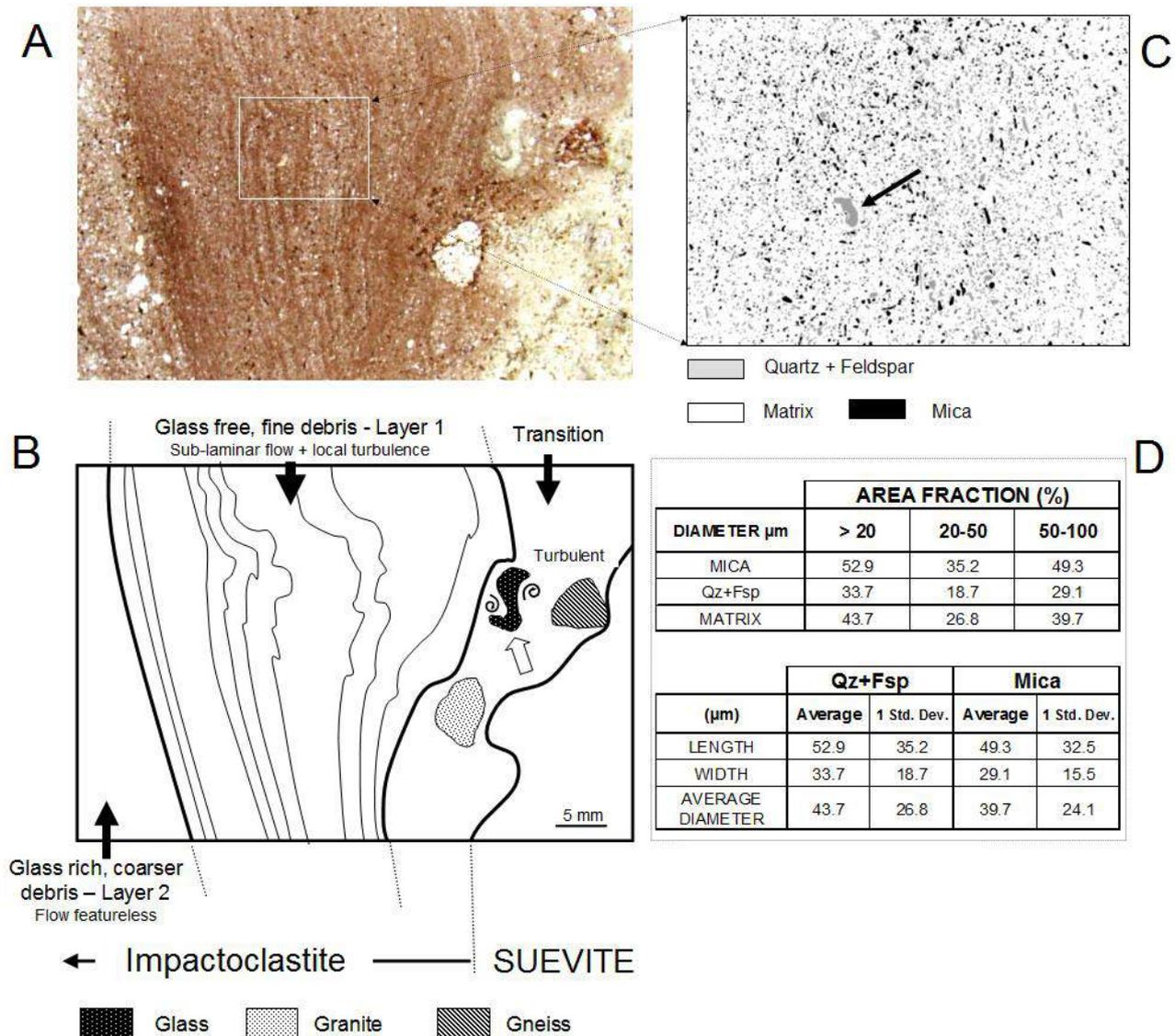


Figure 53: Impactoclastite dike at the top of the Chassenon suevite deposit, at ca 4km of the center of the structure. Detail of Layer 1 in Figure 52. A: Macroscopic view showing a transitional zone with evidence of turbulent flow at the contact with suevite (curving of the fine mica layers of the fine-grained material and deformation of the centimeter sized glass clasts in the neighboring suevite (open arrow: "S" shaped double vortex). B: Detail of the framed area in A. Undulations of the fine grained layer signify flow perturbation. C: Segmented false color image distinguishing different phases of the framed area on view A. Arrow: "large" elongated and contorted clast of green vesicular glass. D: Morphometric data and volume % of the various phases according to modal analysis and granulometric measurements by image analysis, for the population of clasts > 15 μm long.

This fine-grained layer 1 grades into layer 2, which is characterized by a distinct granulometry and texture (Figure 52). Unlike layer 1, there is no or little banding in layer 2. Approximately 13 vol% is made of particles > 0.3 mm, i.e., 40 times more than in layer 1 (Figure 52). Unlike layer 1, this layer meets the textural characteristics of a breccia (more specifically a micro-breccia owing to the granulometry). It is constituted of clasts embedded in the same fine-grained material as that constituting layer 1. Bearing granitic lithic clasts and green glass clasts (altered), it resembles the surrounding suevite except for the clast granulometry. In both Rochechouart suevite and polymict lithic impact breccias, the particles 1 mm in diameter and larger represent, on average, 50 vol% or more (Table 3). In layer 2 they account for only 4 vol% and no particles larger than 5 mm are present, whereas they represent about 30 vol% in the suevite and other impact breccias in the Rochechouart structure (Table 3).

Green glass clasts account for two-thirds of the particles larger than 0.3 mm in layer 2. Besides color, these melt particles display the same petrographic characteristics and the same composition as those observed in the surrounding suevite. The lithic clasts in layer 2 display the same type and the same variety of shock metamorphic features as the lithic clasts in the surrounding suevite.

Layer 2 grades into the layer 3 which, like layer 2, shows little evidence of flow banding. It also has a micro-breccia texture and shares the same clastic matrix with layer 2. The proportion of clasts > 1 mm is the same as in layer 2 (4 vol%) (Table 3). The proportion of clasts > 5 mm is about half that measured in layer 2 (6 vol%) (Table 3). The glass clasts in layer 3 are significantly less abundant than in layer 2 as seen in Figure 52. Glass clasts over 0.3 mm in size represent only 2.4 vol% of the material in layer 3, whereas they account for 7.8 vol% of layer 2 (Figure 52).

Interpretation and implications: The similarities in texture and composition between the impactoclastic deposit and the glass-free layer 1 in the fine-grained multilayered dikes and intercalations with the Chassenon suevite indicate that they are genetically related. The glass-bearing layers 2 and 3 are texturally intermediate between suevite and the sediment-like impactoclastic deposit. The main difference is that the grain size values are an order of magnitude smaller in the glass-bearing layers compared to suevite. This feature is common to both the fine-grained horizontal deposit and the multilayered fine-grained intercalations, which supports the proposal that they are members of a single family where the dominant characteristic is the prominence of comminuted target debris and the fine grain size (Lambert and Reimold, 2009), with two members, the impactoclastic deposit and the impactoclastic dikes (and other intercalations of melt-bearing impactoclastic material).

The undulation of the fine bedding in the fine-grained, glass-free layers in the impactoclastic dikes and the disturbances along the contact with the host suevite suggest the material in the dike flowed very rapidly (sublaminar flow).

Owing to the highly turbulent and energetic conditions of deposition of the allochthonous breccia formations and to the large concentration of solid debris that acts like abrasives, it could be argued that the dikes and the fine-grained character of the impactoclastites relate to mechanical grinding within the suevite at the time of deposition. This might happen rather deep inside the deposit, possibly toward or at the bottom of the suevite as confinement is required to produce the grinding.

Indeed, deep and close to the center of the crater, the deposits remaining in the crater may have experienced a complex history starting with outward and turbulent high-velocity flow during the latter stage of transient cavity

growth, followed by a further impetus either in the same direction (toward the rim) because of the central uplifting of the bottom of the crater, or in the opposite direction because of the collapse of the rim.

These complex movements amount to mega-landslides which could be responsible for major shearing, grinding and compaction leading to the observed fine-grained material in the Rochechouart suevite. The undulating and striated surfaces at the interface between Bunte Breccia and suevite in the Ries crater reflect such an abrasive character. If such a scenario appears consistent with i) the observed field setting (dike and low-angle intercalations of impactoclastites in the suevite) and ii) the fine-grained character of the rocks, it seems incompatible with: a) the fine and regular layering of the ignimbrite-like deposit at the top of the sequence, which rather suggests an aerial deposit, b) a setting at the top of the deposit sequence (see ensuing discussion), and c) the shape of the debris particles which display an increased aspect ratio (elongation) and an increased sharpness of edges compared to the debris in the host suevite. Whilst confined grinding and shearing could considerably reduce the size of the clasts, it

would also significantly reduce angularity. This is the inverse of what is observed in the impactoclastic deposits at Rochechouart.

Morphometrical characteristics of the Rochechouart crater and of its deposits

Crater floor morphology.

The wide access to the crater floor at Rochechouart clearly establishes that Rochechouart belongs to the category of flat floored readjusted crater. The most distinctive feature of the crater floor is the irregularity at the decameter scale and regularity at larger scales. Variations in elevation of the crater floor over the 15 km wide central zone are limited to +/-50 m relative to the horizontal when corrected for the 0.6° dip. In that context the faint 50 m high central raise only observed along a specific N-S traverse **is definitely not a conclusive signature of a central uplift**. The Rochechouart crater is definitely characterized by a large flat floored central cavity at least 15 km in diameter.

Feature	El'gygytyn		Ries	
	Obs.	Model	Obs.	Model
Sediment thickness (m)	0	0	470–750	660
Rim-to-rim diameter (km)	18 ¹	19	?	20
Pre-impact surface diameter (km)	~15	16.8	?	17
Diameter of largest-offset concentric fault (km)	?	16	~22 ²	17.5
Apparent diameter (km)	31–32 ⁴	–	26 ⁵	–
Transient crater diameter (km)	–	11	–	11.3
Rim height (m)	142 ¹	175	?	176
Apparent depth ⁶ (m)	650	800	480–530	800
Gravity anomaly diameter (km)	18 ⁷	–	20–22 ⁸	–

Table 5: Summary of comparative dimensions of El'gygytyn, Ries given by Collins et al., 2008.

¹At current level of erosion.

²Estimate based on depression of basement and major fault at Thalmühle (Collins et al. 2008).

⁴Diameter of outer rim: semi-continuous ring with ~14 m topographic relief (Gurov et al. 2007).

⁶Depth from current surface to top of syn-impact crater fill.

⁷Dabija and Feldman (1982).

⁸Pohl et al. (1977).

Such a flat central zone is not unique to Rochechouart; it is also observed at other craters of similar size developed in crystalline basement or mixed sedimentary-crystalline basement targets. The interpretative cross-section of El'gygytgyn based on geologic observation and seismic survey given by Collins et al. (2008) and reported in Table 5, shows a flat 8 km diameter central zone where the relative variations of the crater floor are the same order as at Rochechouart, followed by a 5 km wide 650 m high wall (depth from current surface to top on syn-impact crater fill given in Collins et al., 2008) before reaching the position of the current erosional rim that possibly correspond the peak ring. A "weakly expressed" outer concentric ring with an average relief of 14 m is present at a radial distance of 15.5–16 km, although it is not clear what this represents and if this is a primary impact-generated feature (Gurov et al. 2007).

Similarly, the central part of the Ries crater seems to be characterized by a flat contact between the impactite deposits and the basement rocks. The cross sections based on geologic observations, drilling and geophysical surveys at Ries (see references in Collins et al., 2008) suggest an inner 6 km diameter central zone where the contact elevation remains within a +/-50 m bracket, followed by the 3-3.5 km wide 480-530 m high wall before reaching the position of the inner crystalline rim.

Size of the original Rochechouart crater

As seen Figure 9, the outer limit of possible impact effects occurs at ca 15 km west of the center of the structure (Lambert, 1977a). Although the field evidence at this site is not unequivocally impact-related and could be related to pre-impact tectonics of Variscan age, it also matches the limited and preliminary geophysical data available on the Rochechouart

structure, which place the outer limit of a small negative gravity anomaly at the position of these cataclastic rocks (Pohl et al., 1978). The 23-24 km diameter value for the Rochechouart impact reported in the literature and in the terrestrial impact crater data bases corresponds to this outer limit and relates to the size of the structure as exposed today; it does not necessarily constrain the size of the initial crater immediately after impact.

The best available field data set for estimating the original size of the Rochechouart final crater is the profile of the crater floor in the 15 km diameter inner zone and the fact that the flat central depression of the crater extends as far as the position of the Cheronnac drilling, 10 km from the center of the crater. To get to the position of the rim (and thus to the estimate of the original crater size), one must add to the diameter of the flat central depression, the lateral width of the wall of the depression. Crater profile data such as at the 9.5 km Deep Bay, which is one of the deepest and steepest readjusted craters on Earth, indicate 2 km is the strict minimum for the radial width of the wall of crater. This sets at 24 km the most conservative value for the estimate of the diameter of the final crater at Rochechouart immediately after impact.

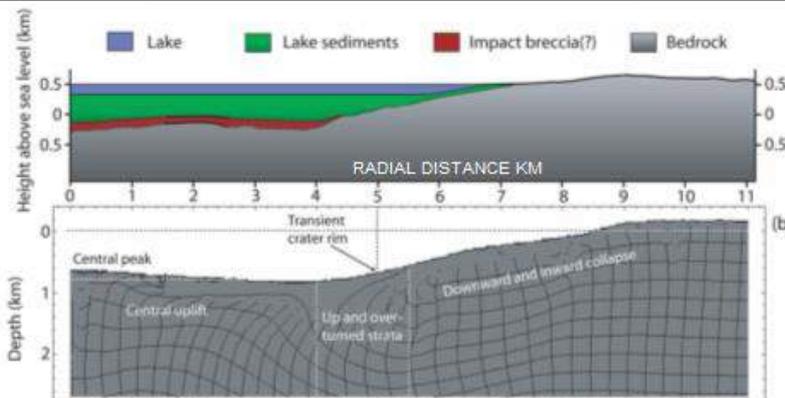
More likely the wall of the original crater at Rochechouart was not as steep as at Deep Bay and comparison with larger structures also developed (or mainly developed) in basement rocks, such as Ries and El'gygytgyn, are more appropriate (Figure 54). Providing that the profile of the crater floors at Ries and Elgygytgyn are reliable, the comparison with Rochechouart implies that the final crater diameter at Rochechouart was in the **40-50 km** range rather than 20-25 km. This is because the diameter of the central flat floored cavity at Rochechouart is approximately twice larger than at Ries and El'gygytgyn.

EL' GYGYTGYN

(Collins et al, 2008)

FIELD BASED DATA

MODEL DATA



RIES

(Collins et al, 2008)

FIELD BASED DATA

MODEL DATA

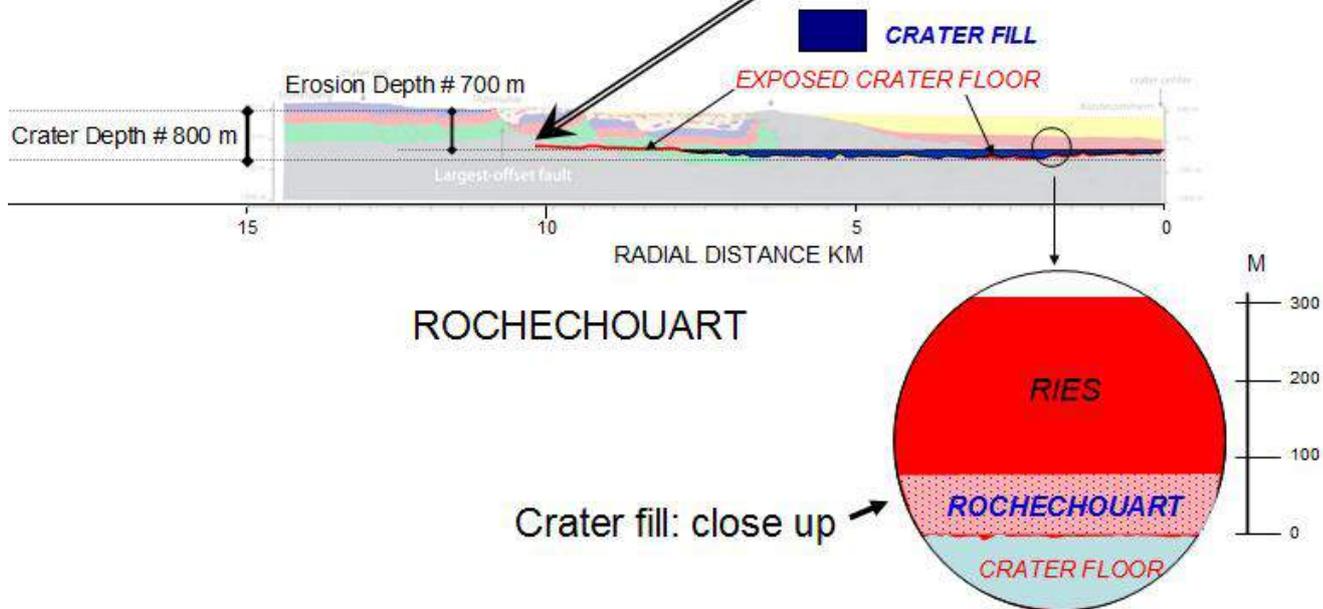
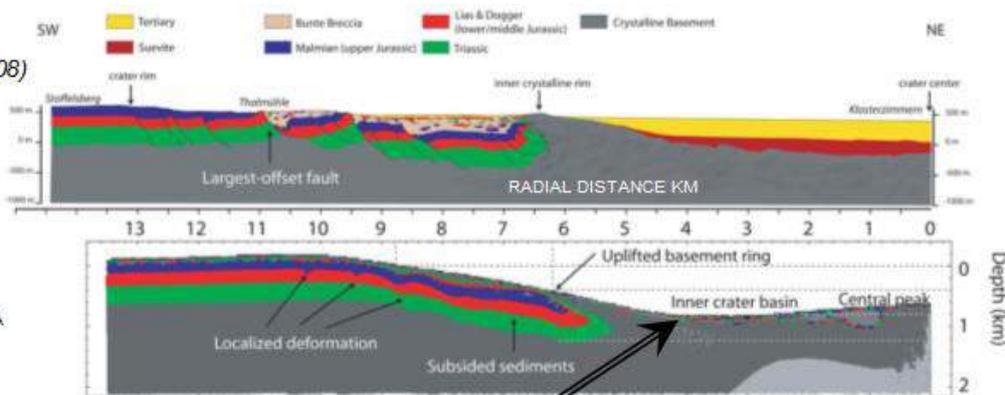


Figure 54: Comparative crosssections of El'gytgyin, Ries and Rochechouart (data from Collins et al., 2008, Lambert, 1977a, 2010)

Target Composition

Although one clast of carbonate has been reported in a polymict lithic breccia from Rochechouart (Sapers et al. 2009), a significant contribution to the Rochechouart impactites from sedimentary rocks, especially from carbonates, seems unlikely, as:

1) The late Triassic-early Jurassic sediments occurring in the vicinity of the Rochechouart impact site at the presumed time of impact (Figure 1) are only a few meters to a few decameters thick and are composed of silicate rocks.

2) The geochemical record shows no positive anomaly in either Si or Ca in the impact melts compared to the granitic basement. A contribution from quartz-bearing sediment would shift the impact melt compositions toward the quartz apex in Figure 3b, which is not observed. A contribution from carbonates would shift the impact melt rock compositions toward the alkali element and/or the Mg poles in Figure 5A, which is not observed either.

Thus, if there is a contribution from sedimentary rocks to the Rochechouart impactites, it is very small compared to the contribution from granitic basement rocks; however, a small contribution from quartz or quartzo-feldspathic sedimentary rocks in the impact melted rocks cannot be excluded. It could account for part of the observed quartz-rich melt clasts and remnants of quartz-rich lithic clasts that occur abundantly in melt-rich impact melt rocks (Figures 32-33). The most likely source for the quartz-rich clasts are pegmatites or quartzo-feldspathic augen in gneiss, but it cannot be excluded that some may derive from quartz-bearing formations such as those forming the late Triassic to early Jurassic sediments known at the margin of the impact site (Figure 3).

In conclusion, the bedrock currently exposed in the Rochechouart structure appears to be an accurate reflection of the target composition at the time of impact; a minor proportion of

sedimentary material cannot be excluded but would be limited to a component in the impact melt.

Stratigraphy of impact deposits

Field data and the petrological and geochemical record suggest the impact fill of the Rochechouart crater structure is essentially composed of two major units deposited separately - the polymict lithic breccia unit at the base, and the upper suevite unit.

It appears unlikely that the impact melt rocks originally formed a continuous sheet at the Rochechouart structure: a continuous melt body would likely have had a homogeneous composition (see review by Dressler and Reimold, 2001) whereas in Rochechouart the geochemical data base indicates significant heterogeneity. Impact melt rocks at Rochechouart are encountered at the bottom of the impactite deposits directly above bedrock. Textures and setting prove these melts were essentially flowing laterally over an already-settled crater floor. The hottest, the most vesicular and, thus, the most fluid melts were restricted to the center of the crater, whilst more massive and cooler melts settled toward the periphery, such as around Mountoume.

Initial volume of deposits and the relative inefficiency of cratering at Rochechouart

The morphological and morphometrical considerations discussed above and the horizontal impactoclastic deposits on top of the suevite provide constraints on the volume of material deposited within the Rochechouart crater. Located in the faint “low” of the crater floor, the Chassenon sequence gives an “upper limit” for the thickness of the impactite deposit over the whole structure, namely 50-70 m at most.

This is extremely thin for a crater of its size developed in a crystalline target, even if we consider the lowest estimate for the initial crater diameter (20 km) and even if we compare it to craters developed in sedimentary or mixed sedimentary-crystalline rocks, such as Ries. The 1973 Nördlingen deep drilling, located ca. 3 km from the center of Ries crater (similar to the Chassenon radial distance) revealed a ca 300 m thick impactite sequence (Stöffler et al., 1977).

The complete impactite sequence is thus 5 times thinner at Rochechouart compared to Ries. This clearly establishes that the initial impact deposit at the Rochechouart crater is significantly depleted, the deficit factor lying between c.a. 5 and 10 depending on the value taken for the size of original final crater (20-50 km). Possible reasons for this could be:

1) *The initial impact crater is much smaller than thought:* A reduction by 5 times of the impactite and melt volumes implies a comparable reduction of the parameters such as the energy released on impact and the volume of the transient cavity. First-order simple model calculations based on the online tool of Collins et al. (2005) show that a 12 km final diameter crater would produce a volume of impact breccia matching the Rochechouart estimates. This value is less than the diameter of the zone covered by the deposits today and arguments have already been put forward that indicate that the crater must originally have been larger than 15 km.

2) *Low-angle trajectory:* Low-angle impacts have significantly reduced cratering efficiency (Melosh, 1989); however, as the constraint on impactite volume estimates relies on a crater diameter value, the low-angle argument does not apply. A low-angle impact at Rochechouart would only imply the size of the projectile was larger than expected.

3) *Sedimentary cover:* It was widely reported that the volume of impact melt rocks recognized in predominantly sedimentary and in mixed (sedimentary–crystalline) targets is on the order of two magnitudes less than for

crystalline targets in comparably sized impact structures (Grieve and Cintala, 1992). More recently it has been suggested that this inconsistency is due to the challenges in recognizing impact melt products derived from sedimentary-rich target rocks, rather than different processes and products occurring at impacts into different target lithologies (Osinski et al., 2008). In the case of Rochechouart, there is no impact formation or material that could have been misinterpreted. It is thus very unlikely that the explanation of the relative depletion in impactites at Rochechouart comes from the presence of a sedimentary cover at the time of the impact.

4) *Sea cover:* Despite the likely absence of sedimentary rock in the target area, the proximity of the impact site to the erosional Late Triassic-early Jurassic sea shore (Figure 3) indicates that the sea was at least very near to, if not covering, the Rochechouart site at the time of the event (either the new T-J boundary age - Schmieder et al., 2009a - or the Late Triassic age - Kelley et al., 1997). However, even if the sea reduced the efficiency of melting and excavation, this cannot account for the apparent deficit, for the same reason as for the low-angle trajectory hypothesis discussed above. The constraint on impactite volume estimates relies on a crater diameter value and a sea cover at Rochechouart at the time of impact would only imply the size of the projectile was larger than expected. Nonetheless, a marine impact is of potential importance for interpreting the characteristics of the Rochechouart structure and is further discussed in the next section dealing with the paleoenvironmental interpretations of the field data presented in the paper.

Projectile contamination

We will not enter in the debate of the Rochechouart projectile identification (see introduction). If the nature of the projectile can still be debated, the chemical contamination is beyond doubt and the “meteorite signal” at

Rochechouart is intense owing to the felsic composition of the target. In that context it is possible to look at the projectile signal distribution. The PGE data indicate an Ir content in melt rich impactites in the 0.1-2 ppb range, ten thousand time above the basement values (Janssens et al, 1977, Tagle et al, 2010). Yet, as of today, PGE measurement remains a heavy exercise and it is not yet appropriate for systematic tracking and mapping the meteorite signal at impact craters. Ni is more readily accessible. It has been measured in a large series of rocks sampling all the lithologies of impactites and basement rocks in Rochechouart (Lambert, 1975, 1977a, 1977c). The results show an exogenic Ni component in all

impactites, with the highest values in melt bearing rocks (typically in the 100 ppm range, up to 700-800 ppm for Bel-air impact melt rocks (ca 100-1000 times the target values) (Lambert, 1977cn Tagle et al., 2010)). The results also demonstrate the mobility of the meteorite signal as the clasts in the breccias and the highly shocked basement below the crater floor also display a positive Ni anomaly (Lambert, 1975, 1977c). Figure 55 gives a schematic and interpretative map of the Ni contamination based on above mentioned Ni studies. This data set will be completed by field measurement, planned during the field trip (see section 2 and see Roald and Lambert, 2009).

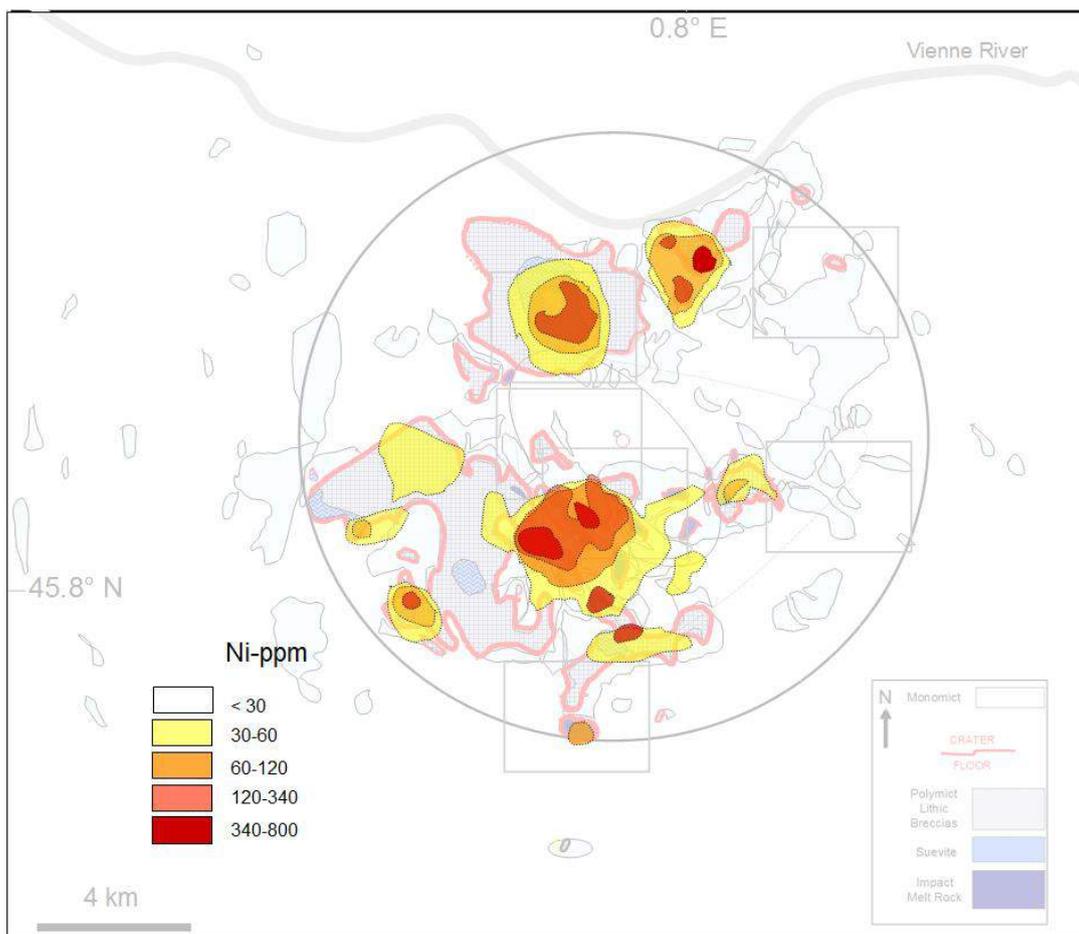


Figure 55. Schematic representation of “intensity” of the meteoritic contamination at Rochechouart based on the measurement of the Ni content (after data from Lambert, 1977a, c)

Paleoenvironmental considerations: Impact and postimpact regional implications

Ground zero

The Rochechouart impactites provide direct constraints on the altimetry position of the paleotopographic surface at the time of impact (ground zero). Ground zero can be inferred from the actual position of the crater bottom and from the estimation of the initial depth of the crater. As seen earlier, the altitude of the bottom of the crater is well established from field data. It oscillates between ca. 200 and 300 m.

The initial depth of the crater is more difficult to assess as it is not directly accessible in the field. However, it can be estimated by considering modeling and geological studies at other craters of similar size developed in crystalline rocks and mixed crystalline-sedimentary targets (e.g., Collins et al., 2008). From comparison with other terrestrial craters and model based estimate a final crater depth of ca 600-900 m is expected for craters between 20 and 50 km in diameter seems. It is thus deduced that ground zero at the time and location of the Rochechouart impact was at 700 to 1000 m above today's sea level (adding to the observed elevation of the crater floor at the center of crater the height of the rim taken as the value of depth minus the relative elevation of rim to ground zero).

Depth of the nearby sea

The level of the bottom of the nearby sea at the time of impact is directly accessible as it corresponds to the altimetry of the bottom of the late Triassic-early Jurassic sediments outcropping west and southwest of the impact site. As seen in the result section, this contact stands at ca 250 m in the southwestern outcrops (Montbron region) and at ca 170 m in the

western area (Mazières) (Figure 3). From this, the bottom of the nearby sea at the time of impact was at precisely the same level or only a few tens of meters below that of the bottom of the final cavity.

The paleo-sea level is more difficult to assess, but it can be constrained indirectly by the presence of the aerielly-deposited impactoclastic deposit in the cavity which indicates that the sea did not flood the cavity after the impact. Consequently, sea level at the time must have been at least below the level of ground zero and the water depth could not have exceeded 500-700 meters.

Tsunamite

Owing to the immediate vicinity of the sea at the time of impact, the collision is very likely to have produced significant effects and possibly triggered a tsunami. It has been tentatively proposed that the Rochechouart impact could be responsible for the puzzling ~2-4 m thick 'seismite' of about 250,000 km² extent partially overlain by 'tsunamite' in the uppermost Triassic of the British Islands (Schmieder et al., 2009b).

Post-impact sedimentary shielding of the crater

The fine-grained impactoclastic deposit at the top of the Chassenon sequence also constrains the paleoenvironmental and post-impact history of the impact crater. Owing to its position, this deposit would have been the first exposed to erosion unless it was rapidly shielded. It is thus inferred that the whole area was rapidly protected from erosion after impact.

The most likely protection is to be found in post-impact sediments, although there is no trace of such a sedimentary record anywhere in this part of the French Central Massif. But it appears to be generally accepted (Curnelle and

Dubois, 1997; Dercourt, 2002) that the region was indeed covered by a sea until the early Tertiary. Furthermore, because of the long exposure to erosion since the early Tertiary, the “ghost” protective sedimentary cover deposited during the Jurassic and Cretaceous must have been very thick to allow shielding of the 50-70 m Rochechouart impactite deposit until the present day.

Post-impact erosion

The present data constrain the minimum thickness of material eroded since the crater was formed and then filled. This value is ca 700 meters. It is deduced from the final depth of the Rochechouart crater ca 800 m (deduced from model estimates and observational data from other craters in the same size range, see Figure 54) minored from the thickness of the crater fill deposits (estimated 100 m or less according to the Chassenon complete sequence).

Post-impact hydrothermal alteration

The pervasiveness of post-impact hydrothermal alteration of the Rochechouart impactites is striking. It has been noticed by all authors having worked in the area (Kraut and French, 1972; Lambert, 1977a, b; Reimold et al., 1987; Sapers et al., 2009). Although hydrothermal alteration of melt-bearing impactites has been reported at many other terrestrial impact structures (see for instance Wittmann et al., 2008 and references therein), the importance of these effects appears as a distinctive and unusual characteristic of the Rochechouart impact.

The mineralogy of the Rochechouart impactites is strongly affected by the hydrothermal alteration as it appears responsible for complete or quasi-complete alteration of glass, for the wide argillisation of melt-bearing impactites and for the systematic occurrence of neoblastic quartz and K-feldspar in the pore space of all impactites, including

the impactoclastites. The composition of Rochechouart impactites is also strongly affected by the hydrothermal alteration, as shown by the systematic positive K_2O/Na_2O - K_2O/CaO anomaly (Table 2).

As the same anomaly is observed in the lithic clasts of the impact melt rocks, it is clearly established that this characteristic is not restricted to the melt phase alone. As the effects extend to all the impactites, including the monomict lithic breccias beneath the crater floor and the impactoclastic deposit at the top of the sequence, it implies a system of hot circulating fluids pervading the entire deposit for a significant duration.

This raises the question of the heat source and of the source of fluid. If the primary heat source available for this hydrothermal activity is obviously the melt and the hot clasts contained in the various deposits, the question is raised whether the limited amount of melt and highly shocked, hot material remaining in the crater allow the production of such a large hydrothermal cell or not.

The answer will require further study. At this stage it can be noted that despite the large deficit of hot material and melt inferred from the discussion above, the cooling conditions of the impact deposit at Rochechouart are not necessarily much different from those in other craters as the entire deposit (defining the size of the cell) is reduced in the same proportion as are the impact melt rocks in the Rochechouart crater.

The source and the amount of fluid required for establishing such a large, pervasive and prominent hydrothermal system can certainly not be related to the crystalline bedrocks. Granite and gneiss are known as amongst the driest rocks in the upper crust. Shock is not responsible either. If high shock is proven to mobilize water by decomposition and melting of hydrous silicates in crystalline rocks (Figure 16 and Lambert and McKinnon, 1984) it is

certainly not sufficient for explaining the observed features.

An exogenic fluid source, such as from a comet, is most unlikely owing to the temperature-pressure conditions prevailing at the point of impact. Sediments as an endogenic source are unlikely, too, as a significant contribution from sediments in the deposit is not supported by the geological and geochemical record. It thus seems that the most likely source of the water is free water in the target environment at the time of the impact.

As discussed earlier, the crater must have been covered by water relatively rapidly after crater formation to enable sediment to deposit and shield the impactites against erosion.

This marine sediment might be considered a source for the water; however, the pervasive and systematic character of the alteration rather suggests the water was incorporated and intimately mixed with the impactites at the stage of the formation of the deposit.

OPEN QUESTIONS AND PERSPECTIVES

Significant scope for research on the Rochechouart structure remains. The main research routes could aim at constraining:

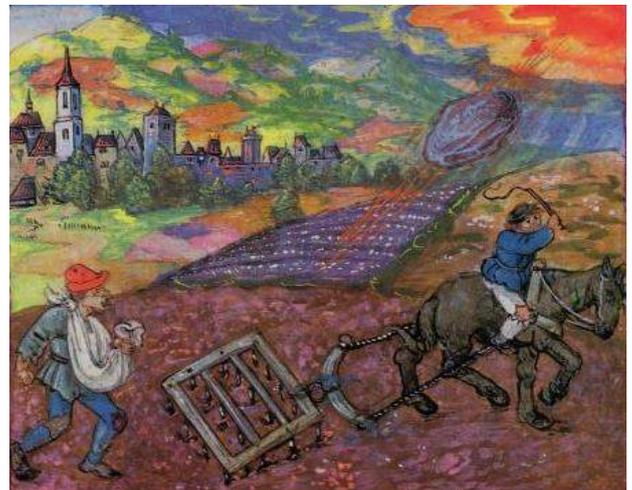
- a) the size of the crater, implying more field work and a detailed geophysical investigation,
- b) the exact age of the crater and the paleo-environment on both the continent and in the nearby sedimentary basin at the time of the impact,

- c) the formation of the impactoclastites, implying a systematic field mapping and shallow digging and/or drillings to restore buried outcrops and to generate new ones at the top of the Chassenon suevite,

- d) the apparent deficit of crater fill, implying further detailed mapping and petrographic studies of the various impactite deposits exposed at Rochechouart,

- d) the distal effects of the Rochechouart impact, implying field work and sedimentary petrology away from the Rochechouart impact, in particular in the Aquitaine and in the Paris Basins,

- e) the postimpact history of the crater including the cooling history of the impact deposit and the conditions and incidence of the probable rapid and thick burial of the impact deposit under a sedimentary cover which has now been entirely eroded away.



Ensisheim meteorite fall, 1492

PART2: SITES OF INTEREST:
ROCHECHOUART IMPACT STRUCTURE

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Field Guide- Meteoritical Society 2009

INTRODUCTION

As indicated in the foreword, this second part is mainly a field data compilation, locating and describing the various sites planned for stops during the MetSoc 2009 field trip to Rochechouart. The petrographical-geochemical description and interpretations of the rocks exposed at these sites are provided in part one of the document. This part is a “naturalistic” approach of the field, aiming at simply documenting the “ground truth” data. As there is a lot to say on the field, as images may replace long stories, and as writing in English is not necessarily my cup of tea, the present document bears a lot of images.

In addition to the geological stops described below, the field trip includes several cultural and/or historical stops which are not referenced here (such as the visit of the Rochechouart castle, the visit of the city of Rochechouart and of Paul Pellias Center, the visit of the Chassenon archeological site..).

As a preliminary, the field trip covers some aspects of the geology away from the impact, including an insight at the sedimentary cover at the boarder of the French Central Massif. A short presentation of ongoing studies on some particular aspects of the conditions of sedimentation is provided separately (Barbarand, 2009). Also several stops concerne the “pristine” material forming the Rochechouart target. They will serve for field characterization of the geochemical signature of the target rocks as the MetSoc conference abstract program includes a real-time geochemical trace test experiment (Tagle and Lambert, 2009). The later aims at tracing and possibly mapping the extraterrestrial contamination of the Rochechouart impactites directly on site utilysing the latest generations of portable μ -XRF instruments by Bruker. The measurements will be performed and processed in real time. They will be compared with those already acquired in the

laboratory and with other sets of geochemical data (Lambert, 1975, 1977a, 1977c, Janssens et al., 1977, Tagle et al., 2010). The field trip participants will have the opportunity to raise an opinion on the exercise. The result of this field test will be presented during the congress in Nancy (Tagle and Lambert, 2009), either as an oral presentation if the results are interesting or at a poster session. More detail on this will be provided on the day of arrival.

OUTSIDE THE IMPACT

The field trip starts in Angoulême. Capital of Charente department with ca 42 000 inhabitants, Angoulême is about 75 km W-SW of Rochechouart (Figure 55). The city is built on late Cretaceous limestones (green formations on the lower left corner of Figure 56). These rocks are intercalated with continental alteration material indicating a shallow sea environment and the proximity of the continent. The total sequence is ca 50 meter thick.

As we go east to reach the western edge of the Variscan continent we go down in the geological times. At the outer limit of the Angoulême city, on our way to Montbron, we pass directly from the late Cretaceous limestones to the Upper Jurassic (Figure 57). The early Cretaceous is missing in this part of the Aquitaine Basin. We cross ca 150-200 m of Upper Kimmeridgian limestone, then 30-40 m of Lower Kimmeridgian where decametric clay layers are intercalated in the limestone, then we reach the Oxlordian formed by detrital limestone (ca 130 m) (see Figure 57).

Before arriving in Montbron, we hit the Middle Jurassic which is not differentiated on the current 1: 50 000 geological map (Figure 57). Middle Jurassic is represented by limestone which is variable in thickness (100-250 m). Montbron, our first stop is positioned at the contact between the Middle and the Lower Jurassic, very near the contact with the crystalline basement.

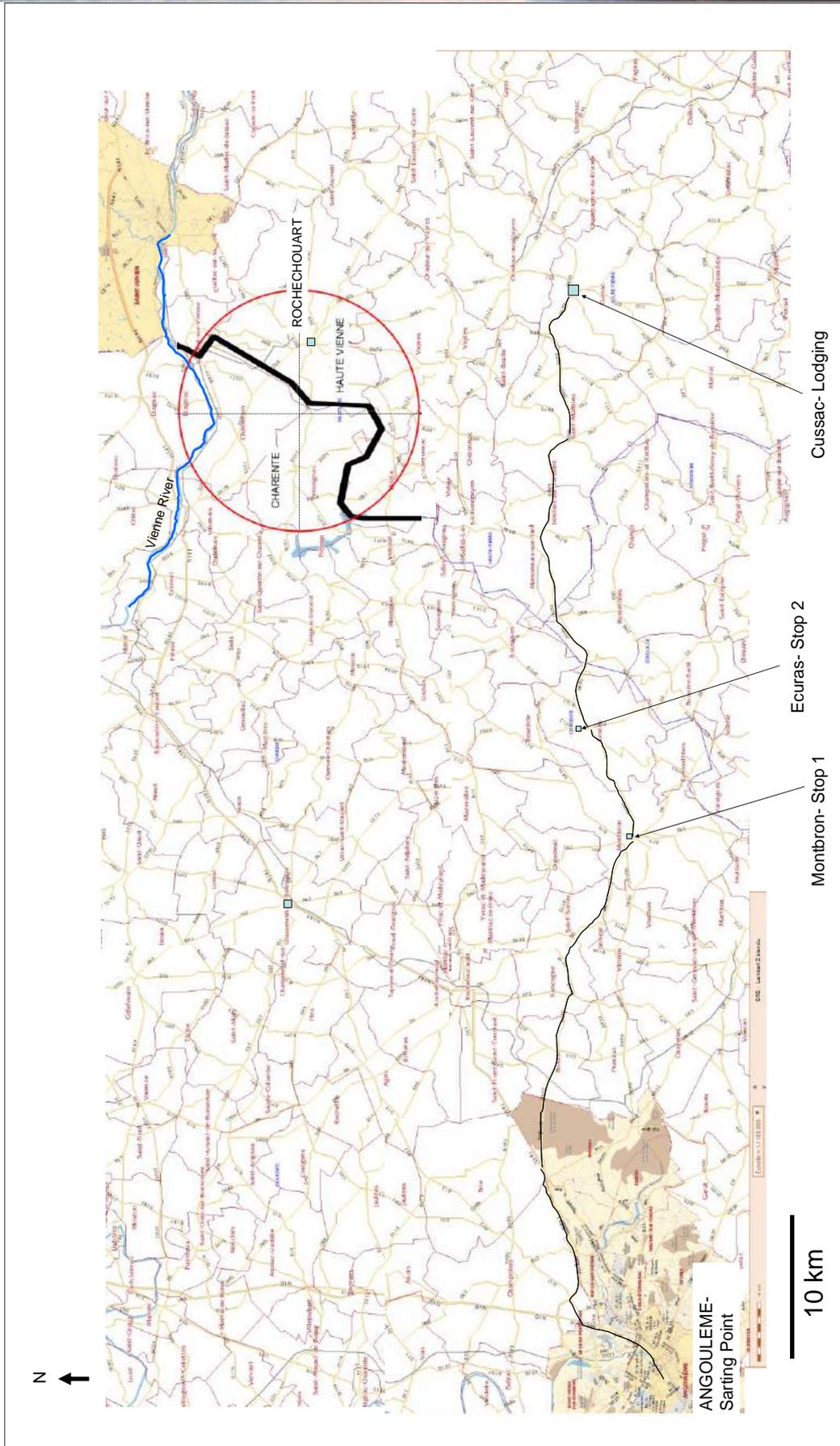


Figure 55: Detailed administrative map of the zone traversed by the field trip starting in Angoulême up to the lodging at Cussac (Haute Vienne). Position of the stops and indication of the itinerary (informations reported on the geological map in Figure 56). Red circle: Rochechouart impactites zone. Large black line: Boundary between the administrative regions (Limousin and Poitou-Charentes).

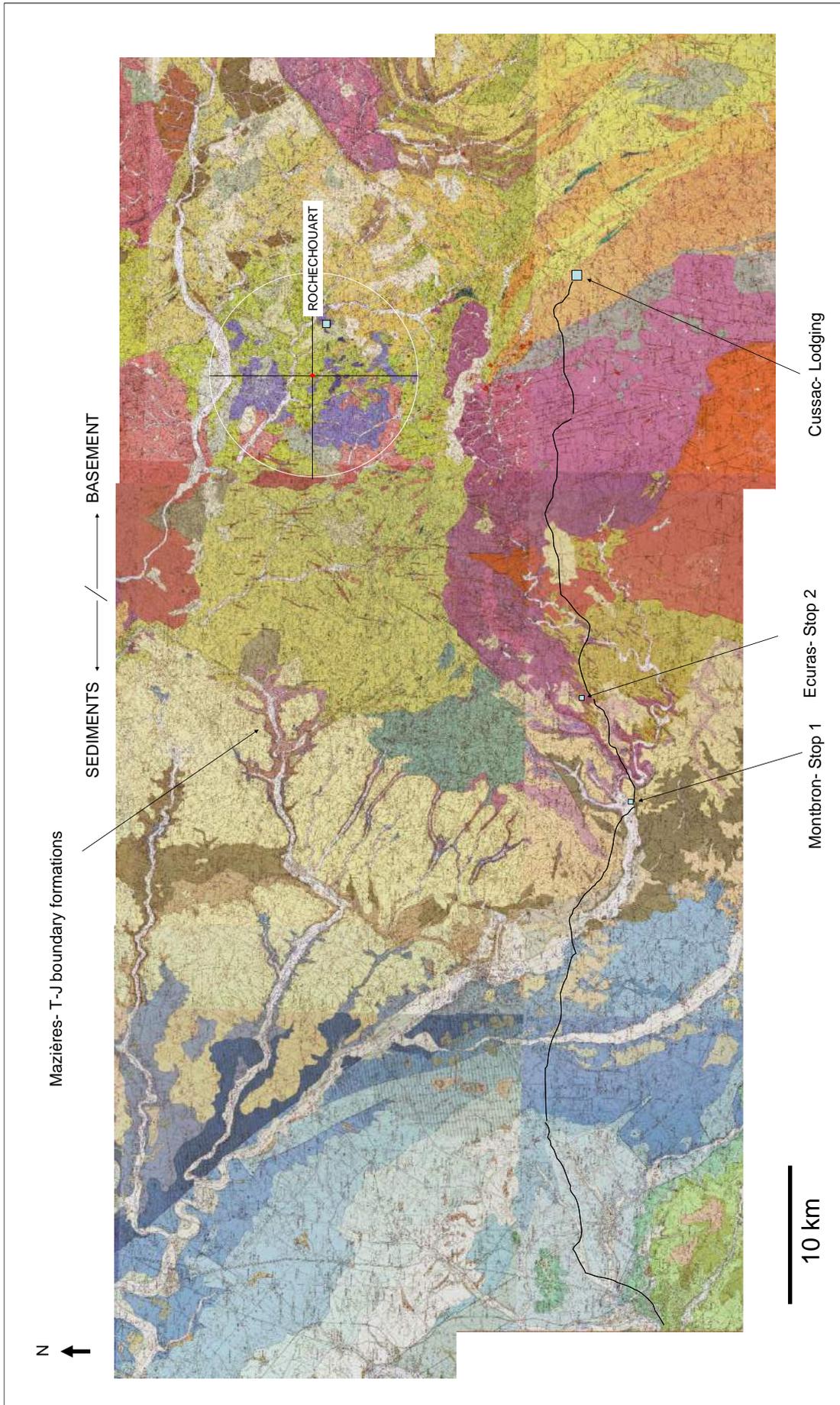


Figure 56: Detailed geologic map of the zone traversed by the field trip starting in Angoulême up to the lodging at Cussac (Haute Vienne). Same scale and same field as in Figure 55. Red circle: Rochechouart impactites zone. Color code according to geological time chart: <http://infoterre.brgm.fr>

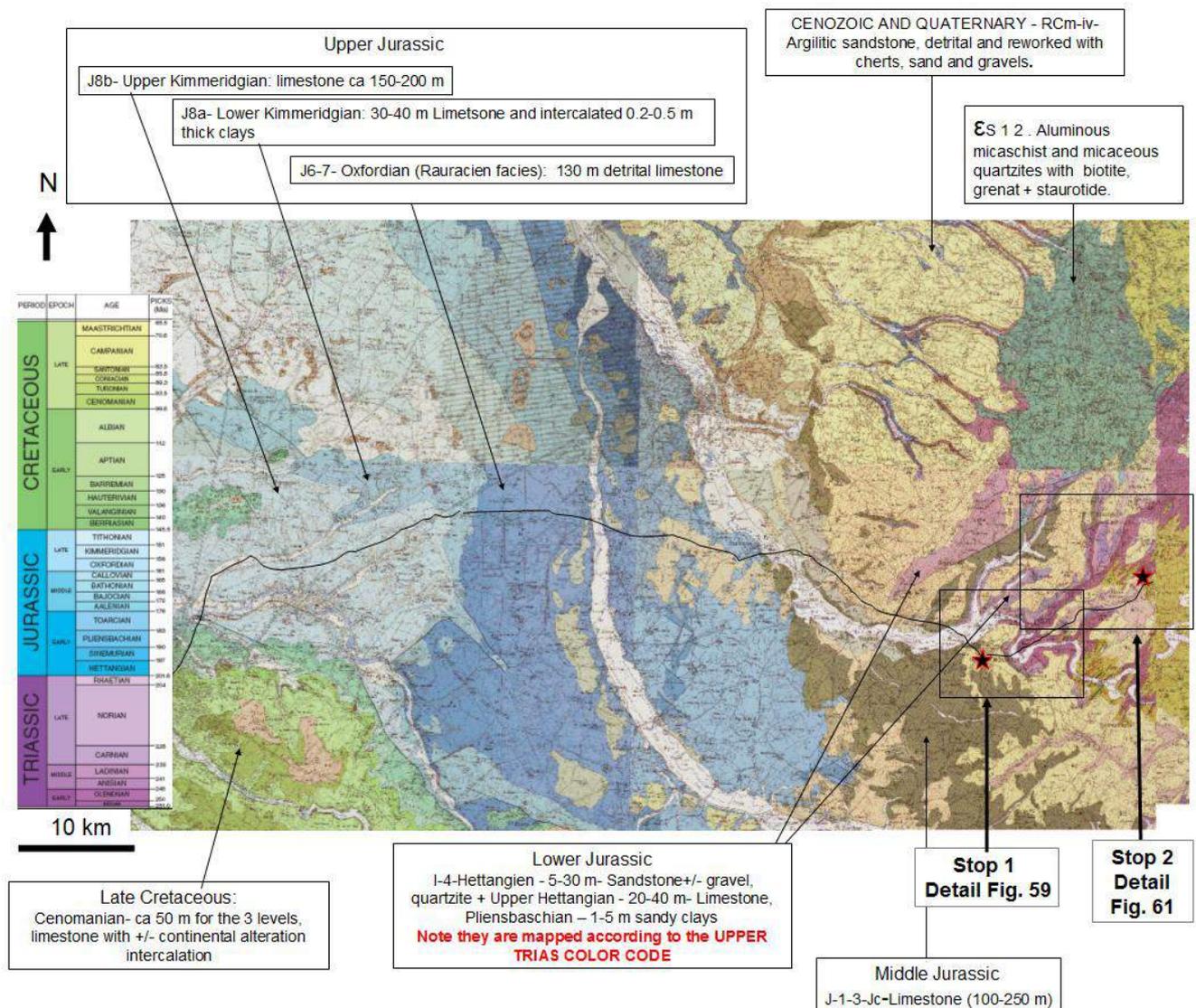


Figure 57: Detailed geologic map of the sedimentary basin formations on the western border of the Limousin (data source, 2009, <http://infoterre.brgm.fr>)

Montbron area: Stops 1-2

These two stops intend to locate and illustrate the paleoshore of the shallow sea bordering the western edge of the French Central Massif at the presumed time of the Rochechouart impact ca 201 ± 2.3 Ma (Schmieder et al., 2009).

Mesozoic sediments overlie the western margin of the Massif Central (see schematic representation in Figure 3 and geological map Figure 56). The basal unit consists of a 5-30 meter thick sandstone deposited horizontally and exposed at Mazières and Montbron, only 16-17 km west and 24 km southwest of the center of the structure, respectively (Figure 56).

STOP 1: Montbron

Radial distance to the center of the Rochechouart impact structure: 39 km.

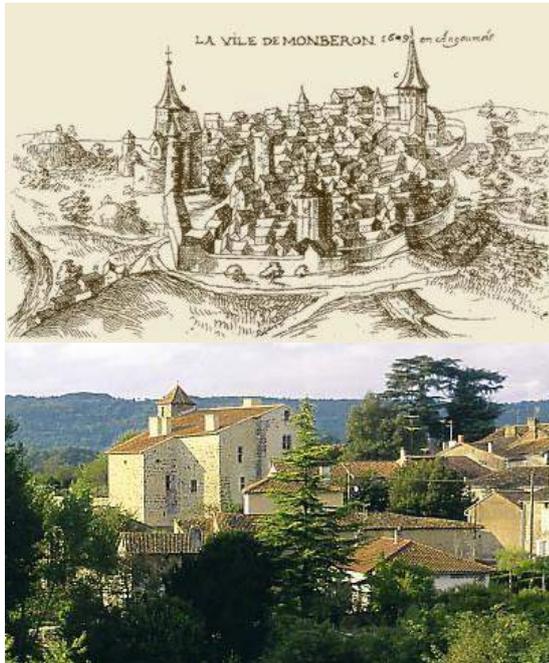


Figure 58: *Montbron village, Charente, as of 1609 and as of today.*

Access:

Rue de la Rochefoucault, Montbron. Parking lot on the north side of the street (see Figure 59A). The cliff on the right side of the street is dominated by the ancient part of the city, including its castle (Figure 58).

Description:

The cliff is made of 20-40 m of limestone forming the basis of the carbonated sequence of the Middle Jurassic. It covers a detrital unit made of mixed carbonates and sands, passing to more or less consolidated sandstones. The contact between the Middle Jurassic limestone and the detrital unit is (not well) exposed at the base of the cliff (Figure 60).

This detrital unit is interpreted as the direct product of the erosion of the nearby Variscan continent. It is the earliest sedimentary deposit encountered on top of the crystalline basement. The basement outcrops in the river cut on the east side of the village (denoted “shore” on Figure 59B).

This detrital unit is not more than about 10 m thick in the Montbron area as deduced from the position of the contacts with the overlying limestone and with the underlying basement rocks in the river cut.

The detrital unit and more precisely the sandstone at the base of the unit is supposedly contemporaneous or almost contemporaneous with the Rochechouart impact. Attributed to the Rhaetian on the basis of rare fossils by the 19th and early 20th field geologists (see for instance Glangeaud, 1901) it was appearing as such on the geological maps of Aquitaine Basin until the 1970's.

The latest editions of the geological maps of the area (released from 1980-1990) are now placing these basal siliceous sediments at the base of Hettangian (denoted I-1-4 in Figure 59). As seen in the upper right insert in Figure 59, the detrital sediments are still mapped with the color code of the upper Trias. The reason for this change of age remains mysterious, including for geologists who have mapped the area. As indicated in part one of the guide, the age of the basal sandstones is in fact poorly constrained and no recent paleontological study has been ran in the region.

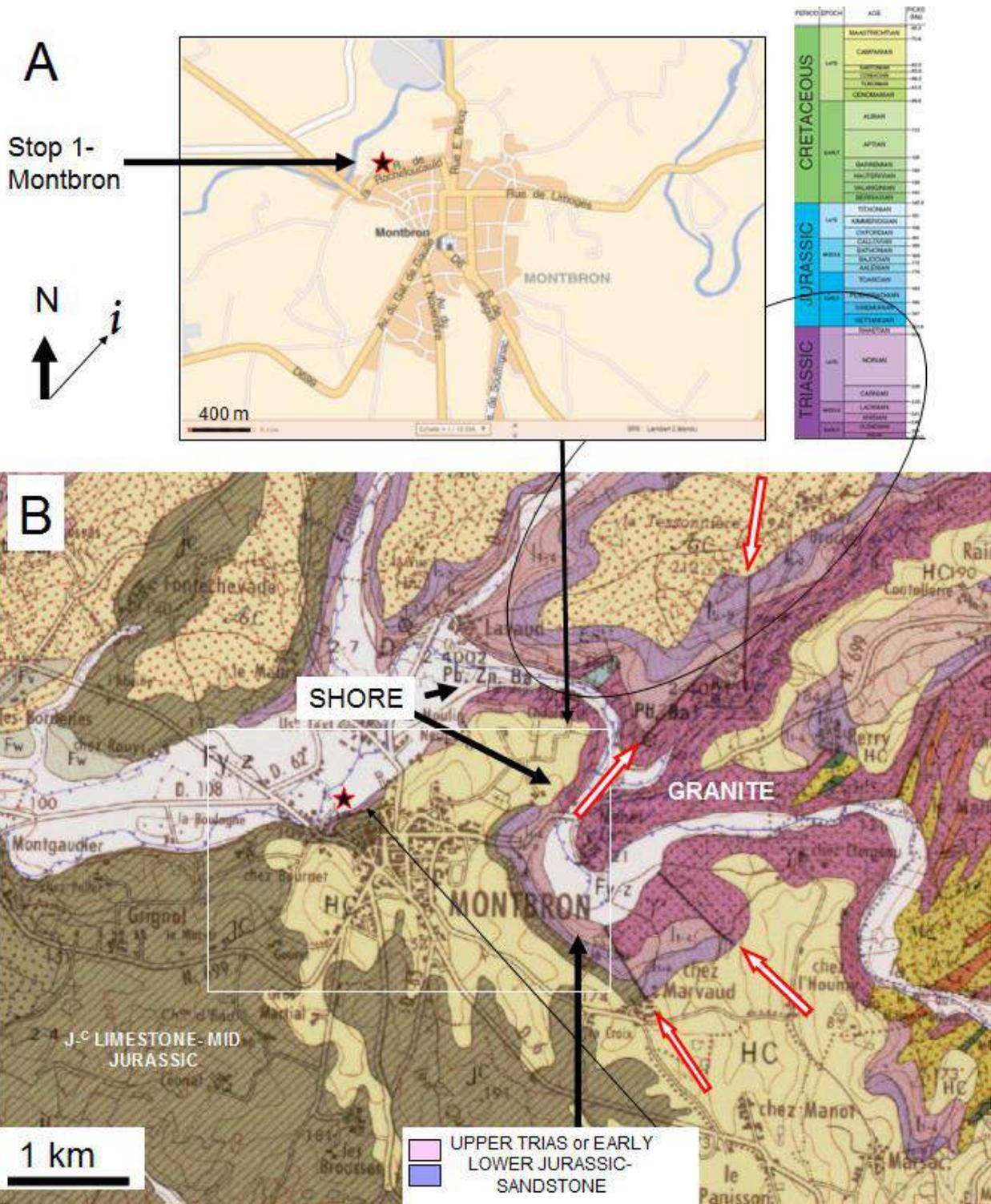


Figure 59: Stop 1-Montbrbron- A: Access map. B: Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>). Note the faults (white arrows) oriented parallel and perpendicular to the direction of the center of the structure, (i: direction of center of the impact). White rectangle: Field covered by A.

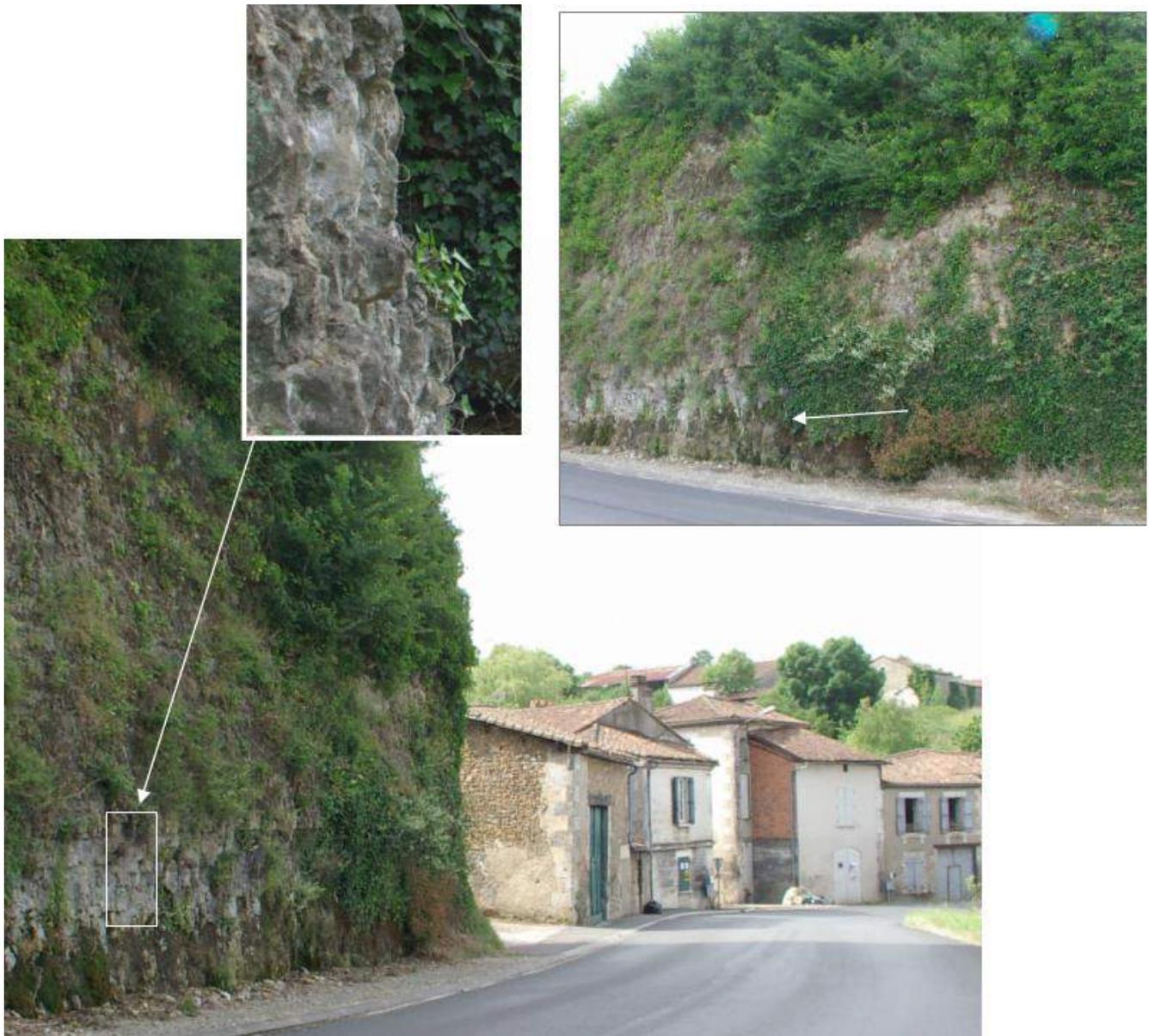


Figure 60: Stop 1- Montbron: Limestone at the bottom of the middle Jurassic forming a cliff at the Northern side of Montbron village overlying the Lower Jurassic +/- detrital carbonated and silicated material.

STOP 2: Ecuras

Radial distance to the center of the Rochechouart impact structure: ca 30 km.

Access:

E-NE of Montbron, D699 in direction of Saint Mathieu. Left on D112 after Chatain-Besson at the Ecuras City Hall. Stop 2 is located in the curve on the right at ca 500 m from the junction between D112 and D699 (see Figure 61).

Description:

Small quarry ca 3-4 m height 25 m long at the boundary between anatectic granite and migmatitised gneiss containing lenses of granite, the whole cut by a microgranite dike (Figures 61-63).

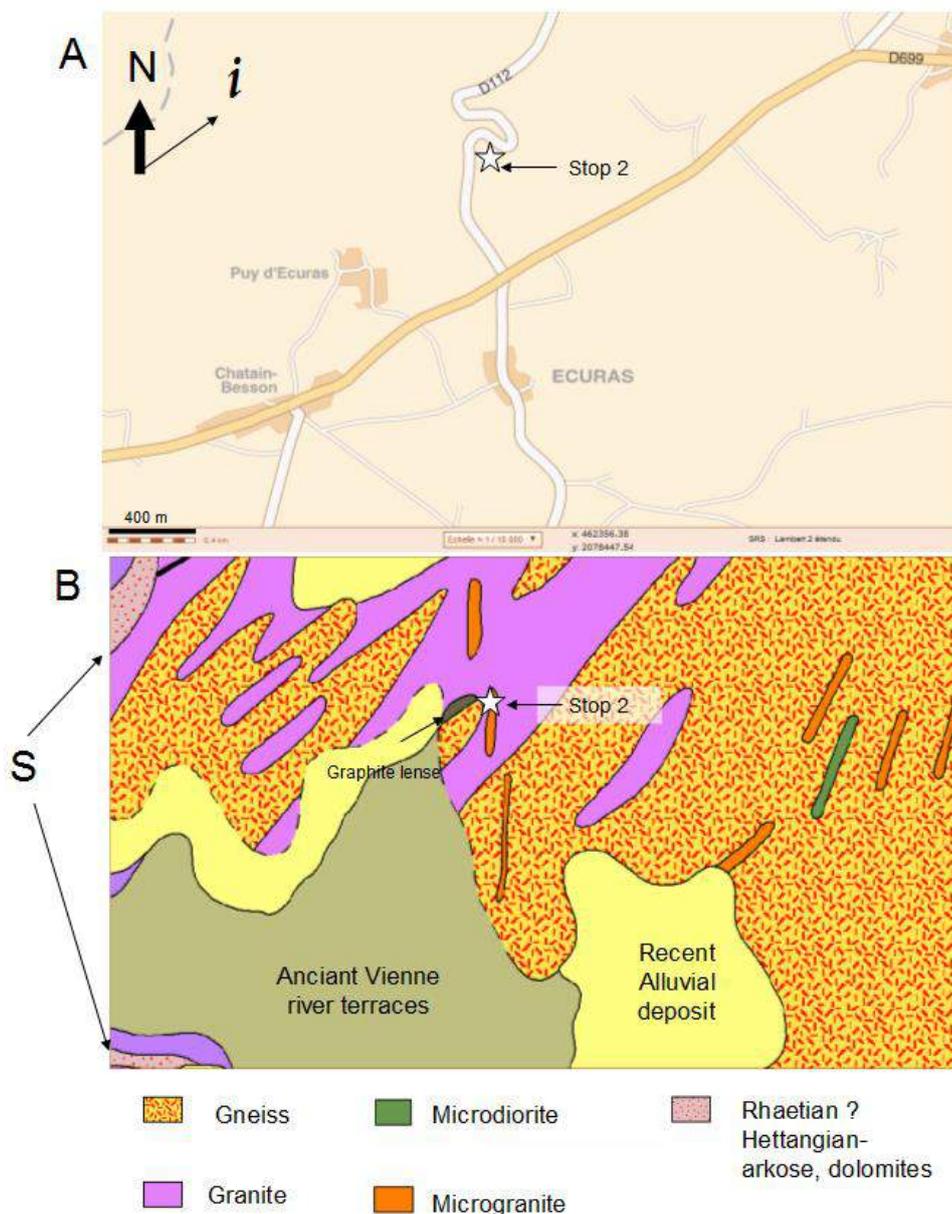


Figure 61: Stop 2-Ecuras- A: Access map. B: Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>). S-Sedimentary cover. (i: direction of center of the impact).

The choice of this stop is purely practical and related to the planned itinerary from Angoulême to Cussac. It was intended to display our first contact with the basement (ie the continent), in order: 1) to visualize in time and space the edge of the Variscan continent and the shore line, 2) to provide a reference for the basement target rocks outside, yet

close, to the impact structure for both geological and geochemical purposes (XRF experiment). The exposed rocks form the outer edge of the continent at the presumed time of the Rochechouart impact. The early Jurassic (or late Triassic) sediments outcrop at ca 1.5 km from spot 2 (Figures 61-62).

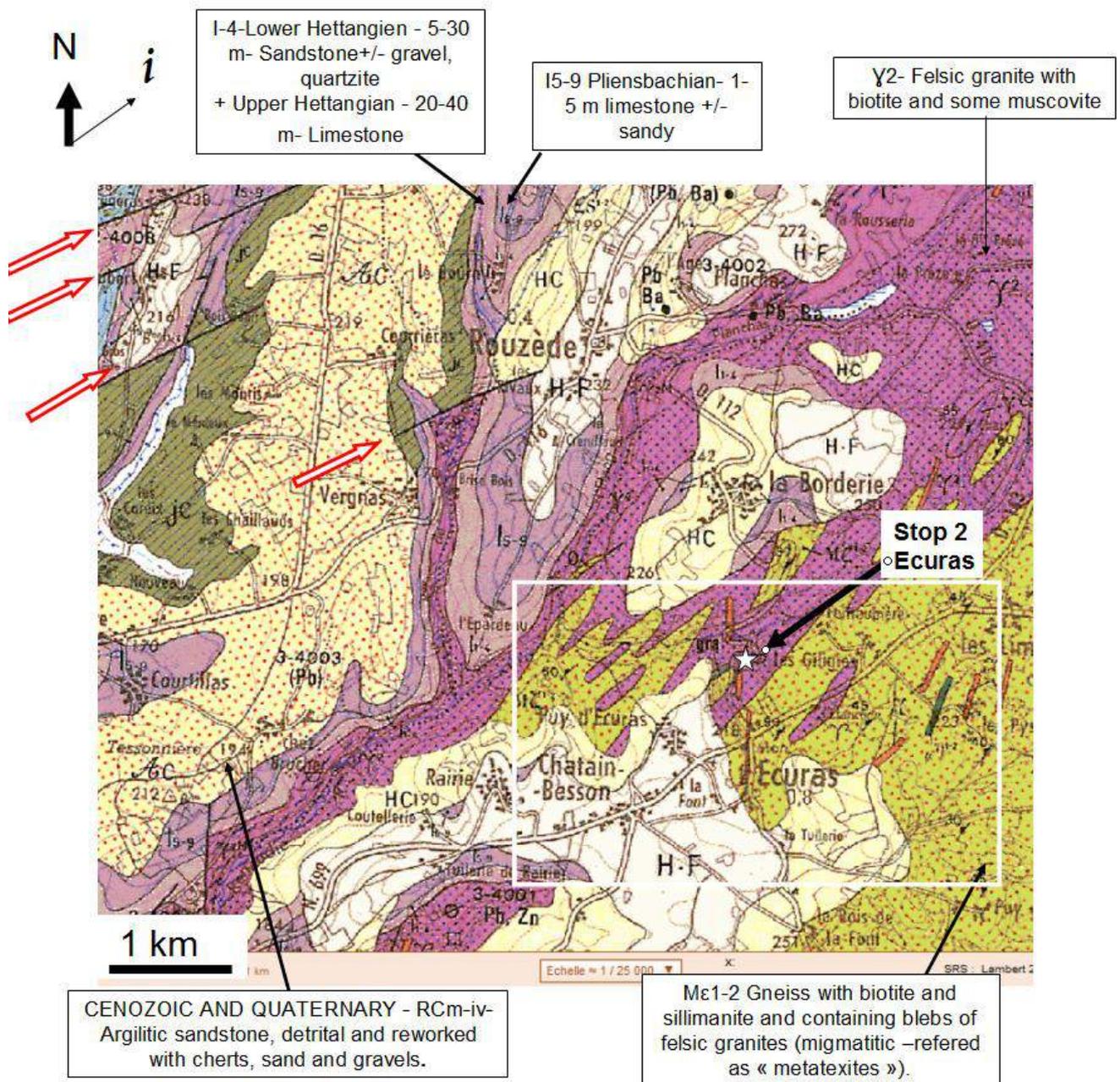


Figure 62: Stop 2- Ecuras. Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>). Note the faults (white arrows) oriented parallel and perpendicular to the direction of the center of the structure, (i: direction of center of the impact).

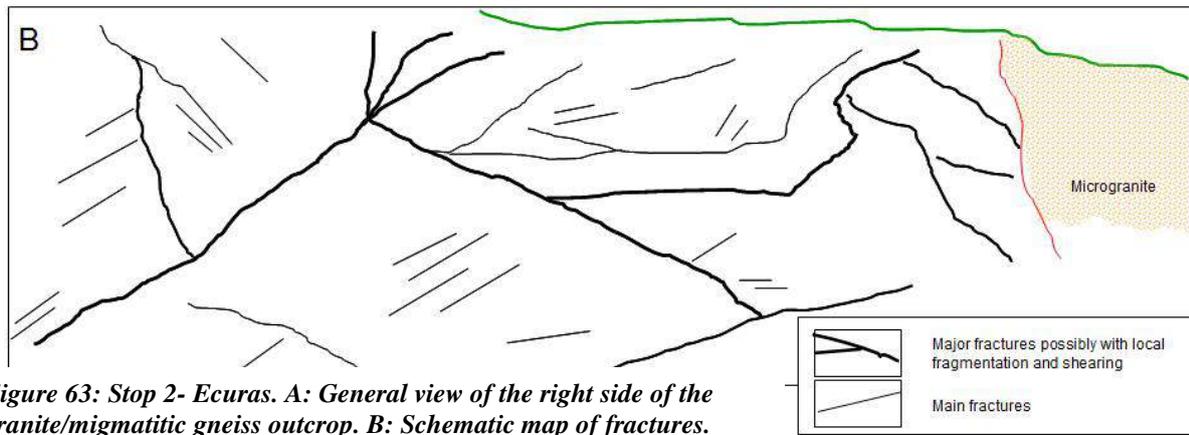


Figure 63: Stop 2- Ecuras. A: General view of the right side of the granite/migmatitic gneiss outcrop. B: Schematic map of fractures. Note the abundance of fractures and the anastomosed character of the main discontinuities (see detailed views in the next figures).



Figure 64: Stop 2- Ecuras. Detail of the central part of the field seen in Figure 63. Note the abundance of fractures, the listric and the anastomosed character of the main discontinuities.

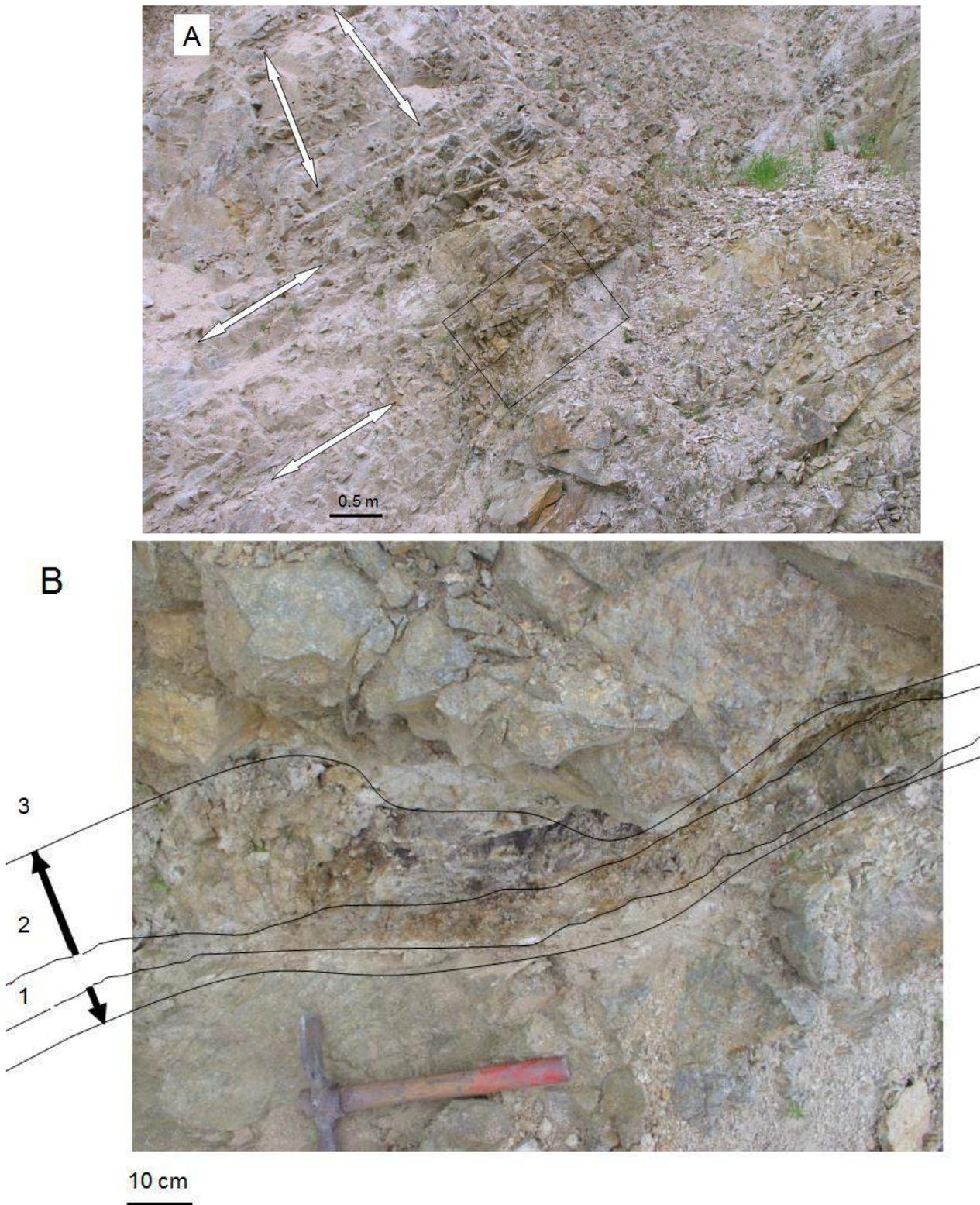


Figure 65: Stop 2- Ecuras. A- Detail of the left part of the field seen in Figure 63. Note the abundance of fractures, the two major sets of orientation of fractures, the dense network of small fractures resulting in a quasi fragmentation of the rock in centimeter-decimeter sized blocks. B: detail of framed zone in "A". Note the gradient of damages intensity along the 30° angle fracture. 1- Fine grained layer, 2- Highly fractured zone (millimetric-centimetric fracture network), 3- Fractured rock (centimetric-decimetric fracture network).

Yet, as seen on the field, the basement rocks exposed at Ecuras stop are bearing definite evidence of deformation. The rocks display a dense network of fractures (Figures 63-65), including multiple sets of intersecting fractures, low angle listric like fractures and quasi breccias and breccia dikes (Figures 63-64).

Macroscopically, the rocks conform to the definition of cataclasites. The texture compares to that of the cataclasites produced by impact and observed in the crater fill deposit zone (the 15 km diameter inner zone at Figure 4 (part one)). The apparent damages observed here will be compared to those observed at different stops in the Rochechouart structure (for instance stops 3, 8, 9).

Field observations indicate that the average cell size of the fracturation network at Ecuras is decametric. Beyond “classical” fractures, irregular anastomosed metric to decametric veins like features are crosscutting the basement rocks at stop 2 (Figures 63). The morphology, morphometry, the

geometry of these veins resemble that of impact generated veins and breccia dikes observed in the Rochechouart structure.

Figure 65 illustrate an example bearing some similarities with the complex dike described in the Cheronnac drill core (Figure 18 part one). There is a gradient of deformation around the axis of the discontinuity (Figure 65). The symmetry plane of the discontinuity is occupied by a millimeter-centimeter wide core where the material has lost its original texture (denoted 1 in Figure 65B). It is characterized by a fine-grained texture. The core is surrounded by a quasi brecciated zone (denoted 2 in Figure 65B) where density of fracture is about one order of magnitude higher than in the host (yet fractured) material outside of the vein (denoted 3 in Figure 65B).

Further field work is planed on these rocks together with petrographic investigations to interpret these deformations.

Figure 66. Chateau de Cromières at the entrance of Cussac (in part 15th-16th century)



IMPACT ZONE

The second and the third day of excursion are devoted to the impact area. Figure 67 locate the

various access maps and the positioning with respect to the main geological units.

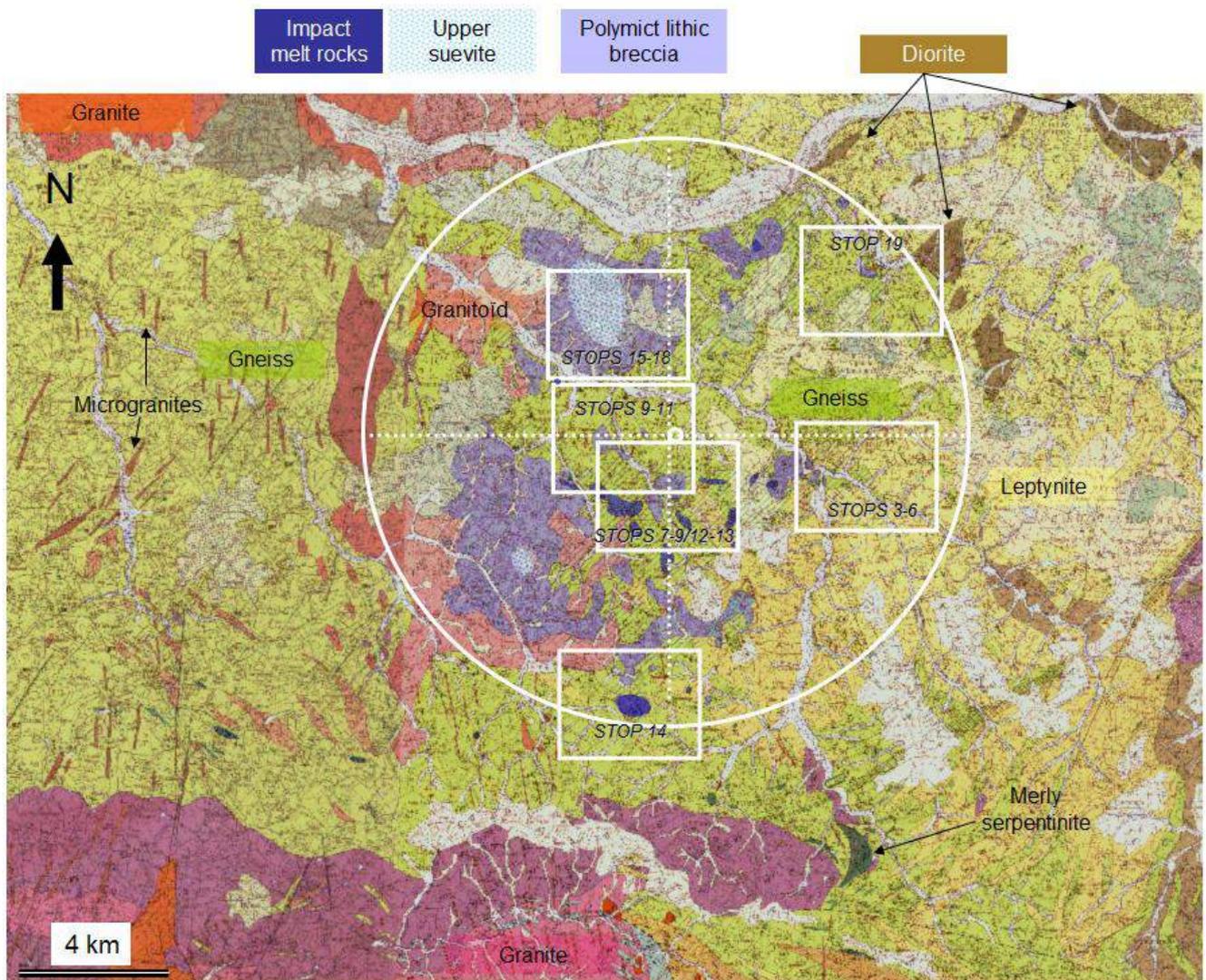


Figure 67: Positioning of the various stops and related maps on the geological map (modified after Chèvremont et al, 1996).

Rochechouart Area: Stops 3-6

This series of stops aims at illustrating one of the major components of the Rochechouart target, the leptynite, and the impactite forming the majority of the preserved crater fill deposits, namely the

polymict lithic breccia. This serie of stops also aim at visualizing the crater floor geometry and the thinness of the crater fill deposit.

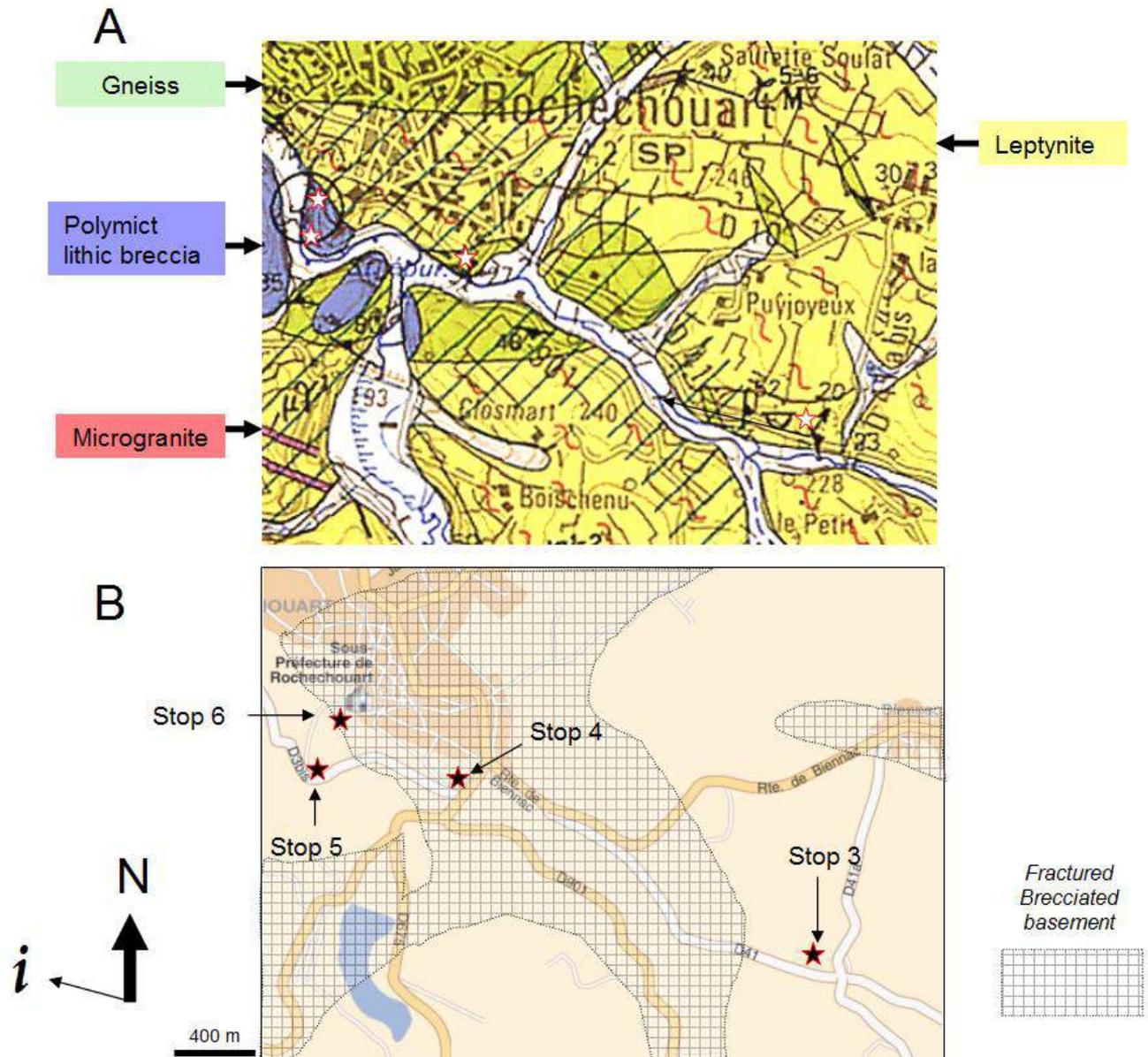


Figure 68: A-Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>) and B- access map for stops 3-6. (i: direction of center of the impact).

Stop 3: Puyjoyeux leptynite quarry

5.5 km E-SE of center of the structure

Access:

Puyjoyeux quarry site is located 2 km southeast of Rochechouart on D41 near the junction with D41a (Figure 68).

Description:

This ancient L shaped old quarry is a satellite of a larger quarry exploited for road construction until the late 1960's. The quarry expanded at the eastern side of the present site. The main quarry about ca

150 long, 40 m high was transformed into a waste disposal field in the early 1970's. The unfilled satellite quarry was acquired by the city of Rochechouart to host the "gens du voyage" (gypsies). The left wall is about 4 m height, 10 m large and is covered by the vegetation. The front wall is at most 10 m high, 20-30 m wide. This stop is mainly intended to get a reference for the orthogneisses developed on the east side of the Rochechouart structure. Orthogneisses belong to the Lower Gneiss Unit (LGU) (see part 1) and referred to here as "leptynites". Leptynites are the secondmost widely exposed metamorphic rock type in the target area, occurring in the southwestern region of the target (see part 1-Figure 4).

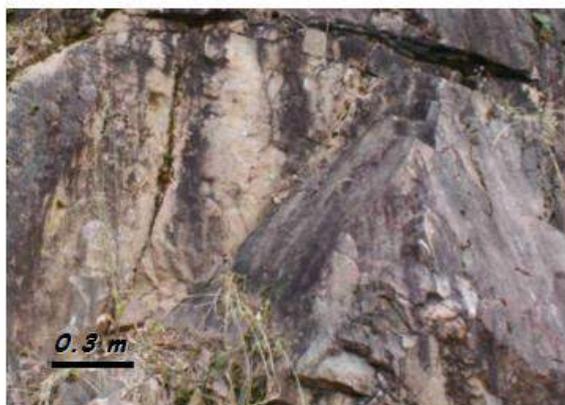


Figure 69: Stop 3- Puyjoyeux quarry. General view of the front wall of the ancient quarry. Some limited fracturing. The original rock fabric is preserved.

The leptynite is granitic in composition and is composed of millimeter sized grains of quartz, orthoclase and biotite. The later are oriented and result in a milimetric layering visible on crosssections (Figure 70). There are local variations in grain size resulting in a decimetric layering visible at Figure 69.

It displays a layered locally more massive leptynite dipping to the east. The leptynite displays less deformation than the granite-gneiss exposed at stop 2 in Ecuras. Apart from some fractures there is little macroscopic damage visible in the rock. The petrographic study shows no evidence of shock at the mineral scale. A specimen from this site will be used as reference for the geochemical field test experiment (Table 7).



Figure 70: Stop 3: Leptynite at Puyjoyeux quarry (location see Figure 68). Close up view of a fresh saw cut in the leptynite showing the oriented texture and the mineralogical assembly (quartz- light pink orthoclase and biotite)



Figure 71: Stop 3: Main quarry at Puyjoyeux situated on the eastern side of the remaining quarry (location see Figure 68). Photo taken before complete cover of waste disposal site. Jean Pohl at scale. Arrow: 20-50 cm wide breccia dike crosscutting leptynite. The dike was also visible on the opposite wall (Figure 72).

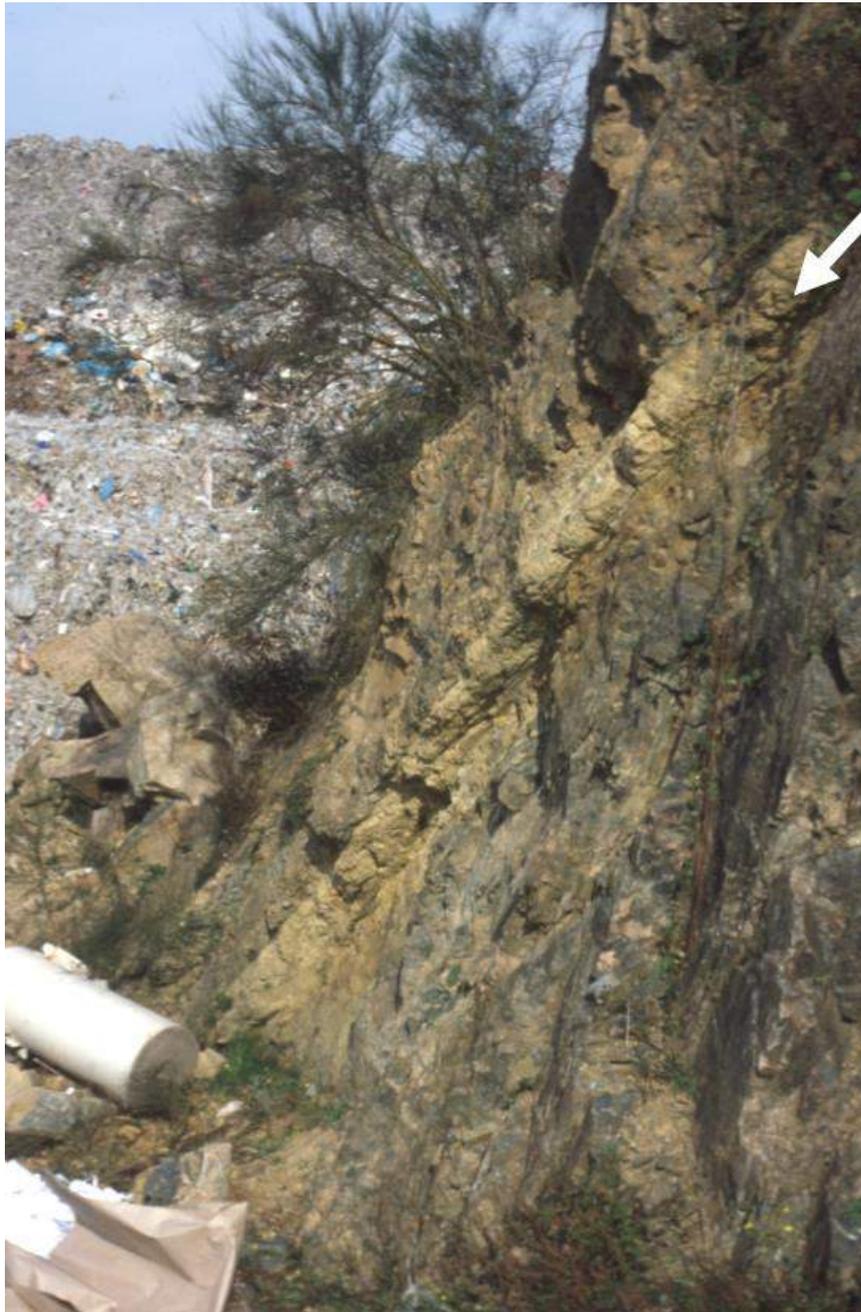


Figure 72: Stop 3: Main quarry at Puyjoyeux situated on the eastern side of the remaining quarry (location see Figure 68). Photo taken before complete cover of waste disposal site. Arrow: 20-50 cm wide breccia dike crosscutting leptynite. The dike was also visible on the opposite wall (Figure 70). Note the fractures in the leptynite wall are much more pronounced than in the leptynite at distance from the dike. The damages in the bedrock next to the breccia dike compare to those observed in the granite-gneiss at stop 2. Width of view field: ca 5 m.

The filled quarry was characterized by one of the best examples of breccia dike, local brecciation and fracturing seen in place in the Rochechouart structure (other examples as described in part 1, comes from drilling where we miss the general setting, and from Champagnac quarry where the intense mining associated with the important active

exploitation is somewhat perturbing the original information (see stop 19)).

Figures 71-73 illustrate the field setting and the characteristics of the damaged zone around the dike.



Figure 73: Stop 3: Main quarry at Puyjoyeux situated on the eastern side of the remaining quarry (location see Figure 68). Photo taken before complete cover of waste disposal site. Close up view of the breccia dike. Note the sharp contact and the fine grained breccia texture of the dike. Note the high density of fracture in the leptynite wall.

The dike strikes in a radial direction with respect to the center of the structure and is inclined at ca 45°. The steeply dipping oriented fabric of the leptynite is folded at the contact of the dike. The leptynite wall at the contact is highly fractured. It is

crosscut by a abundant and dense fracture network that compares to that observed at stop 2.

The 20-50 cm thick dike shows a complex dike-in-dike breccia texture previously described in part one (Figure 17).

Stop 4: Chez Richard

4.5 km E-SE of the center of the structure

Access:

At the southern entrance of Rochechouart city on the west side of D673 a few meters after the junction with the road to Babaudus-Pressignac (Figures 68 and 74).



Figure 74. Aerial view of Rochechouart city- Photo courtesy of Rochechouart City Mayor-2006. Position of stops 4-6

Description:

Small road cut ca 3 m high, 10 m long (Figure 75). Gneiss bedrock is exposed as part of the Lower Gneiss Unit (LGU) (see part 1). Steeply dipping to the North the gneiss is almost intact (yet some

fractures) at the lower left side of the outcrop (Figure 75B). Elsewhere it is heavily fractured (cataclastic). The contact between the two zones is relatively sharp and is irregular (Figure 75). The fractured gneiss is crosscut by a ca 20-30 cm thick breccia dike inclined 60° (Figure 75).

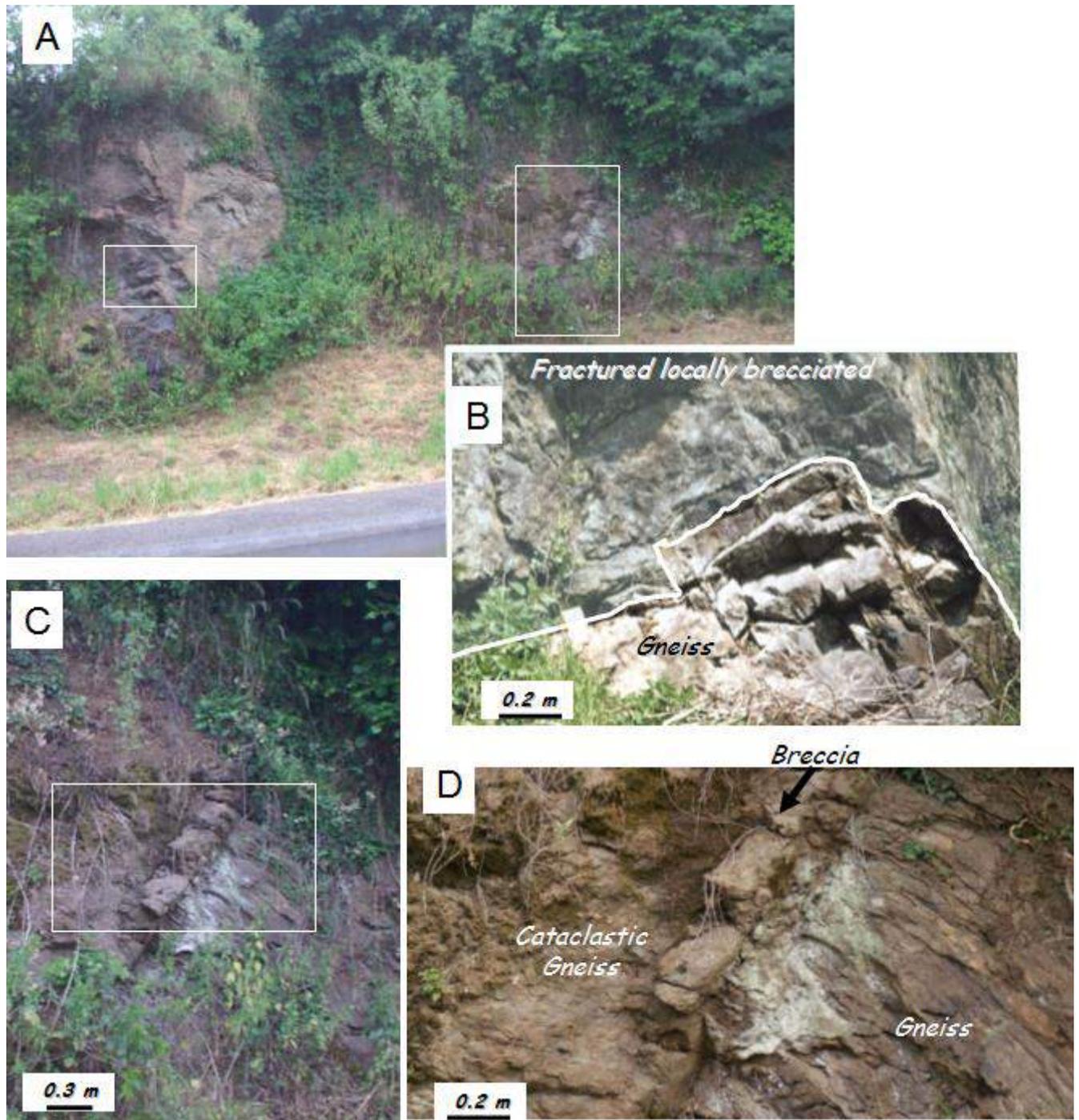


Figure 75: Stop 4: Chez Richard: Road cut (location see Figure 68). A- General setting. B- Close up view of the contact between the relatively intact gneiss and the fractured +/-locally brecciated gneiss (frame on the left in A), C- Close up view of the framed zone on the right in A; D detail showing the fractured gneiss crosscut by a polymict lithic breccia dike .

Stop 5: Rochechouart

4 km E-SE of the center of the structure

Access:

At the southern entrance of Rochechouart on road to Babaudus-Pressignac, at the junction with route du Chemin Neuf (Figures 68, 74 and 76).



Figure 76: Stop 5: Rochechouart. Roman door marking the entrance of the city. Rock cliff in the background made of the typical “Rochechouart” polymict lithic breccia.

Description:

Large rock cliff dominating the small Graine river valley (Figures 75-76). With Chassenon, Babaudus and Montoume visited later, this particular site is historic and instrumental of the recognition of the Rochechouart structure as an impact. The rock is a polymict lithic breccia.

Petrographic and geochemical descriptions are given in part one.

As seen in Figure 77 from the bottom of the cliff, the cliff is not stable and rocks tend to fall (red arrow in Figure 77 = recent fall), explaining the name of the city (Rochechouart meaning rock falling in ancient French).



Figure 77: Stop 5: Rochechouart cliff seen from below. Note the faint stratification (double white arrow), the faults (black arrow) and the difference of color (frame) due to a recent (artificial) rock fall (ca 30 years ago). Upper insert, detail of the framed area showing large clasts

The breccia deposit displays a faint inclined bedding (Figures 77-78). This bedding is parallel to the crater floor which is also inclined. A highly fractured leptynite is outcropping on the top of the meadow at the foot of the castle (Figures 78-79).

This enables to virtually draw the physical limit of the crater (Figure 79). The limit between the impact deposit and the bedrock corresponds to inclined plane of the meadow rolling down to the Graine River (Figure 79).

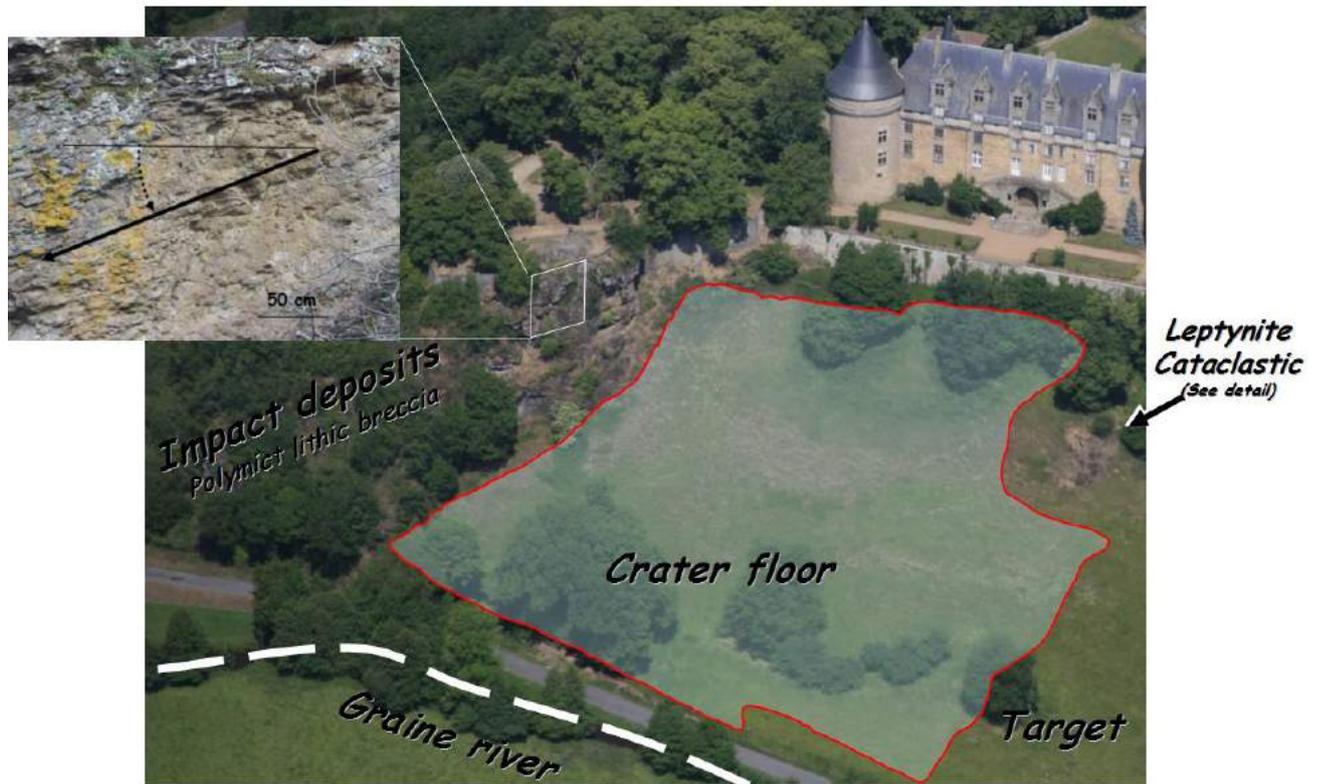


Figure 78: Stop 5- Rochechouart. Aerial view of the historic Rochechouart site forming a cliff overlooking the Graine River on top of which is installed the city and its castle. Photo courtesy of Rochechouart City Mayor-2006. The limit between the impact deposit and the target corresponds precisely to inclined plane of the meadow rolling down to the Graine River. The insert on the left shows a faint stratification within the breccia layer that runs parallel to the crater floor.

We can thus experience a very unique experience at Rochechouart: a walk on the bottom of an impact

crater, and then a look to what happen both above and below the limit...

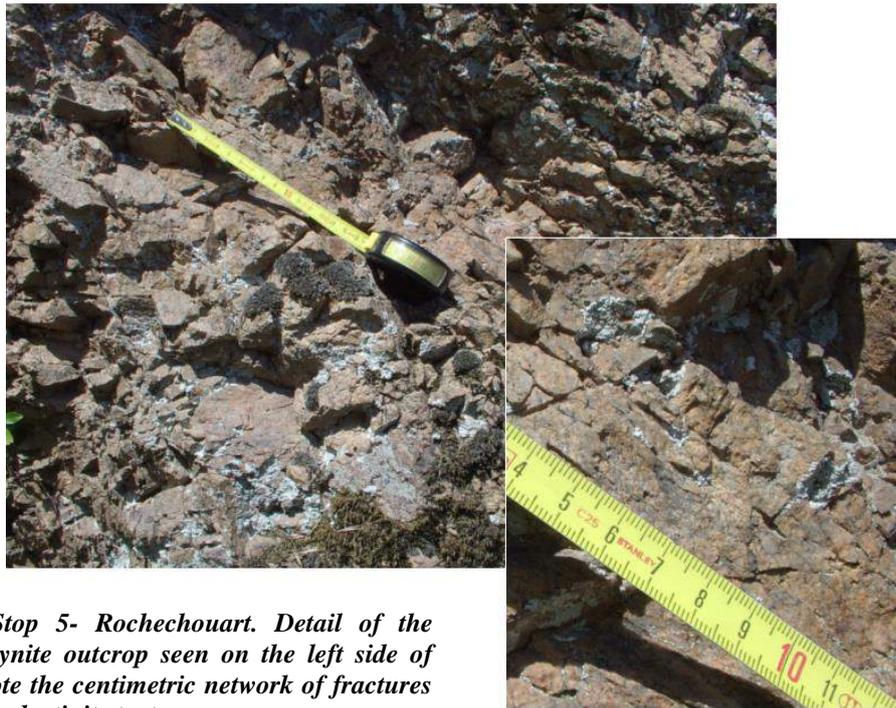


Figure 79: Stop 5- Rochechouart. Detail of the fractured leptynite outcrop seen on the left side of Figure 78. Note the centimetric network of fractures obliterating the leptynite texture.

Such a concept of “walking” on the physical limit of an impact crater (which, at some earlier stage, was also the limit of the transient cavity) takes all its sense on the west side of the Rochechoart cliff next to the Roman door. There it is indeed physically possible to place the foot on that limit, as the bedrock (underlying the impact deposit) is physically exposed together with the breccia cap (Figure 80).

There, the bedrock is characterized by striations and “grooves”. The striations are roughly oriented in the direction of the center of the structure (Figure 79).

It is not clear whether the striations are endogenic and simply result from the intersection with the topography of a fine bedded texture (schistosity ?) in the basement rock, or if it relates to the impact event.

The leptynites forming the basement in this location are rather massive gneiss with little schistosity.

The striations and grooves resemble to abrasion features observed on the bedrock at Ries crater, at the base of Bunte Breccia where they are interpreted as the result of the flow of large debris at the base of the Ries allochthonous deposit (note these features are observed outside the crater rim at Ries, here we are inside the crater).

Sampling and machining out a thin section out of this outcrop would clarify the nature and origin of these striations. Yet it is a beautiful exposure of the exact surface of the bottom of the cavity of a large crater, and we want to preserve and to show it this way.

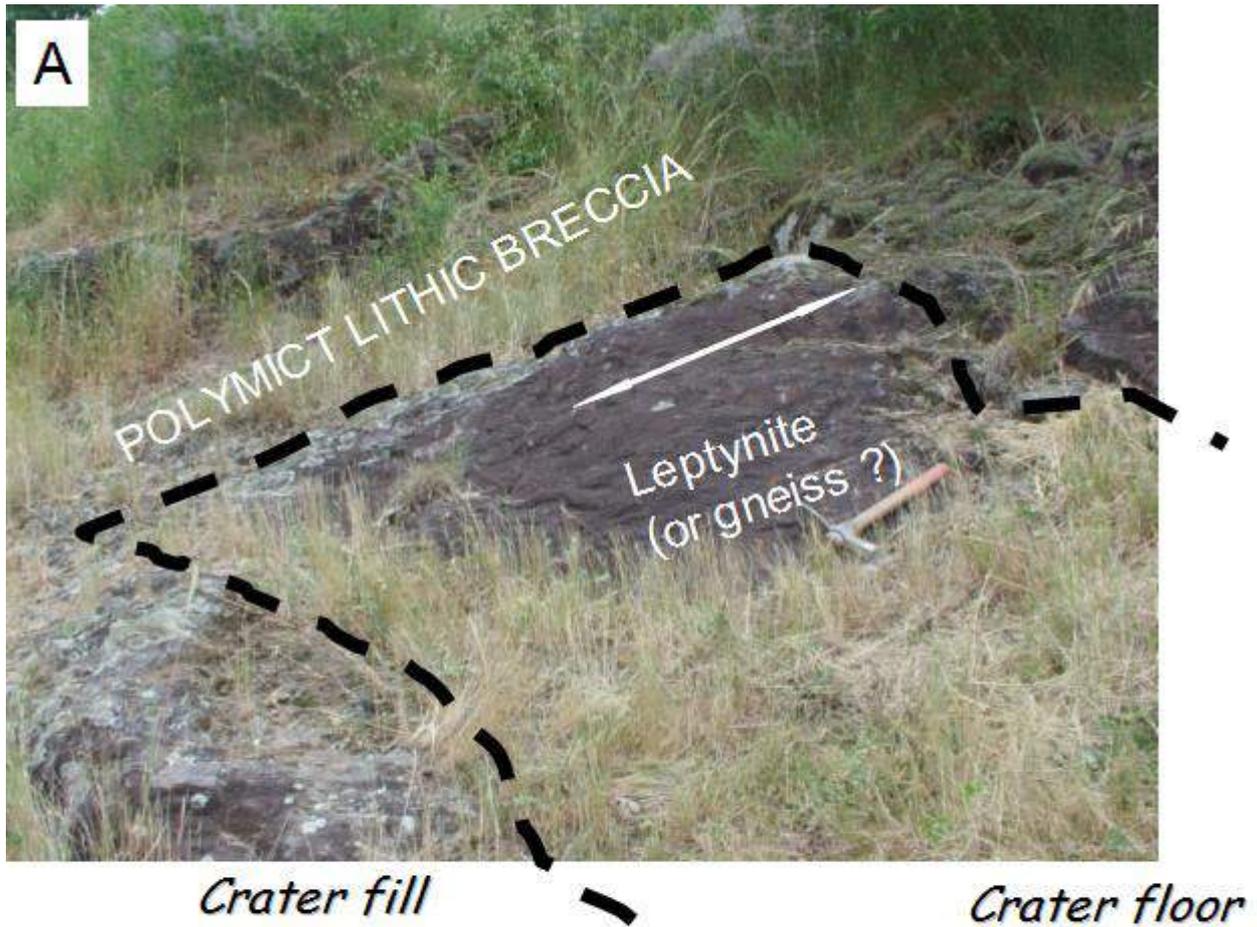


Figure 80: Stop 5: Rochechouart. Opportunity to walk on the physical limit of the crater ie on the contact between the gneiss and the crater fill deposit. Note the striations (white arrows) and the orientation of the striations (double arrow).

Stop 6: Rochechouart “Allées du Chateau”

4 km E-SE the center of the structure

Access:

Walk from stop 5, on the Route du Chemin neuf toward Rochechouart castle and right turn on the Castle alleys up to the “belvedere” (view point) (Figures 81-82).

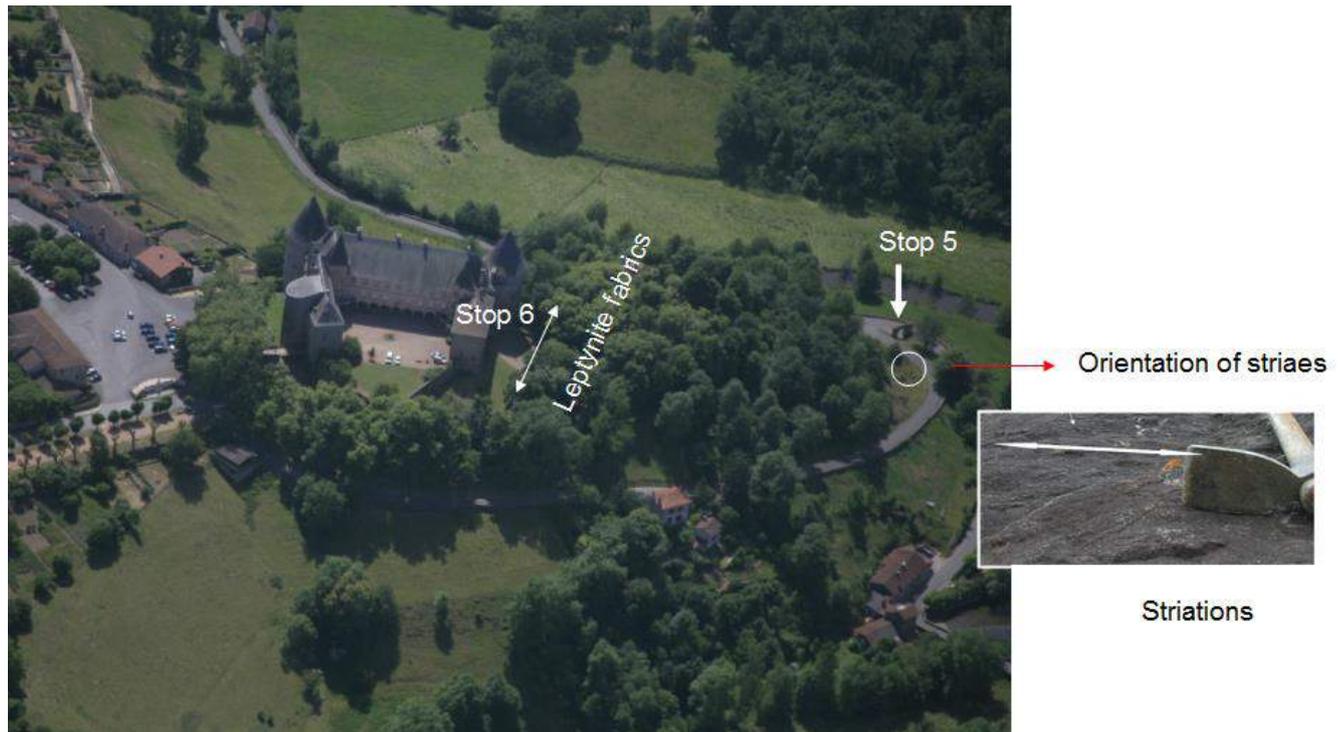


Figure 81: Stop 6- Rochechouart “Allées du Chateau” and steep « Rue du Chemin neuf » providing a cross section through the Rochechouart polymict lithic breccia deposit. Arrows showing the difference of orientation between striations seen on the basement at stop 5 and the leptynite fabric exposed at stop 6.

Description:

Polymict lithic breccia and contact with bedrock next to the west wall of the Rochechouart castle (Figures 81-83). This small stop is intended to display i) the homogeneous character of the polymict lithic breccia, ii) the complex geometry of the crater floor limit at the decameter-hectometer scale.

The first aspect is illustrated by the walk from stop 5 at the bottom of the breccia cliff, up to the “belvedere”, representing the highest part of the breccia deposit. The entire section (ca 40 m) displays the same textureless, grey polymict lithic breccia character (brown at fresh cut) (Figure 82). Petrographic investigation confirms the homogeneous character.

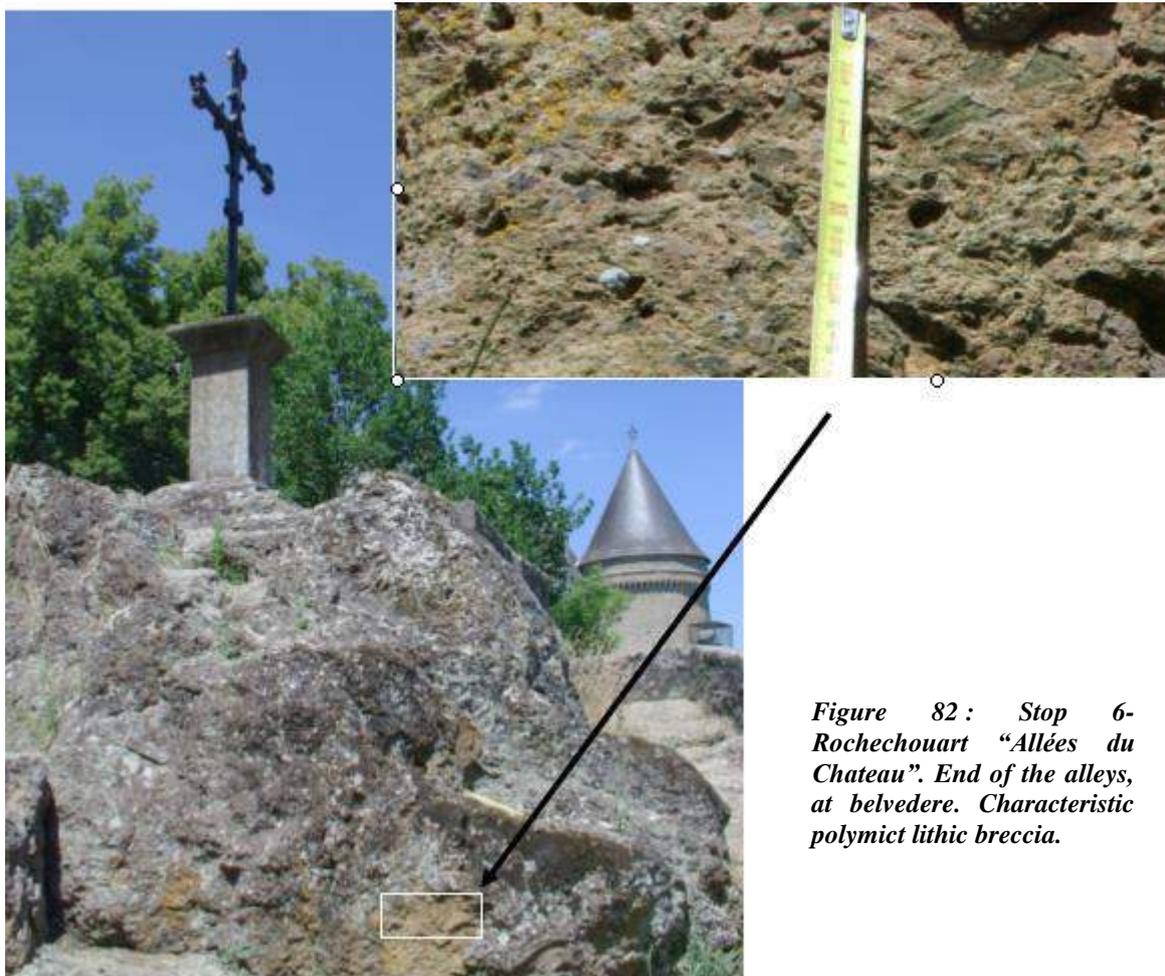


Figure 82 : Stop 6- Rochechouart "Allées du Château". End of the alleys, at belvedere. Characteristic polymict lithic breccia.

The second aspect is illustrated by the difference of elevation of the contact between the polymict lithic breccia deposit and the bed rock at stop 5 and at stop 6. At stop 6 the contact appears next to the west wall of the castle, only a few tens of meters from the belvedere. The rocky settlement of the castle wall as well as the small ridge seen in Figure 83 are characteristics of a fractured leptynite (Figure 83). The leptynite is dipping at ca 45 ° to the east (90° from the striations seen at the surface of the dasement rock exposed beneath the breccia deposit at stop 5).

The leptynite display signs of severe fracturing and is locally brecciated and/or percolated by polymict lithic breccia veins (no detailed petrographic study available so far for this outcrop)

The lateral distance between stops 5 and 6 is 250-300 m. The difference of elevation of the contact is ca 40 m. Such amplitude of variation over a few tens or hundred of meter is a common feature of the Rochechouart crater floor. Yet the average elevation remains the same (+/-) 50 m, over the whole 15 km diameter deposit zone.

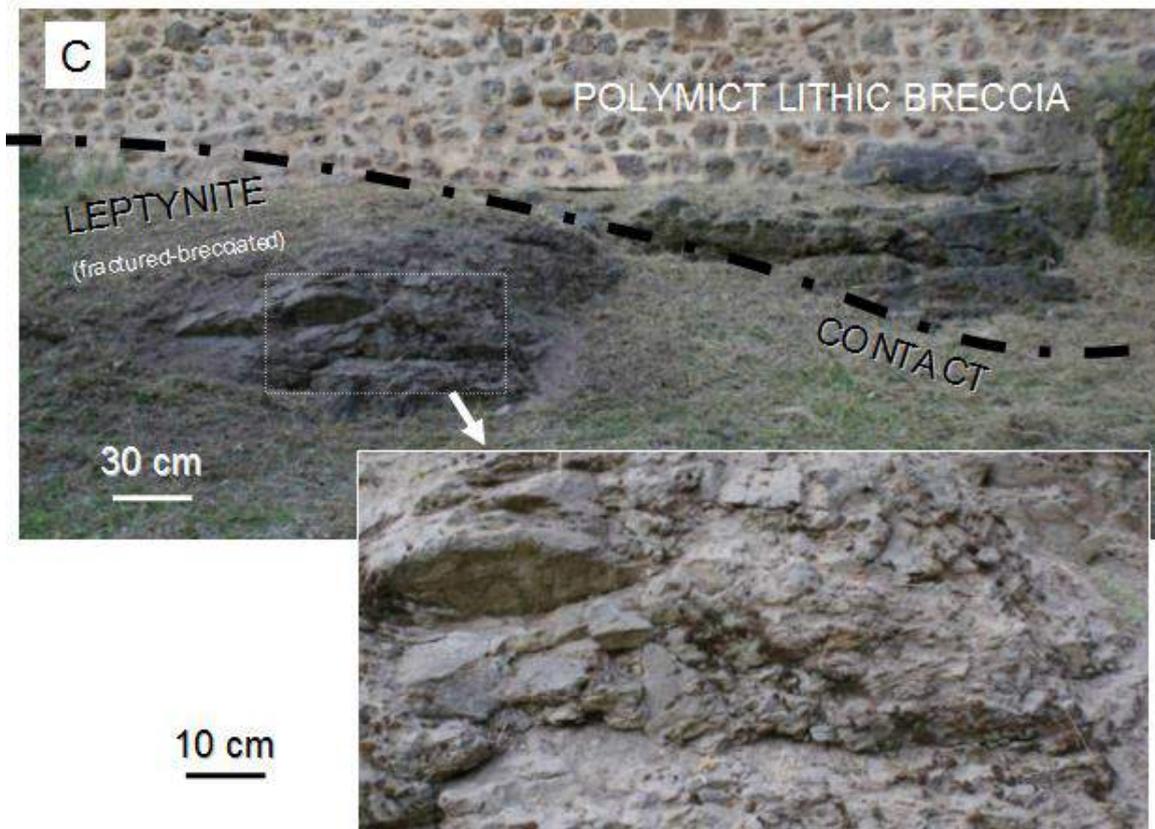


Figure 83 : Stop 6- Rochechouart "Allées du Chateau". Contact between 45° dipping fractured locally brecciated leptynite and the polymict lithic breccia deposit.

Center of the structure: Stops 7-13

Stop 7: Babaudus

1.5 km SE of the center of the structure

Access:

At the south exit of Babaudus village, in the direction of Breuil de Vayres, in front of the school/leisure center (Figure 84).

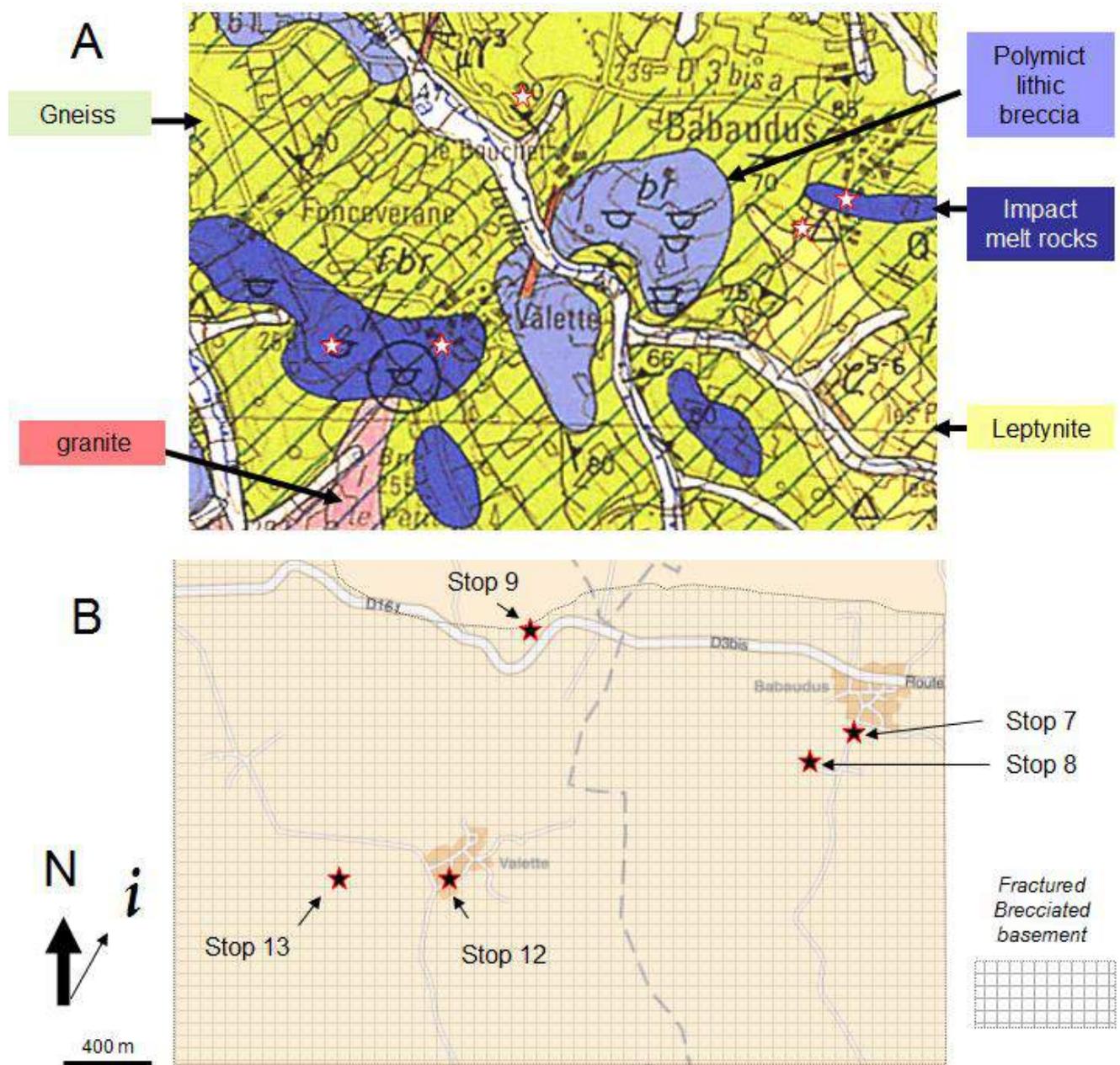


Figure 84: A-Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>) and B- access map for stops 7-9 and 12-13 (i: direction of center of the impact).

Description:

Impact melt rock at a small 1m high 30 m long road cut (Figure 85).

As seen Figure 85, the reference site for the best example of melt rich impact melt rock in the Rochechouart impact structure (90-95% melt,

Lambert 1977a) is not representing much on the field. The Babaudus impact melt sheet is about 1 meter thick and is responsible for the small lense like cap forming the top of the smooth hill seen in Figure 85. The bedrock is outcropping 100 m behind us in the village, and 100 m ahead, where the road disappears in Figure 85.



Figure 85: Stop 7- Babaudus impact melt rock outcrop.



Figure 86: Stop 7- Typical yellow-white Babaudus impact melt (at fresh cut).

Almost white at fresh cut, the Babaudus impact melt rocks become yellow brown when aging. For further detail on the petrography, the texture and the composition, refer to part one.

Stop 8: Babaudus bedrock

1.5 km SE of the center of the structure

Access:

At the south exit of Babaudus village, dirt road starting in front of the school/leisure center (location on Figure 84).

Description:

Water drainage cut along the dirt road. The rocks exposed at stop 8 are weathered. They display evidence of severe fracturing (Figure 87).

Very close to Babaudus impact melt this stop is intended to draw the attention on the extreme thinness of the Babaudus impact melt sheet. It also illustrates the fact that the impact melt is directly in contact with the bedrock. It eventually shows that the bedrocks is apparently not significantly more damaged than further away from the center of the structure (such as at the Rochechouart castle).

Note before the dirt road was built and the leisure park was installed, a black microdiorite-microgabbro dike was outcropping in the trail. It delivered the best shatter cones of the Rochechouart structure, with small, yet almost complete cones. The outcrop is now lost and buried under the new road construction.

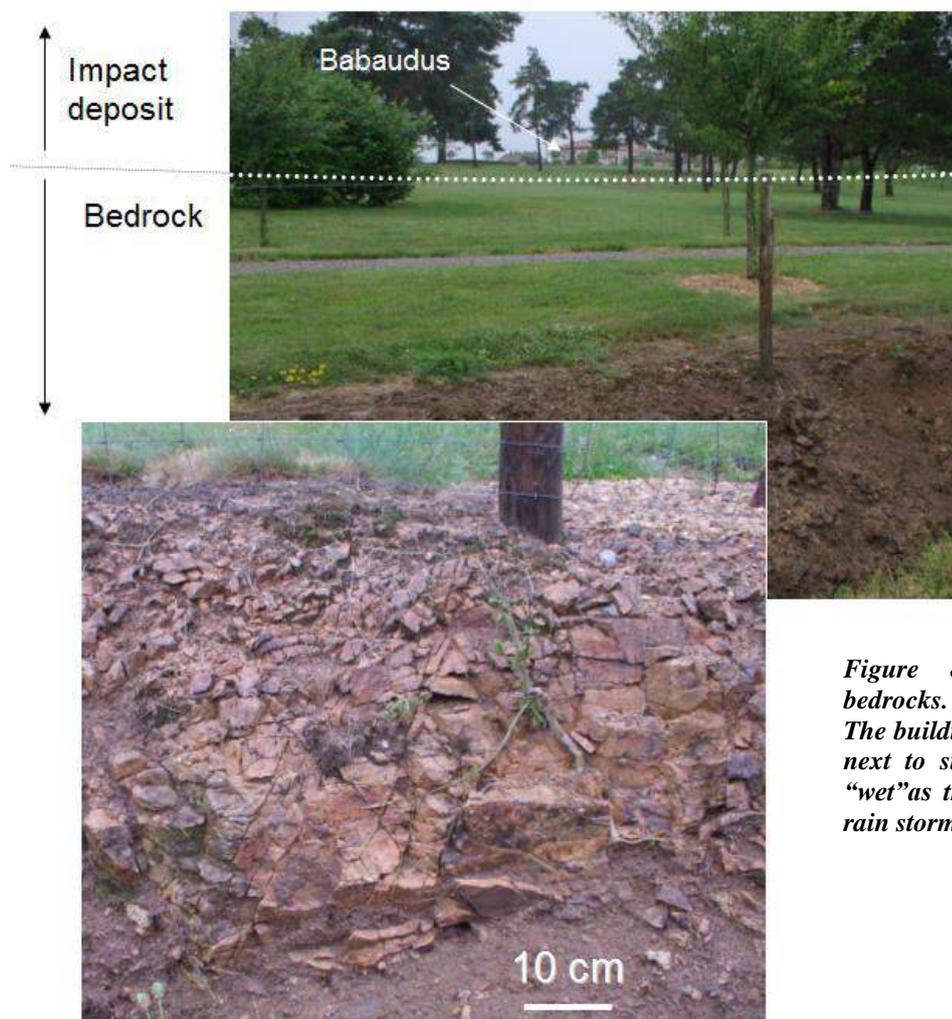


Figure 87: Stop 8- Babaudus bedrocks. Here a fractured leptynite. The building on the top of the hill are next to stop 7 (note the outcrop is “wet” as the picture is shot during a rain storm).

Description:

Small road cut ca 3 m high, 15 m long displaying a highly fractured basement (gneiss). Damages includes dense fracture network (cataclasis), small pervasive anastomosed and intersecting veins (mm wide) decimeter wide aphanitic dike (pseudotachylite like dike). The initial gneiss fabric is difficult to recognize due to the fracturing.

Stop 9: “Hauts de Laurière

At the center of the structure

Access:

On the left side of road D161 in the direction of Pressignac, after the junction for Laurière (location on Figure 84).

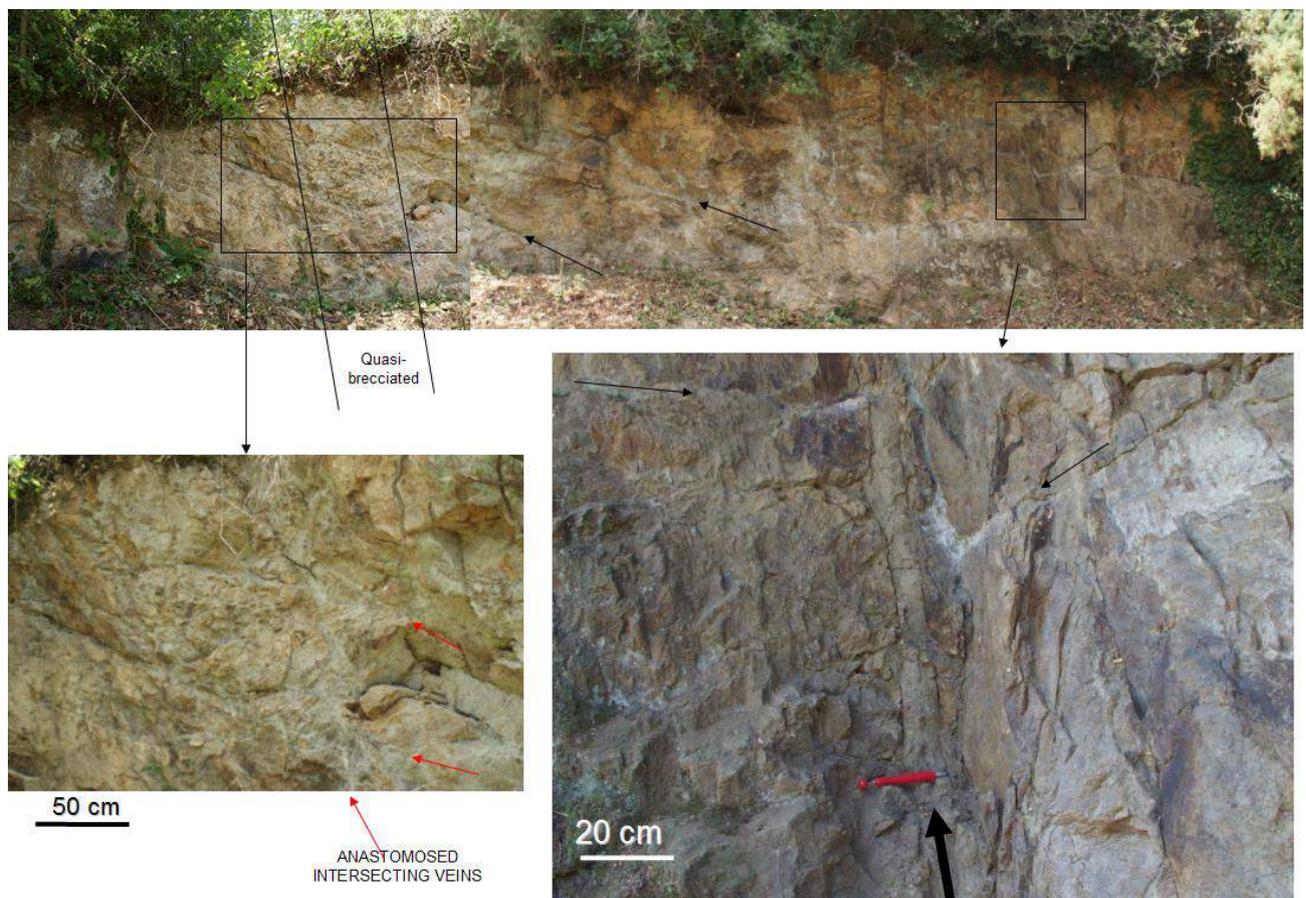


Figure 88: Stop 9- Haut de Laurière bedrock at the center of the impact structure. Highly fractured gneiss. The initial texture is difficult to recognize due to the damages attributed to the shock (and the weathering). Small veins (arrows). Large (10 cm wide) aphanitic dike (large arrow).

Stop 10: Moulin de La Brouse quarry

1.5 km NW of the center of the structure

Access:

From stop 9 on D161 returning in the direction of Rochechouart, first left in the direction of Chassenon then left after the descent and before the

bridge on Graine river, then on the dirt road up the the old quarry (see access map Figure 89).

Description:

Old quarry in the gneiss, abandoned in the late 1900's after the tragic death of the owner (killed by rock falls in the quarry). The gneiss is 45 ° dipping to the north (Figure 90A). The same type of rock as the bedrock outcropping at stop 9 (LGU) is exposed here.

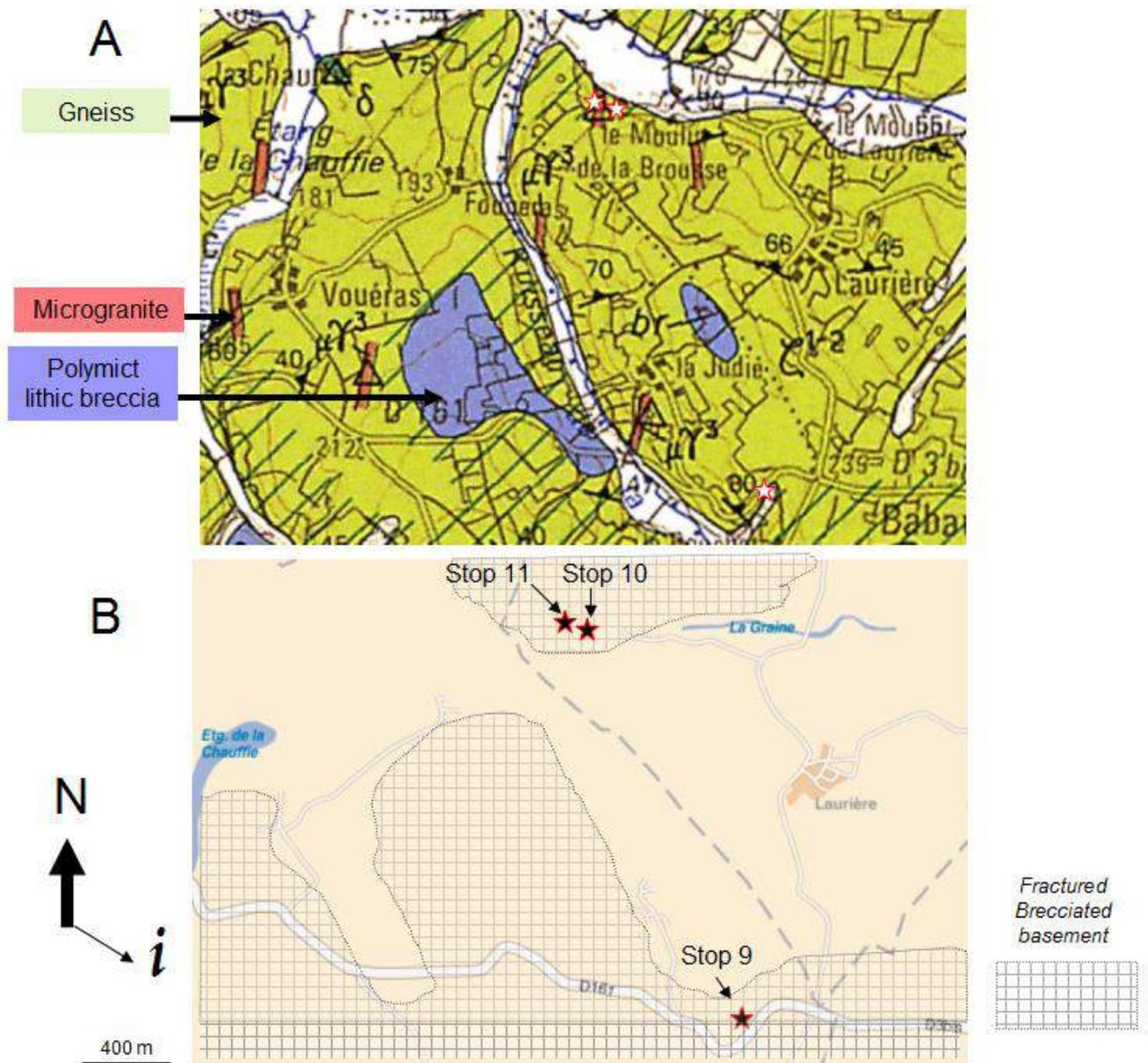


Figure 89: A-Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>) and B- acces map for stops 9-11 (i: direction of center of the impact).



20 cm



5 cm



« shatter surfaces » ?

1 cm



3 mm

Figure 90: Stop 10- Moulin de La Brousse quarry. Typical LGU gneiss and non-typical striated features, possibly related to shock ? (see text).

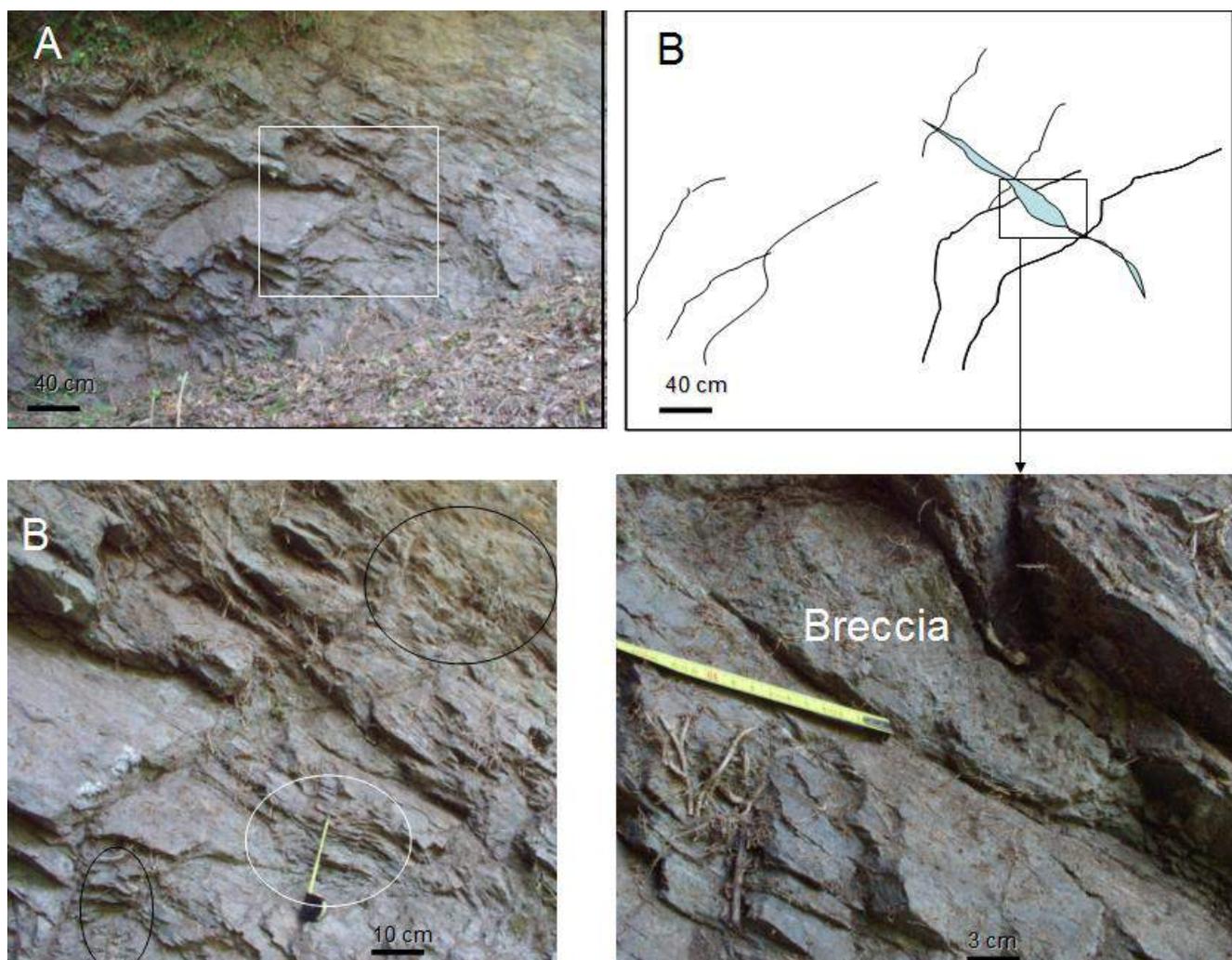


Figure 91: Stop 10- Moulin de La Brousse quarry. A- Gneiss transected by veins and dikes. B-Schematic map or veins (lines) and breccia dike (light blue). C- Local development of fracture (circles). D- Close up view of the breccia lense

The gneiss is significantly less fractured than at stop 9 and the metamorphic fabric is well expressed (Figure 90). The material is darker than leptynite, the difference being related to a more mafic composition (see geochemical data in part 1) with a larger proportion of phyllosilicates and plagioclases than in the gneiss. Note the millimeter wide intercalated quartz rich layers, and the occurrence of lenses of granitic composition (Figure 90).

The material displays +/- diverging striations in the direction of the gneiss fabric (Figure 90 D). Although these features are not unequivocal of shock, they could also represent “irregular” shatter surface. Unequivocal shatter cones are encountered in the nearby massive microgranites intrusions (see

next stop and stop 15 at Champonger). “Irregular” shatter cones have been described in association with real shatter cones in microgranite at other sites and referenced as “shatter surface” (Lambert, 1977a). They are characterized by a smooth striated breakage surface with a low angle inclination of the axis of diverging striated surface relative to the plane of foliation of gneisses. These features were previously noted by Kraut, but no or very little description of these “pseudo-shatter cones” exists in the literature.

The gneiss is locally fractured and displays anastomosed intersecting fractures and veins, including breccia dikes and dikes looking like the aphanitic dike seen at stop 9 and (Figure 91).

Stop 11: Moulin de La Brousse microgranite

1.5 km NW of the center of the structure

Access:

After stop 10, continued on the dirt road.

Description:

Lense shaped outcrop ca 2 m high- 8 m long on the flank of the trail (Figure 92). The exposed rock is a massive microgranite intruding the gneiss formation. The microgranite is characterized by fractures (two major sets – lines in Figure 92), and by shatter-cones (Figures 93).



Figure 92: Stop 11- Moulin de La Brousse microgranite. Lines : Major sets of fractures.



Figure 92: Stop 11- Moulin de La Brousse microgranite. Centimeter fracture network, fractures bearing the striations typical of shatter cones





Figure 93: Stop 11- Moulin de La Brousse microgranite. Shatter cones (centimeter to decimeter in size).

Stop 12: Valette

2 km SW of the center of the structure

Access:

On D161 from Rochechouart to Pressignac, at ca 1 km after stop 9, small road at sharp angle to the SW in direction of Fontceverane, Valette, Pers (see Figure 94).

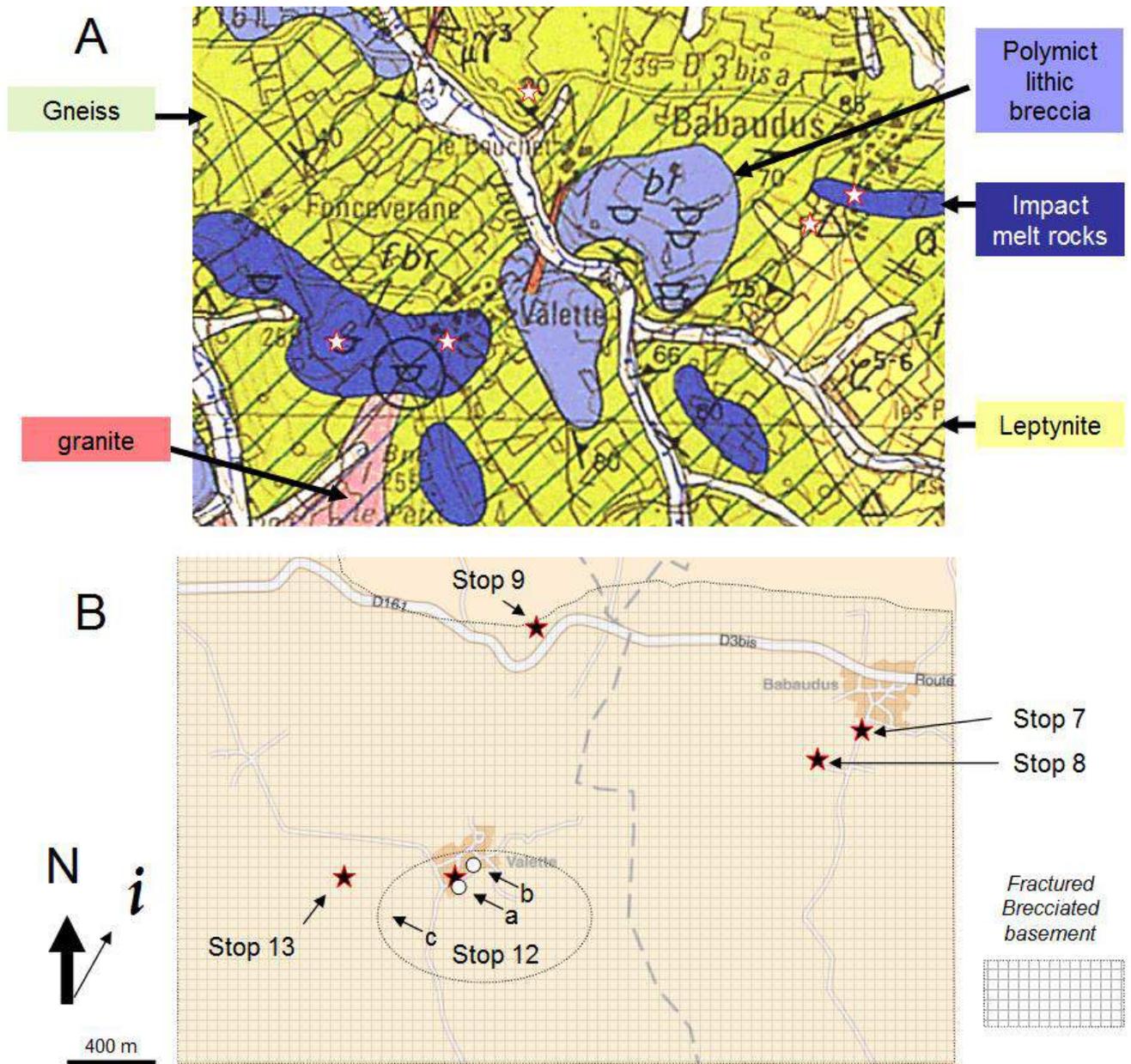


Figure 94: A-Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>) and B- acces map for stops 7-9 and 12-13 (i: direction of center of the impact).

Description:

This stop declines in 3 sub-stops:

Stop 12a-Valette Impact melt: Valette village

There use to be a 10-20 m wide shallow depression at stop 12, trace of an ancient excavation made by the village people to dig out rocks for building the village. This transformed into a pond, and it was unfortunately filled a couple of decenies ago. This was the reference site for Valette impact melts rocks. Impact melt rocks still outcrop locally on the ground and at the base of the old houses.

There Valette impact melt rocks are similar in color to the Babaudus impact melt rocks (light yellow), like at Babaudus (and everywhere else) the melt is crystalised and altered and like at Babaudus, the clasts are essentially quartz or quasi-quartz in composition (Figure 95). Yet the proportion of clast is higher at Valette than at Babaudus (ca 20% against ca 5 %). Also no or few vesicles are observed in the Valette melt. The sacharoid milky aspect of some of the clasts (*tq* in Figure 94) is due to high shock-high thermal annealing effects as seen from petrography investigation.

Stop 12b-Basement at the eastern exit of Valette

This small outcrop only a few decameter away from the impact melt rocks, display the characteristic texture of fractured gneiss (Figure 96). It marks the eastern limit of the Valette impact melt sheet. This outcrop together with the next one (sub stop 12c) illustrate both the thin character of the Valette impact melt sheet and the permanence of the expression of the crater floor in the Rochechouart impact structure. Here again we walk on what was, at one stage, the floor of the transient cavity of a large impact crater...

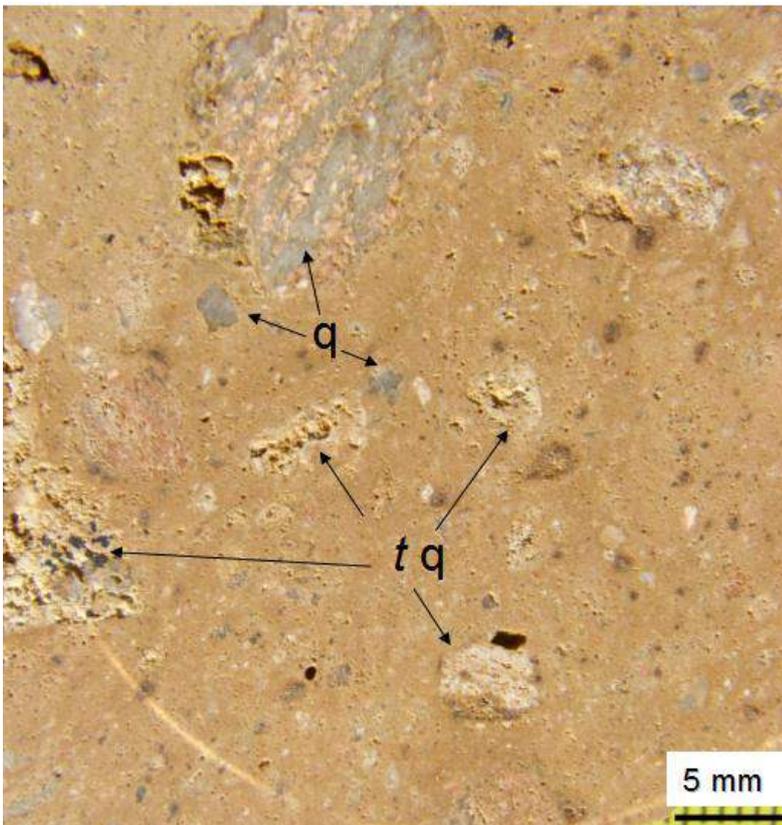
Stop 12c- Valette basal suevite.

Located at the western limit of the Valette impact melt sheet, only some 500 m away from the opposite limit seen at sub-stop 12b (see Figure 94), the outcrop from a small relief in the trail (Figure 97).

The rock displays a complex texture and is characterized by a mixture of impact melt breccia and polymict lithic breccia. This type of material is referred as basal suevite owing to both the position and the presence of clastic matrix material (see description and discussion in part one).



Figure 95: Stop 12a- Valette. Impact melt rock. Massive texture, relatively abundant clasts dominated by quartz debris and quartz rich rocks (q), some being significantly "altered" (tq) (see text).



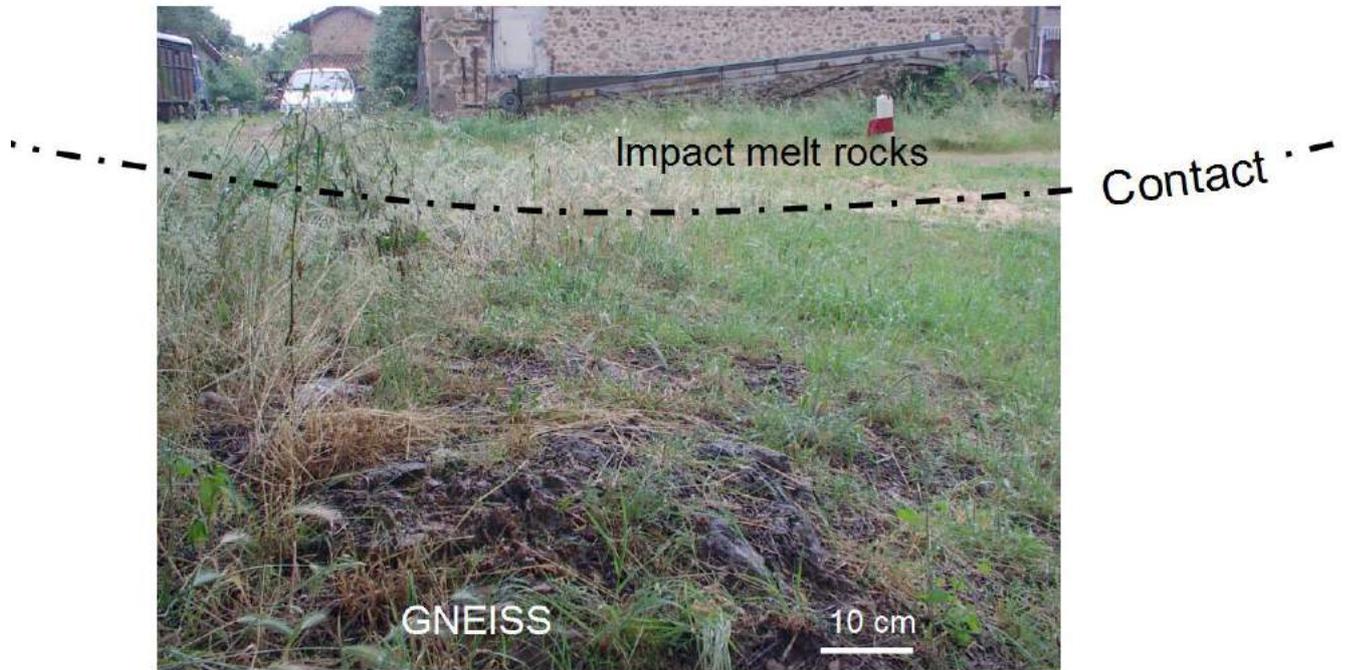


Figure 96- Stop 12b- Valette. Deformed (fractured) gneiss and contact between the Valette impact melt rocks and the crystalline bedrock.



Figure 97: Stop 12c- Valette. Bottom of the melt sheet, basal suevite and bedrock.

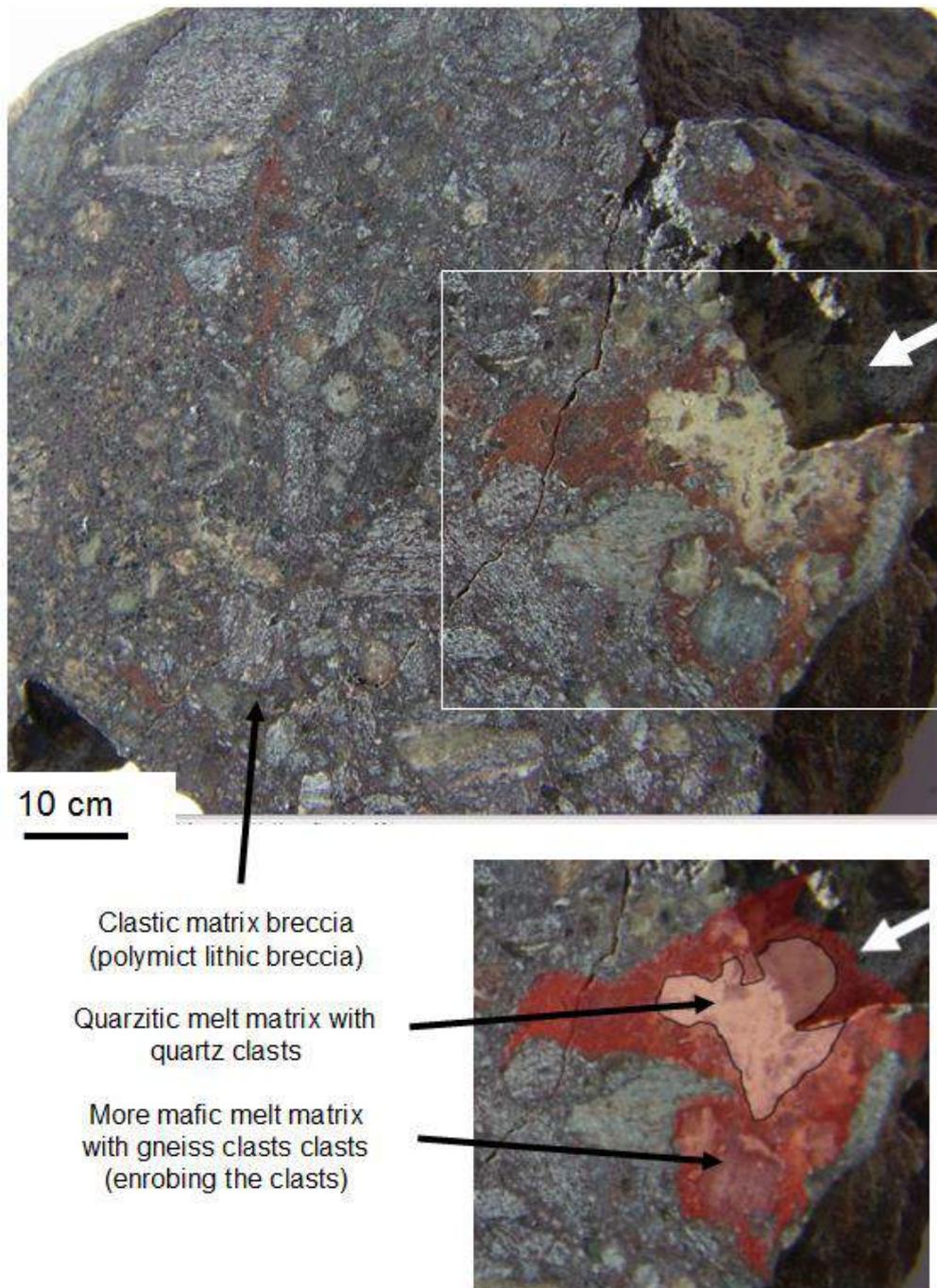


Figure 98- Stop 12c- Valette basal suevite

Figure 96 illustrates an example where the basal suevite is dominated by the clastic matrix member. In this particular example, the clast population is essentially represented by a single lithology, mafic gneiss, giving to the whole rock its dark tint

(Figure 98). It includes schlierig clast of impact melt rocks, itself bearing a complex texture, with a core and a periphery with distinct composition and colors (Figure 98).

Description:

Series of small outcrops lost in the wood possibly related with fallen trees during the last tempests. Several outcrops are spread over a 20-20 m2 zone (Figure 99).

Stop 13: Grosses Pierres

2 km SW of the center of the structure

Access:

Trail in the W-SW direction at the southern exit of Valette. To the right on the second trail, then in the forest.



Figure 99: Stop 13- Grosse Pierre. The site is "lost" in the forest (upper view). Claude Marchat at scale showing the large clast of microgranite in the breccia.



This site has just been recognized at the favor of the preparation of the field trip by Claude Marchat whom I asked to try to identify outcrops in the Fontceverane-Valette area, in replacement of the

serie of small quarries in the impact I investigated in the 1970, which have since been filled by the farmers to let larger space for their cattle exploitation.

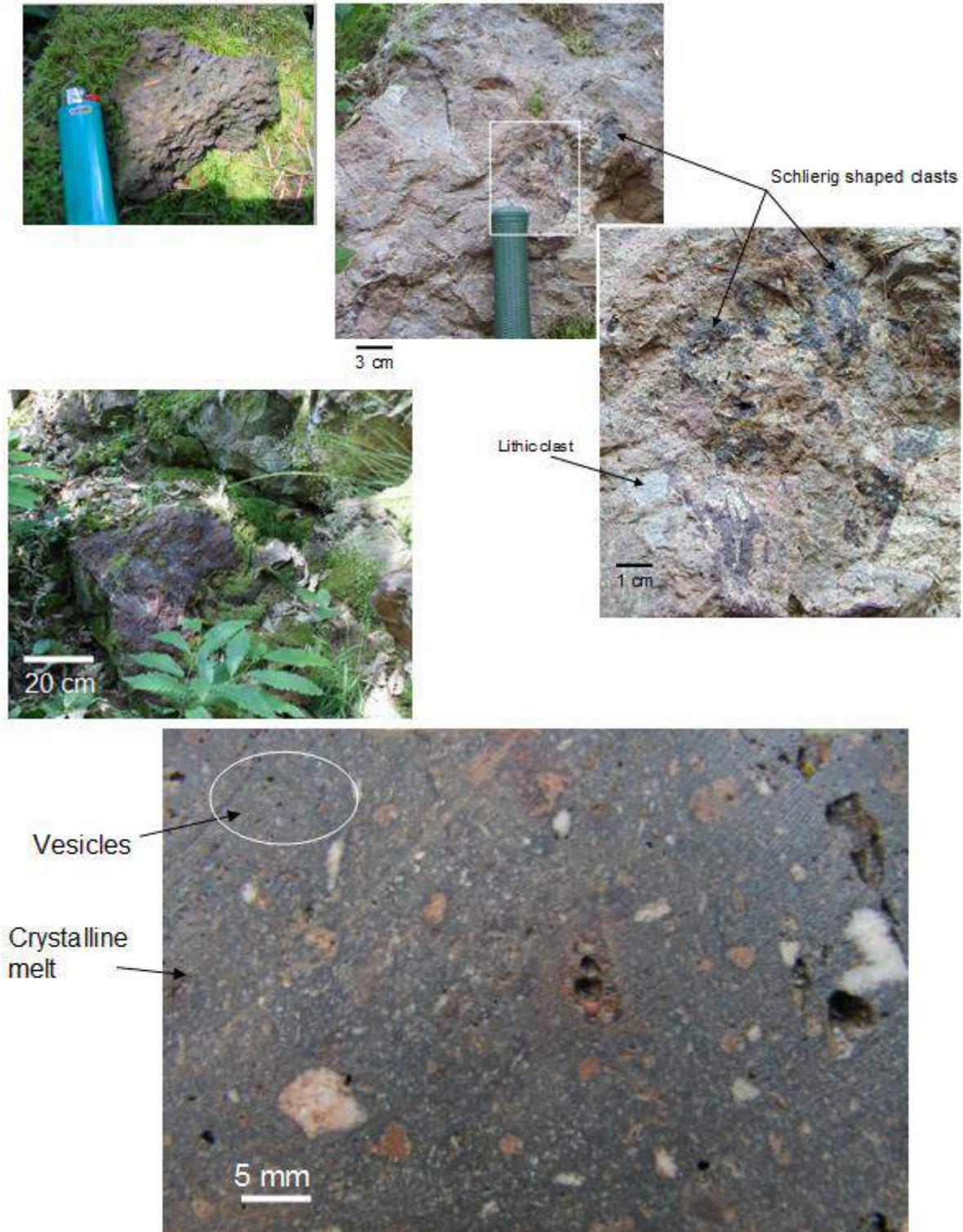


Figure 100: Stop 13- Grosse Pierre. Varied texture; A: Vesicular impact melt, B: massive melt poor impact melt or melt rich basal suevite, with shlierig clasts (melts) and relatively abundant lithic clasts; C: melt rich impact melt, with few small clasts and an homogeneous melt matrix with small vesicles.

The petrographic study of the rocks outcropping at stop 13 has not been realized yet. A large clast (50 cm) of microgranite is seen in the breccia (Figure 99). There may be significant textural variations at the scale of the outcrop (Figure 100). Some loose blocks present large vesicles (Figure 100A). The rock seen in Figure 100B is massive and displays dark contorted schlierig clasts (Figure 100). The texture compares to clast rich impact melt rocks and/or to melt rich basal suevite. Eventually the rock shown in Figure 100C corresponds to a clast poor impact melt rock, characterized by a dark matrix and

It is suspected that the composition of the dark schlierig clasts seen in Figure 100B matches that of the dark melt matrix of the rock in Figure 100C and compares to that of the dark gneiss clasts forming most of the breccia seen in Figure 95. Field

geochemical measurements on site with the portable XRF instrument will possibly provide some clues.

Peripheral melt rocks: Stop 14

Stop 14: Montoume quarry

7.5 km S of the center of the structure

Access:

From Rochechouart, on D10, left turn on D90 in direction of Chéronnac. Dirt trail on the left at the entrance of Montoume (Figure 102).



Figure 101- The Montoume impact melt sheet seen from D10 at a distance of ca 1km north of the hill

Description:

This site is located in the largest quarry in impactites in the Rochechouart impact structure. Used for building stones, the site has been abandoned since over ½ century. The quarry is now the property of the Community of Communes of Pays de la Meteorite. Figure 103 illustrates the site which has developed an important vegetal

cover over the past years (compare with Figure 37 in part one).

This particular site is one of the 3 main historical sites instrumental of the recognition of the impact origin of the Rochechouart structure. Characterised by a distinctive deep red color (Figure 103) and a massive texture (Figure 104), the rock conforms to the definition of a clast rich impact melt.

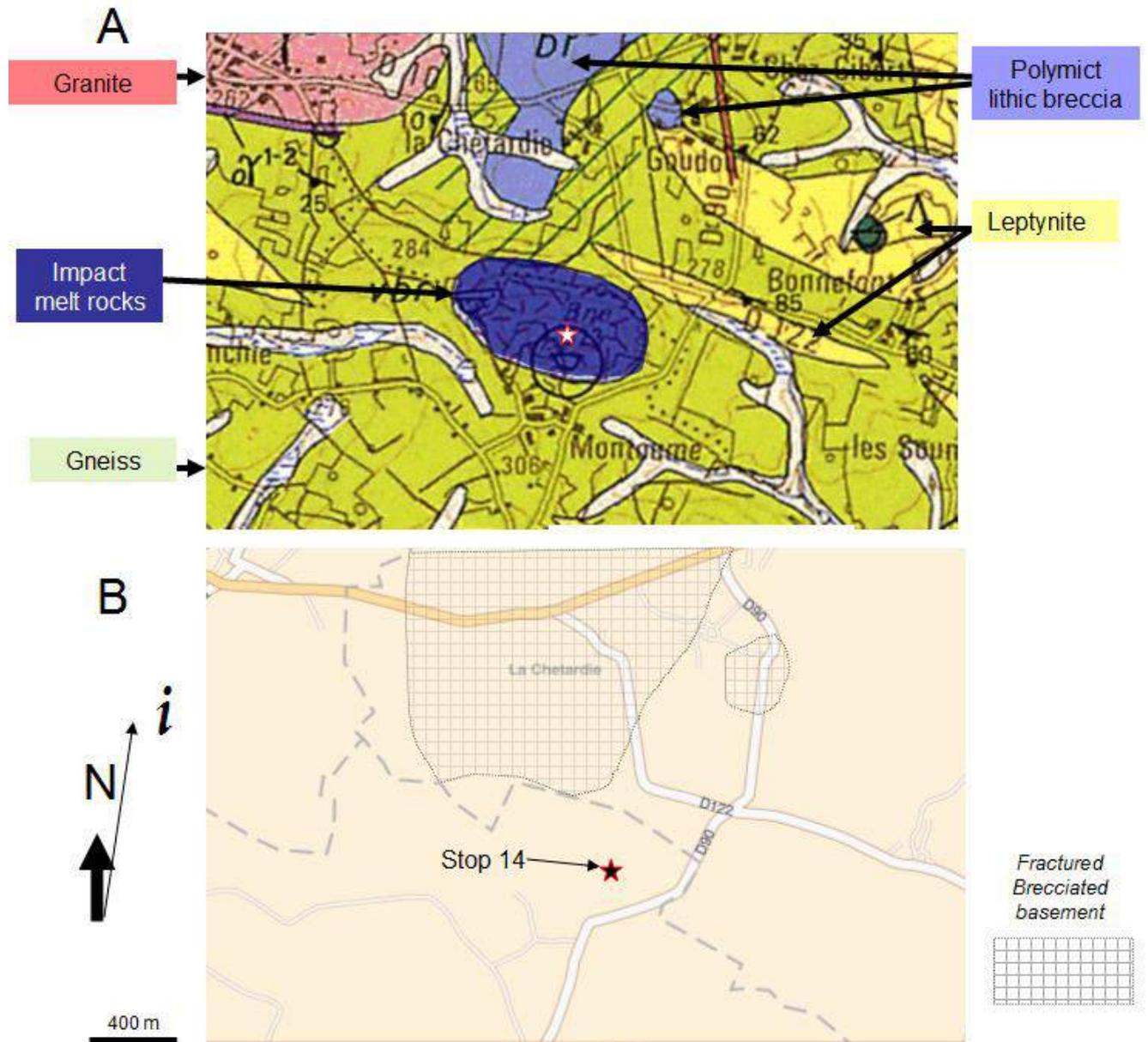


Figure 102: A-Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>) and B- acces map for stop 14 (i: direction of center of the impact).



Figure 103-Stop 14- Montoume quarry as of 1970 and today.

The Montoume impact melt sheet forms a 900 m long, 600 m wide, ca 25 m high hill (Figure 102) at the southern edge of the Rochechouart impact deposit.

As stated in part 1, Montoume breccia is massive structure, lacks vesicles, and displays large vertical-subvertical joints interpreted as cooling joints (comparable to those commonly found in large impact melt sheet and lava sheets). The paleomagnetic studies of Carpozen et al. (2006) suggest the Montoume impact melt remained at equilibrium temperatures above the Curie point (680°C) resulting in a complete reset of the

paleomagnetic record. This is consistent with the igneous character of the rock, and the complete decomposition of micas. This last mechanism releasing Fe is probably accounting for the red color of the Montoume melts. Note the total iron content of Montoume impact melt rocks is not higher than the average target in the Rochechouart impact (see part one).

The Montoume site will serve for the μ XRF testing on the various clasts and textures observed in the wall of the quarry and on hand specimen. Selected samples are shown in Figure 104.

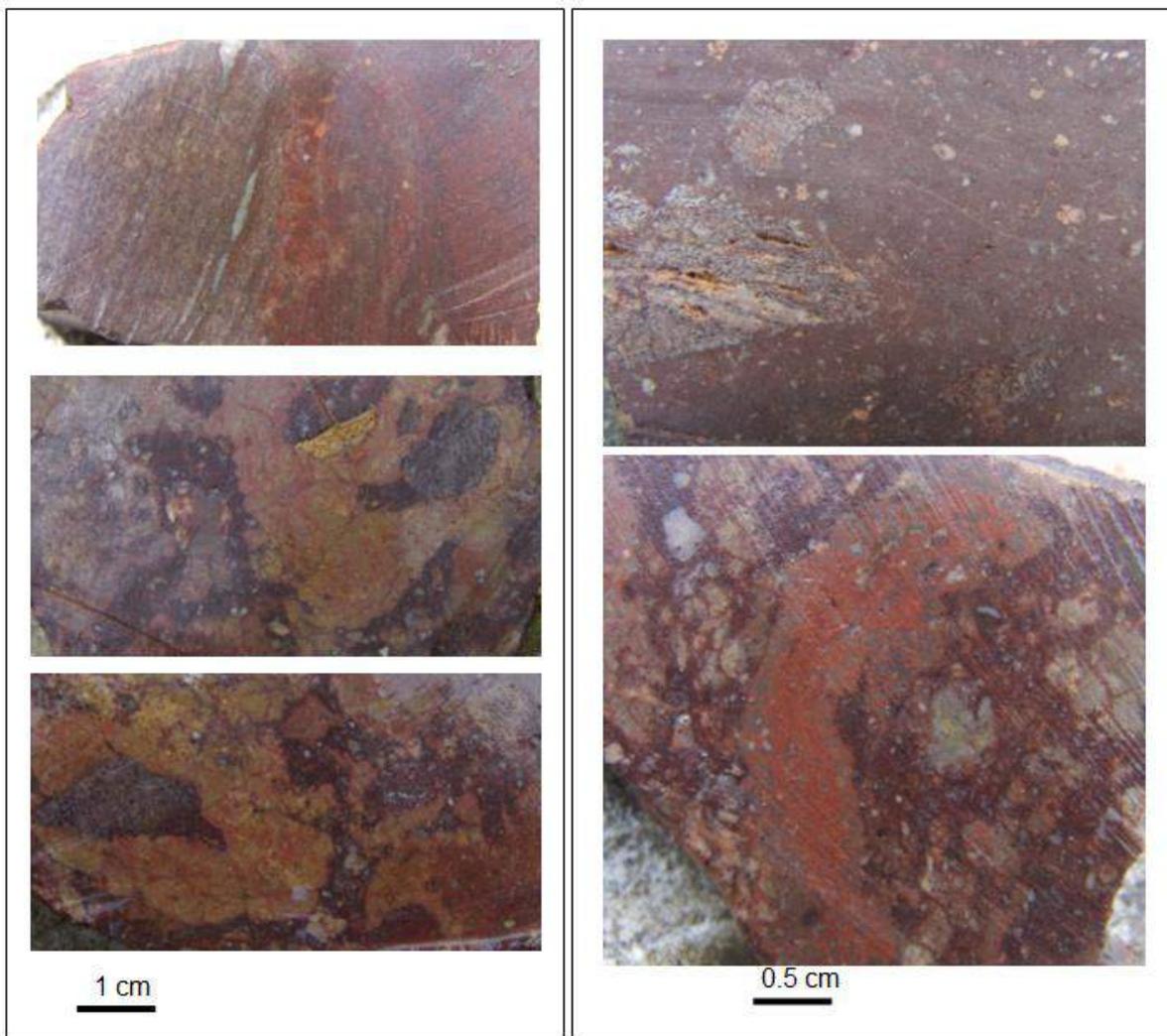


Figure 104-Stop 14- Montoume quarry. Specimen for μ XRF testing experiment sampling various textures, clast types and weathering stages.

Chassenon deposit: Stops 15-18

Stop 15: Champonger quarry: bottom of the crater fill

2 km NW of the center of the structure

Access:

In the village of Chassenon, coming from Rochechouart, turn left at the first intersection (50 m before the main square and the church). Stop at the small “village” of Champonger (a few houses). The old quarry is located down in the field, south of Champonger (see Figure 105).

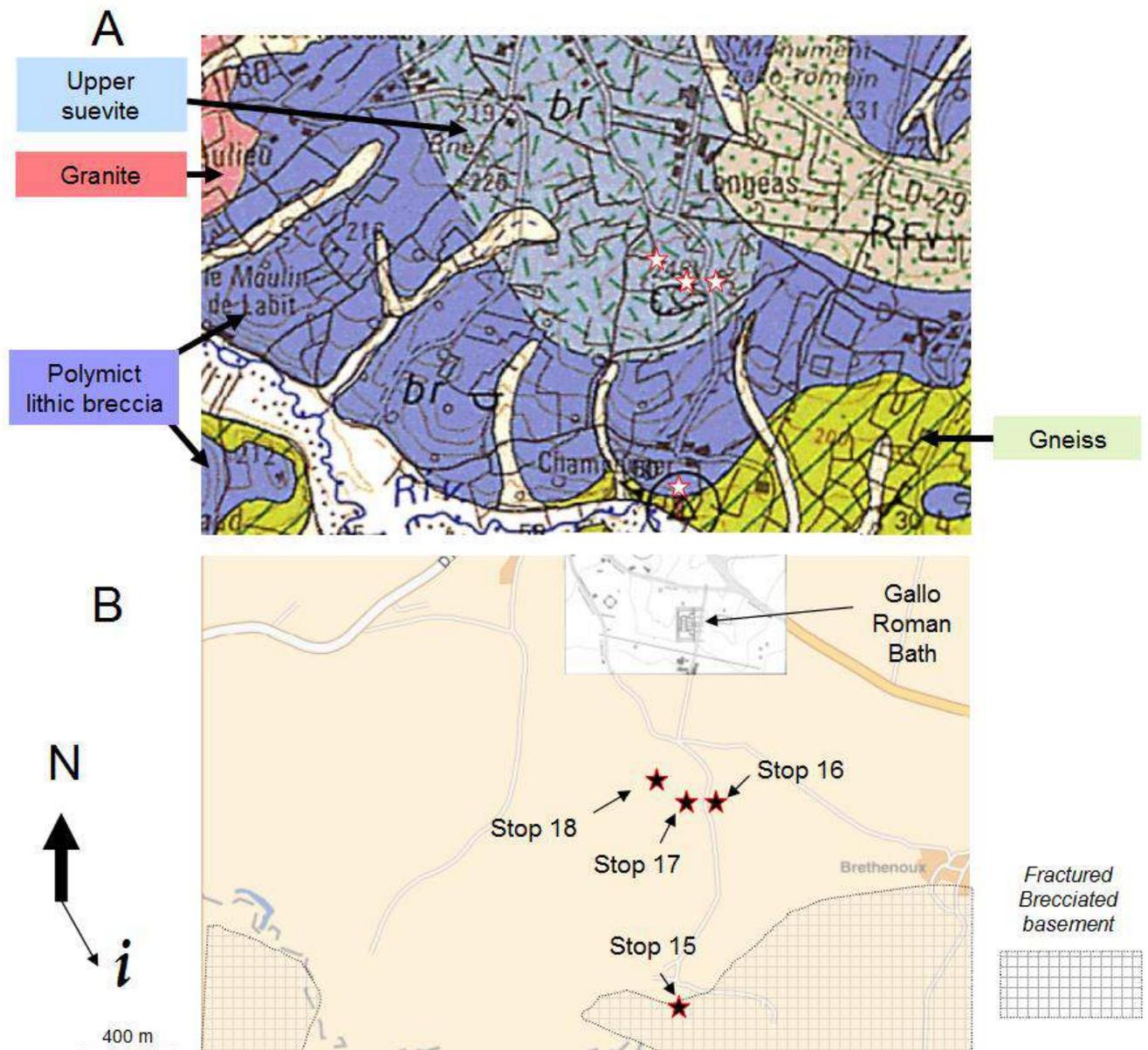


Figure 105: A-Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>) and B- acces map for stops 15-18 (i: direction of center of the impact).

Description:

Old little quarry ca 2.5 m high- 5-10 m wide.
There too the vegetation has considerably modified

the site as seen by comparison with the early 1990
view of the quarry (Figure 106).

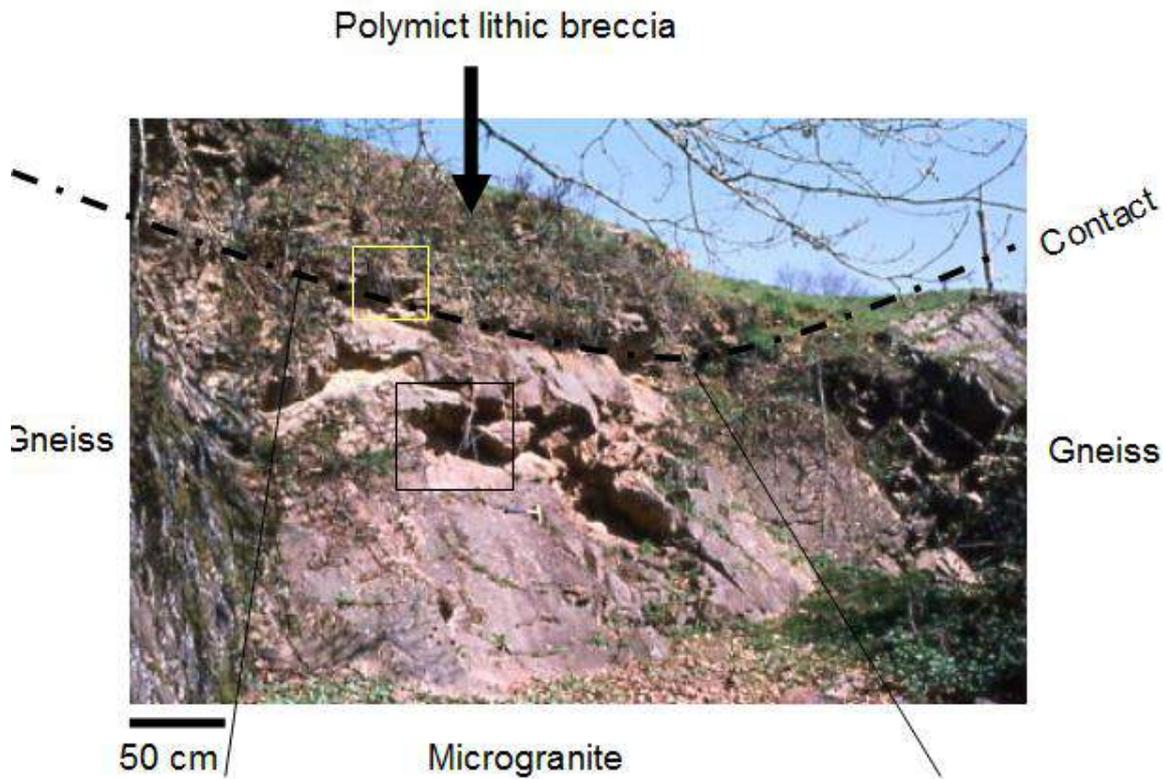


Figure 106: Stop 15: Champonger old quarry in the early 1990's (top view) and today (bottom view).

The quarry displays the basal contact between the Chassenon crater fill sequence and the bedrock. Here again we can place the finger on the crater floor (Figures 106-107). The bedrock is formed by

gneiss intruded by a microgranite dike (Figure 106). Both rocks display a relatively massive texture, with lesser density of fractures than at previous



Figure 107: Stop 15: Champonger old quarry. A: Detail of the Polymict lithic breccia. (field of view represented by the yellow square in Figure 106). B: Detail of the microgranite and its shatter cones (arrow) (field of view represented by the black square in Figure 106).

B



Yet the rocks displays unequivocal shock effects (at least in the microgranite) in the form of shatter cones (Figure 107). The gneiss also bear striated surface. Although they are not showing the typical cone shape of shatter cone, they display diverging striations and are interpreted as “shatter surfaces” resulting from the same mechanism as shatter cones, the anisotropic fabric of the gneiss being of significance for the development of the visible

striations and the absence of conical fracture surface (Lambert, 1977a). Yet this hypothesis need to be further assessed and tested. More generally, the understanding of shatter cones certainly requires considering features that are departing from the didactic and scholar cones. This may be one. Other anomalous types of shatter cones are known at other sites, such as opposite cones which are not reported so far at Rochechouart.

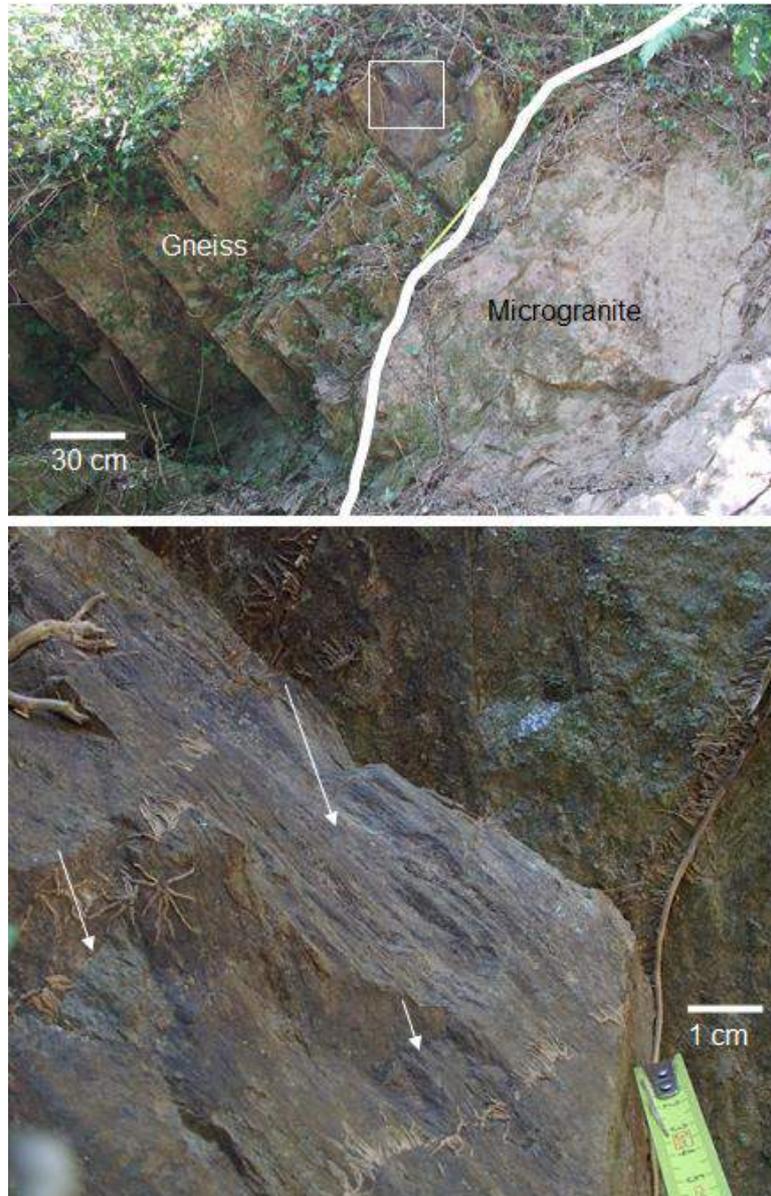


Figure 108: Stop 15: Champonger old quarry. Top: General view of the west side of the quarry showing the contact between the gneiss and the microgranite intrusion. Note the massive texture of the gneiss and the well expressed stratification (relatively few fractures compared to other sites previously visited in the basement) and preservation of the gneiss fabrics). Bottom view: close up of the framed zone in A. Arrow: striated surfaces interpreted as shock produced “shatter surfaces”.

Stop 16: “Grosse Pièce” quarry: Top of the crater fill

4 km NW of the center of the structure

Access:

On the right side of road from Champonger to Chassenon, 400 m before the junction to Longeas and the trail to Bretenoux (see Figure 105).

Description:

This quarry is actually ca 8-10 m high, 50 m long (Figure 109). The quarry has been re-activated early 2009 on the site of an historical quarry (Roman). As part of the development of the new and nearby archeological park in Chassenon suevites are currently excavated here for the restoring of some of the 3th century buildings and monuments in the park. The later are made of rock coming from this particular site.



Figure 109: Stop 16: Grosse Pièce quarry. Chassenon suevite. Lines : trace of the bedding

This quarry displays the largest and nicest exposure of upper suevites in the entire Rochechouart structure. The detailed petrographic and geochemical characteristics of these breccias are given in part one. Figure 110 shows the typical grey tint, the clastic matrix breccia texture, the typical green glass clasts and a less typical example of impact breccia clast in the breccia.

Positionned near the topographic high of the Chassenon deposit, and owing to the occurrence of

impactoclastites nearby, the rocks exposed here are considered to be representative of the top part of the suevite layer (and representative of the top part of the initial crater fill). The field displays evidence of bedding like features that are smoothly undulating close to the horizontal position (Figures 109 and 111). The thickness of the apparent beds vary from a few decimeter to ca 1.5 meter. On average it is ca 1 meter and regular over the length of the bed. Yet some beds are intercepted by others at low angle resulting in an apparent crossbedding (Figure 111).

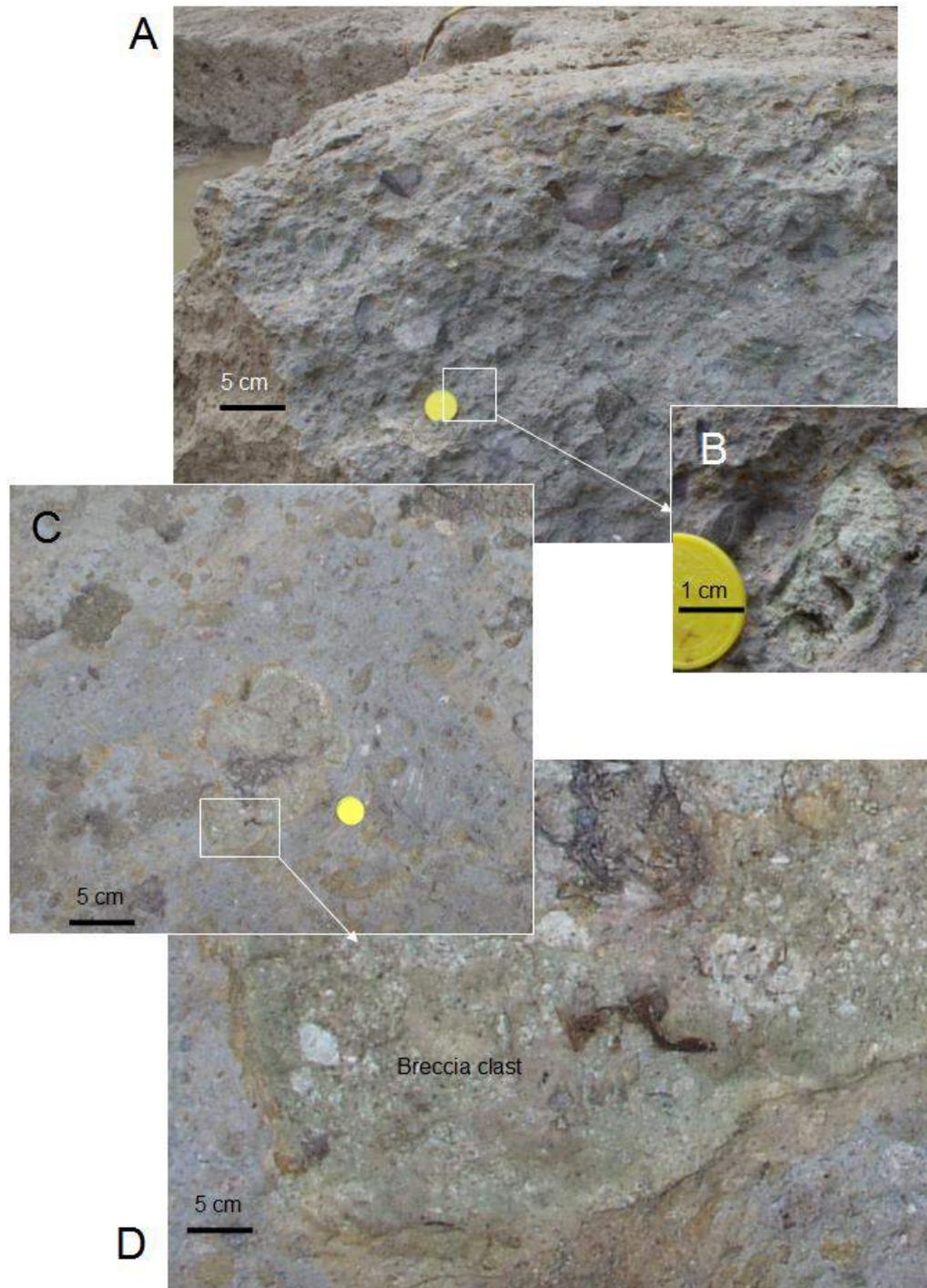


Figure 110: Stop 16: Grosse Pièce quarry. Chassenon suevite. Views of the suevite rock texture, with a close up on a green glass clast (B) and on an impact breccia clast possibly bearing itself green glass in the matrix and/or among the clasts (D).

This new outcrop is probably very important for the understanding of the condition of deposition and postdeposition of the suevite. It has not been yet investigated in detail and no petrographical work has yet been done. The interpretation of the

observed apparent bedding and crossbedding definitely requires detailed petrographic studies, especially across the beds and in the zones of interceptions.



Figure 111: Stop 16: Grosse Pièce quarry. Chassenon suevite. Bedding of the suevite in the horizontal and near horizontal position, with locally a cross bedding (Ellipse).

Meanwhile, several hypothesis can be envisioned to explain the observed textures :

1- Weathering and ground water circulation-dissolution. Although weathering is certainly “increasing” and revealing the bedding in the top part of outcrop which has been exposed to erosion idea seems difficult to reconcile with the fact that bedding is also observed quite deep in the new quarried part. It is also difficult to explain such a way the very regular and horizontal bedding seen at the nearby stop 17 (see next).

2- Compaction. If compaction can explain the bedded aspect, the undulation, it seen difficult to reconcile with the cross bedding?

3- Slumping-inward-outward drifting or thrusting related to crater readjustement. This could explain the bedding and the crossbedding. But we should expect some irregularities of thickness over

the length of the bed and some shearing or griding or other erosional features at the contact zones. It does not seem to be the case and the material seem to be homogeneous through the beds

4-The observed texture suggests the whole deposit could be emplaced as pile of large flakes forming a pile of “giant bull sheet”. This so called “bull sheet” theory as well as all other alternatives need to be “properly” investigated.

Yet, whatever is the explanation for the mode of emplacement of the suevite, the observed features confirms the disconformities previously suspected on the basis of ancient photographs shot at another historical quarry (Carrière des arènes as seen Figure 28 in part one).

17: “Stratified suevite” quarry: Top of the crater fill

4 km NW of the center of the structure

Access:

In the forest, ca 200 m west of stop 16 (see Figure 105).

Description:

Double front small ancient quarry lost in the wood (Figure 112).



Figure 112: Stop 17: « Stratified suevite” quarry.

This site is a backup site in case the stop 16 site is not available for the visit. The same suevite material as at stop 16 is exposed. The stratified aspect is also exposed. The beds are regular in

width and lay close to the horizontal position. One note the relative regularity and horizontality of the decimeter thick layer (hammer).

Stop 18: Impactoclastites intercalation ridge

4 km NW of the center of the structure

Access:

In the field, ca 200 m south of the junction between the Chassenon-Champonger road and the road to Longeas (see Figure 105).

Description:

Small ridge in the field with small outcrops owing to the tempest and the fall of some trees giving access to the bedrock (Figures 113 and 114). The dramatic difference of texture between the suevite and the impactoclastite is clearly seen in Figure 113. The “dike” geometry is also clearly seen, as the surface of contact between the impactoclastite and the host suevite is well exposed. This surface is smooth and regular (shapr cut in the suevite) (see petrographic details in part one).

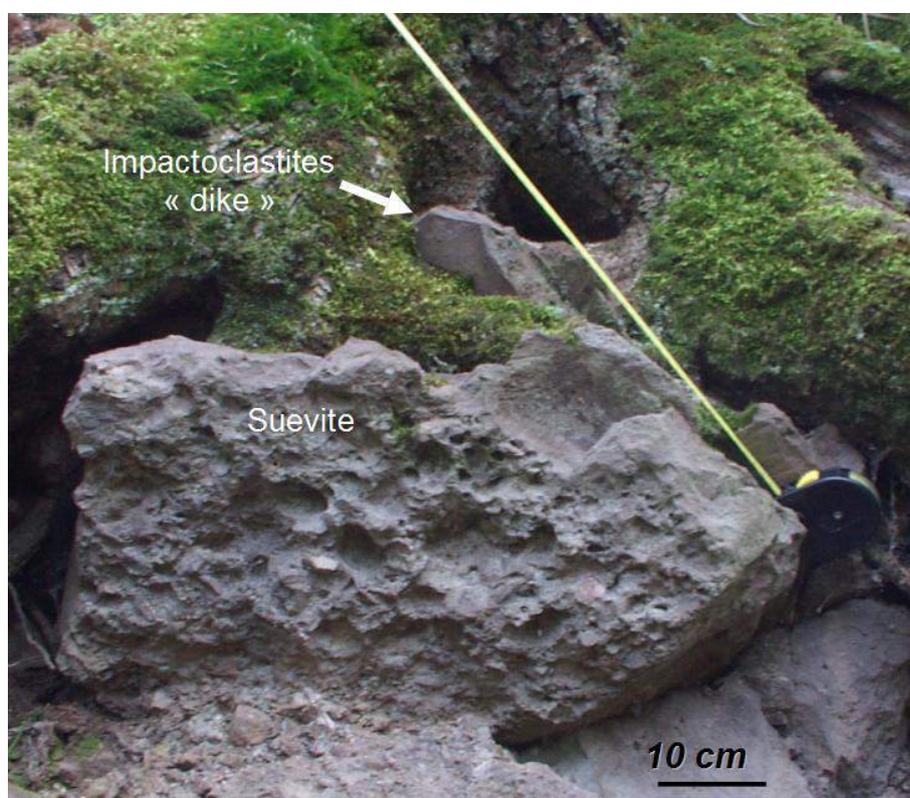


Figure 113: Stop 18: Chassenon impactoclastite intercalations/dikes. Note the difference of texture between the host suevite characterized by a rough and blocky surface typical of a breccia and the dike characterized by a massive and smooth surface. The flat surface seen in the picture represents the contact between the suevite host and the fine grained material

The rocks at Figure 113 are definitely not in place and have been uplifted by the tree fall. The original setting of the dike is closer to the horizontal. Several similar materials have been observed in place in the ridge (in winter times when the vegetation is less) (Figure 114). These

exposures suggest the impactoclastites form several flat lying intercalations (see interpretative diagram in Figure 114). Yet at Longeas, impactoclastites dike with a vertical setting is also observed (Lambert, 2010).

The dramatic difference of texture between the suevite and the impactoclastite is clearly seen in Figure 113. The “dike” geometry is also clearly exposed, as the impactoclastites form a raised wall above the suevite (owing to difference of mechanical properties between the dike and the

suevite materials). The surface of contact between the impactoclastite and the host suevite is well exposed and is smooth and regular. Further details and description of the multi-layered texture of these dikes are given in part one.

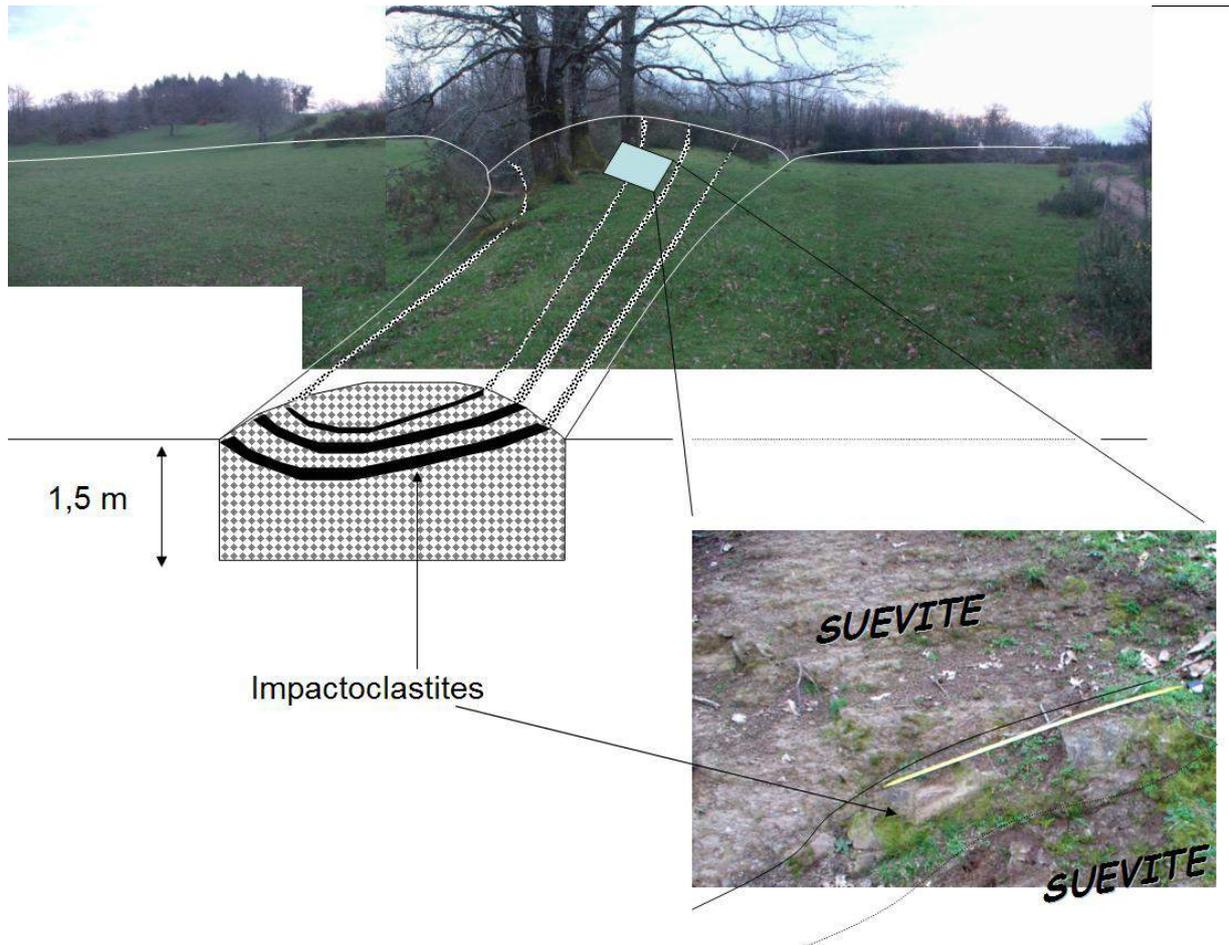


Figure 114: Stop 18: Chassenon impactoclastite intercalations/dikes seen in place (bottom view) and interpretative diagram

Megablocks-Stop 19

Stop 19: Champagnac quarry

7.5 km NE of the center of the structure

Access:

From Rochechouart, D96 to the North (route de Saillat), stay on D86. Right turn after the descent

before the bridge on the Gore River (Carrières de Champagnac) (see Figure 115).

Description:

Large active quarry 90 m high, ca 1 km long – 0.5 km wide (3 km long developed wall) (Figure 116-118).

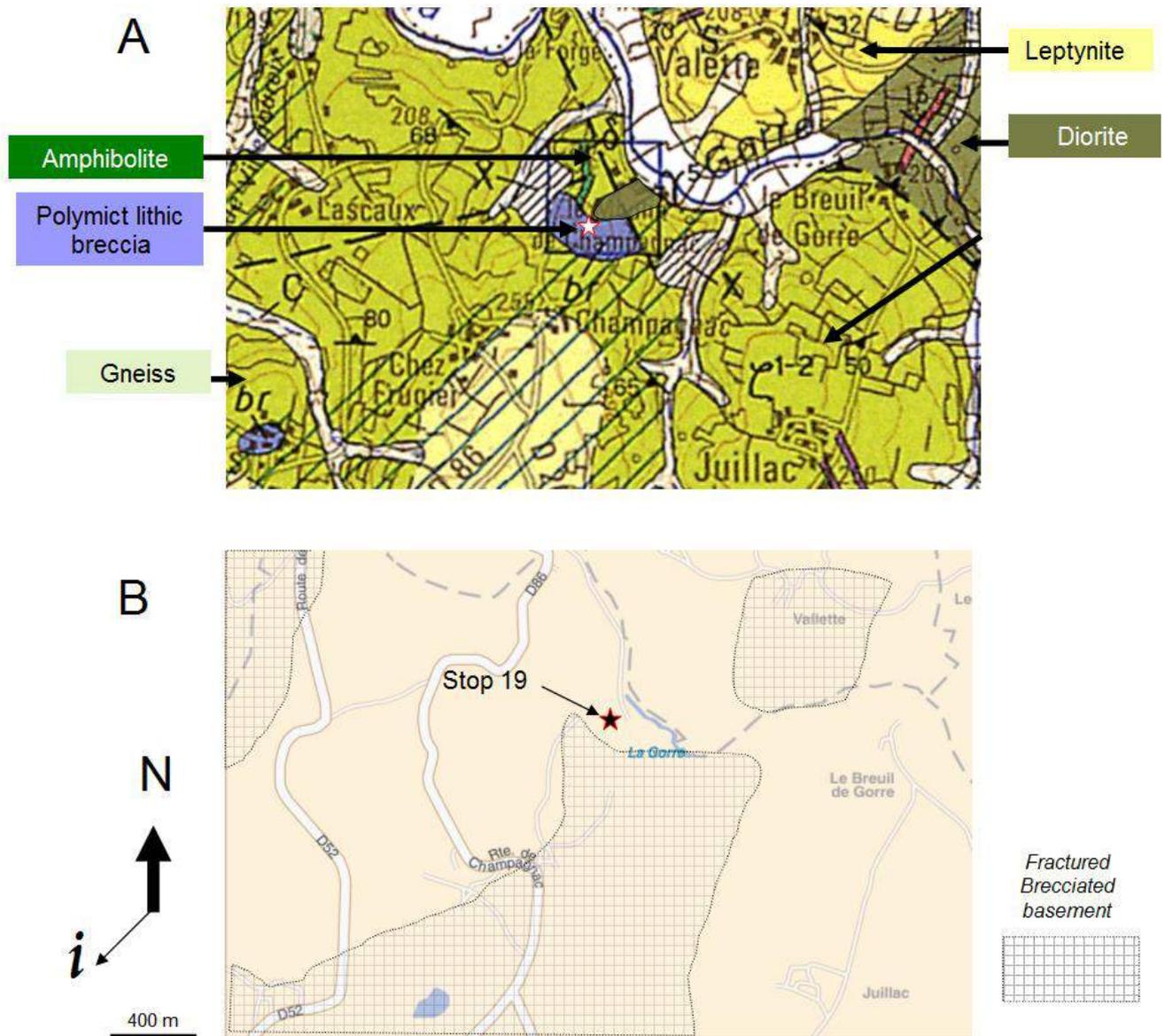


Figure 115: A-Detailed geologic map (data source, 2009, <http://infoterre.brgm.fr>) and B- access map for stops 19 (i: direction of center of the impact).

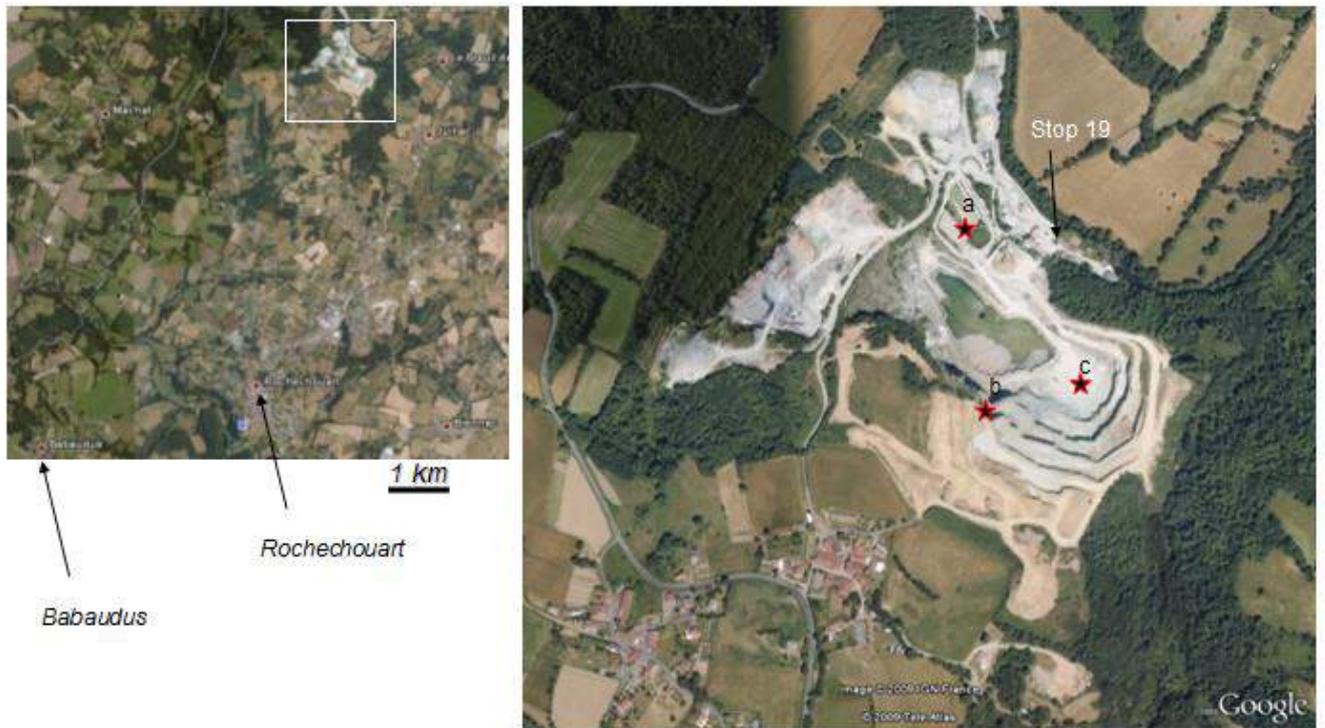


Figure 116: Stop 19: Champagnac active quarry. Satellite images (Google Earth) of the site and positioning of the 3 sub-stops. Bottom right: Schematic interpretation of the main impactite units (see text).

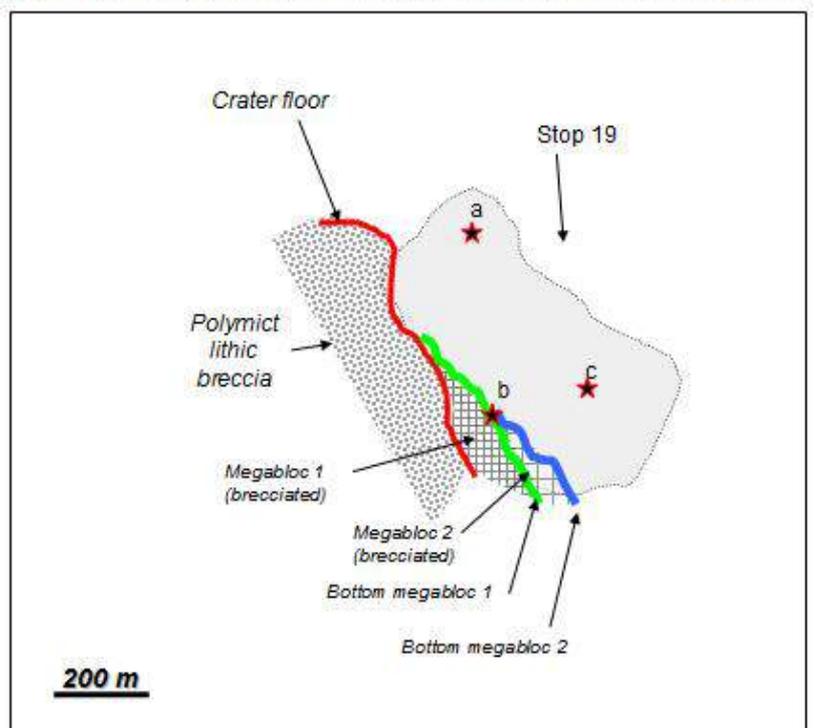


Figure 117-next page: Stop 19a: Champagnac active quarry seen from the panorama stop “a” and close up view of the S-E part of the quarry. Bottom: same as top views with position of the major features and units.

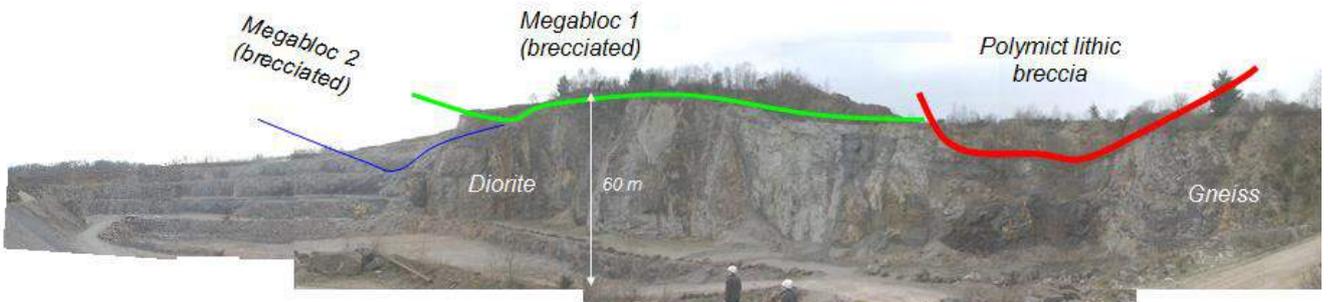




Figure 118- Stop 19b: Winter view of the Champagnac active quarry seen from the megabloc zone at the top of the quarry, looking east in the direction of the S-E part of the quarry. Arrow: displaced rocks (waste). Foreground: Big blocks of the orthoclase rich gneiss-granitoid lenses intercalated in the diorite body (see the position of the source material in Figures 117 and 121).

The main lithologies exposed at Champagnac includes: gneiss (rather mafic) exposed in particular on the northeastern side of the quarry, intruded by diorites and containing interlayered felsic lenses of orthogneiss-granite as well as mafic lenses of amphibolites (both in the gneiss and in the diorite) (sub anatectic conditions of intrusion during the Variscan orogeny, see introduction). Impactites are also displayed and include polymict lithic breccia, monomict breccias, breccia dikes, cataclasites, and pseudotachylites (Reimold et al., 1987). The

dominating geological feature at Champagnac quarry is “DAMAGE”. As we shall see there are 3 major successive “damage” events all resulting in fracturing and brecciating :

- 1- the Variscan orogeny
- 2- the Rochechouart impact
- 3- Mr Lafond (intensive use of explosive)

This site is by far the largest rock exposure in the Rochechouart area and. 3 sub stops are planed for the visit (Figure 116).

Stop 19a. Panorama stop

(see position in Figure 116)



Figure 119- Stop 19b: Champagnac active quarry. View of the upper gneiss megabloc at the top of the quarry at stop19 b. Pierre Delage at scale in front of a breccia dike (monomict breccia). Bottom view: detail of the breccia. The rocks on both sides of the dike are also highly deformed and fractured, locally brecciated. The gneiss fabric is hardly recognizable. The dike zone is just showing definite evidence of relative transportation of the fragments, while outside, fragments remain in their original position (or close to their original position).

The rapid growth of the quarry render the field description somehow temporary as some features disappear, consumed by the activity, yet other appear. The document mainly focusses on what is exposed today. The owner of the quarry Mr Didier Lafond is preserving the historical part of the quarry where the contact between the crystalline basement and the breccia deposit was first observed. This portion corresponds to the left part of the field viewed from the panorama stop (Figure 116). This zone is marked by the contact between a polymict (quasi monomict) breccia interpreted as the basis of the crater fill deposit, and the basement.

The contrast in color between the allochthonous breccia (brown) and the autochthonous gneiss is clearly seen in the field. The crater floor displays a complex geometry and is not flat, like the bottom of the megablocks described further down. The crater floor is changing from horizontal to vertical position and disappears above the plane of topography (red line in Figure 117).

The diorite massif occupying a large central part of the quarry (Figures 115 and 117) is cut by a steeply dipping body of felsic rocks a few decametres wide that is described at stop 19c. This felsic zone in the diorite is bordered by amphibolite lenses running parallel to the felsic intercalations body. The whole forms a mega fabric steeply dipping and roughly running N-S (see Figure 121).

The upper and higher part of the quarry is occupied by brecciated gneiss contrasting in color and texture with the underlying basement formations. The nature and conditions of formation of these rocks are described next at stop 19b.

Stop 19b. Megabloc zone

(see position in Figure 116)

Beyond the nice view over the whole quarry and the surroundings (see Figure 118), stop 19b shows the nice and sharp contact between the top brown formations and the underlying gray diorite. The brown rocks correspond to highly fractured – brecciated gneiss. The initial layered fabric of the gneiss is hardly recognizable. This cataclastic texture is attributed to the impact. Locally the fractured-fragmented gneiss turns into a real breccia

with rotated fragments. The monomict breccia forms metric to plurimetric dikes as exemplified in Figure 119.

The brown gneiss formation is transecting the underlying diorite and its megafabric (the steeply dipping mafic-felsic intercalations in the diorite). The contact is sub horizontal and regular (Figure 120). The contact is marked by a textureless zone completely argilized (Figure 121). The width of the argilized contact zone is decimetric and can locally reach one meter. It is interpreted as a zone of intense shearing. The whole brown gneiss at the top of the quarry is interpreted as a fractured megablock shifted over the diorite-gneiss autochthonous bedrock. This megablock is formed of two slabs and probably result of the partial overlapping of two megablocks as the top brown allochthonous gneiss cap is transected by a low angle fault (Figure 120)

Stop 19c. Felsic-Mafic intercalations

Bottom of the quarry (see position in Figure 116).

This site is located in the middle of the autochthonous diorite body intruding the autochthonous gneiss. The diorite is highly fractured. Low angle fractures in the diorite body are responsible for the stair case like appearance of the front wall (the middle of Figure 121). The setting of the felsic intercalation zone crosscutting the diorite is visible on the left side of the view field in Figure 121). This zone is 20-30 m wide.

The unstable character of the front wall prevents from approaching the felsic zone. But large blocks issued from this part of the quarry are displayed at stop 19c. As seen from these blocks the felsic zone in the diorite is not simple dike geometry, but a complex zone of intermixing between felsic lenses derived from orthogneiss and mafic lenses derived from the diorite and the amphibolites. Such intermixing results texture somehow converging with “breccia”. The contact between “clast” and host components (granitoid-orthogneiss and diorite-amphibolites) are either weavy (Figure 121) or angular (Figure 122).

A complex array of fractures pervades the diorite and the intermixed felsic and mafic lenses (Figure 122). These fractures are filled and significant hydrothermal alteration is observed in the host diorite at the contact with these filled fractures. Although some of the hydrothermal veining at Champagnac may relate to the impact and to the conditions of cooling of the impact deposits (Reimold et al., 1987), some hydrothermal mechanism resulting in a similar veining is likely to predate the impact. Similar diorite intrusions and intermixed amphibolite and felsic lenses intersected by hydrothermal veins are observed at other places further away from the impact in the French Central Massif (see introduction).

Complex network of fractures filled by dark material pervading in the diorite and the felsic intercalations in the diorite, are commonly observed in the zone next to the amphibolite lenses (Figure 121C). The pseudotachylites reported at Champagnac relate to this type of setting.

Stop 19c eventually demonstrates the textural convergence between impact and endogenic textures and illustrates the complex history of the exposed rocks. More work is definitely required to deconvolute the various textures and to interpret the various superimposed mechanisms at work related to the Variscan and the impact events.

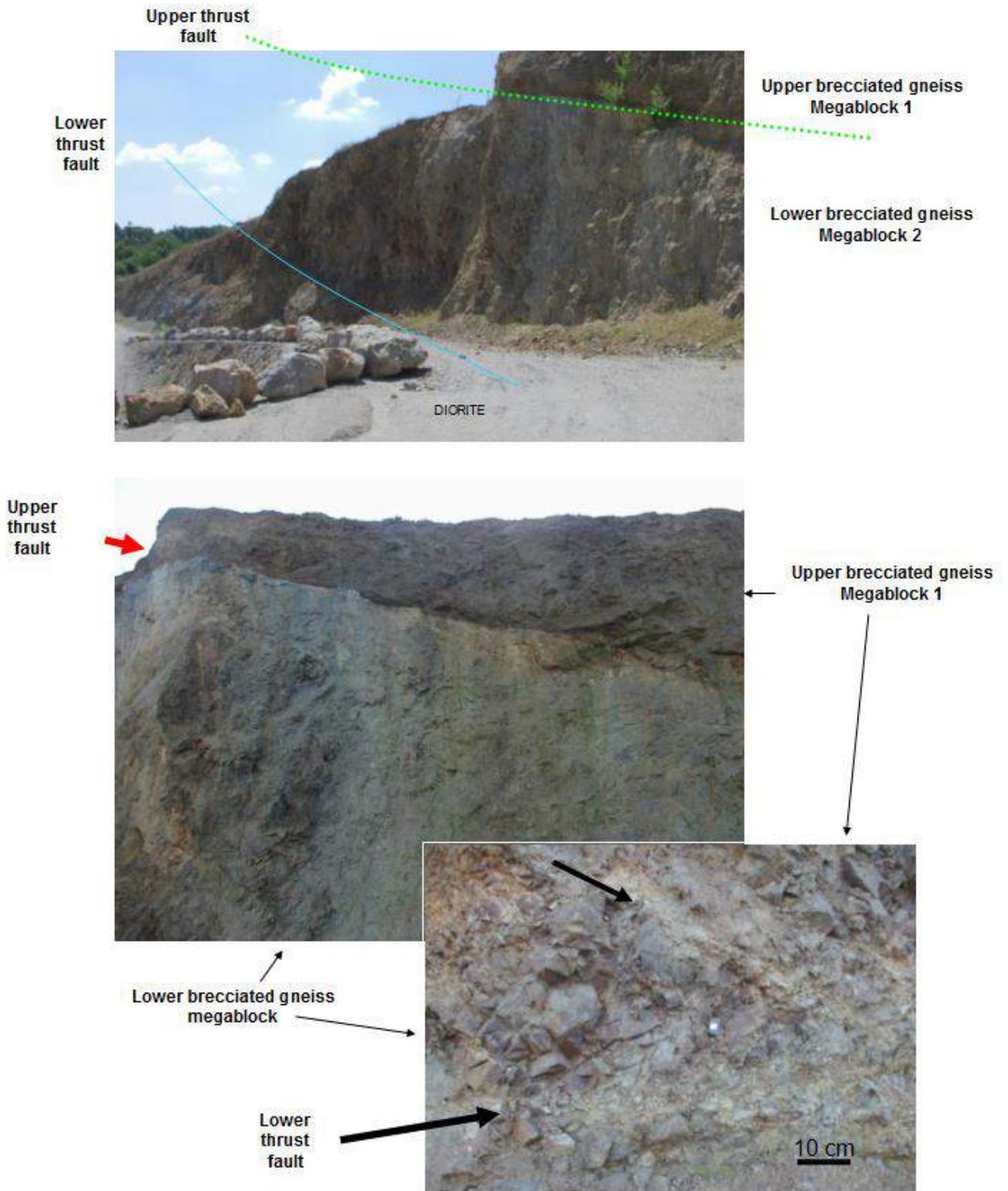


Figure 120- Stop 19b: Champagnac active quarry. View of the contact between the upper and the lower gneiss megablocks and with the underlying diorite. Detail showing the fragmented character of the gneiss in the megablocks. Arrows: Textureless zone at the contact (shearing), completely arigilized (altered friction melts ?).

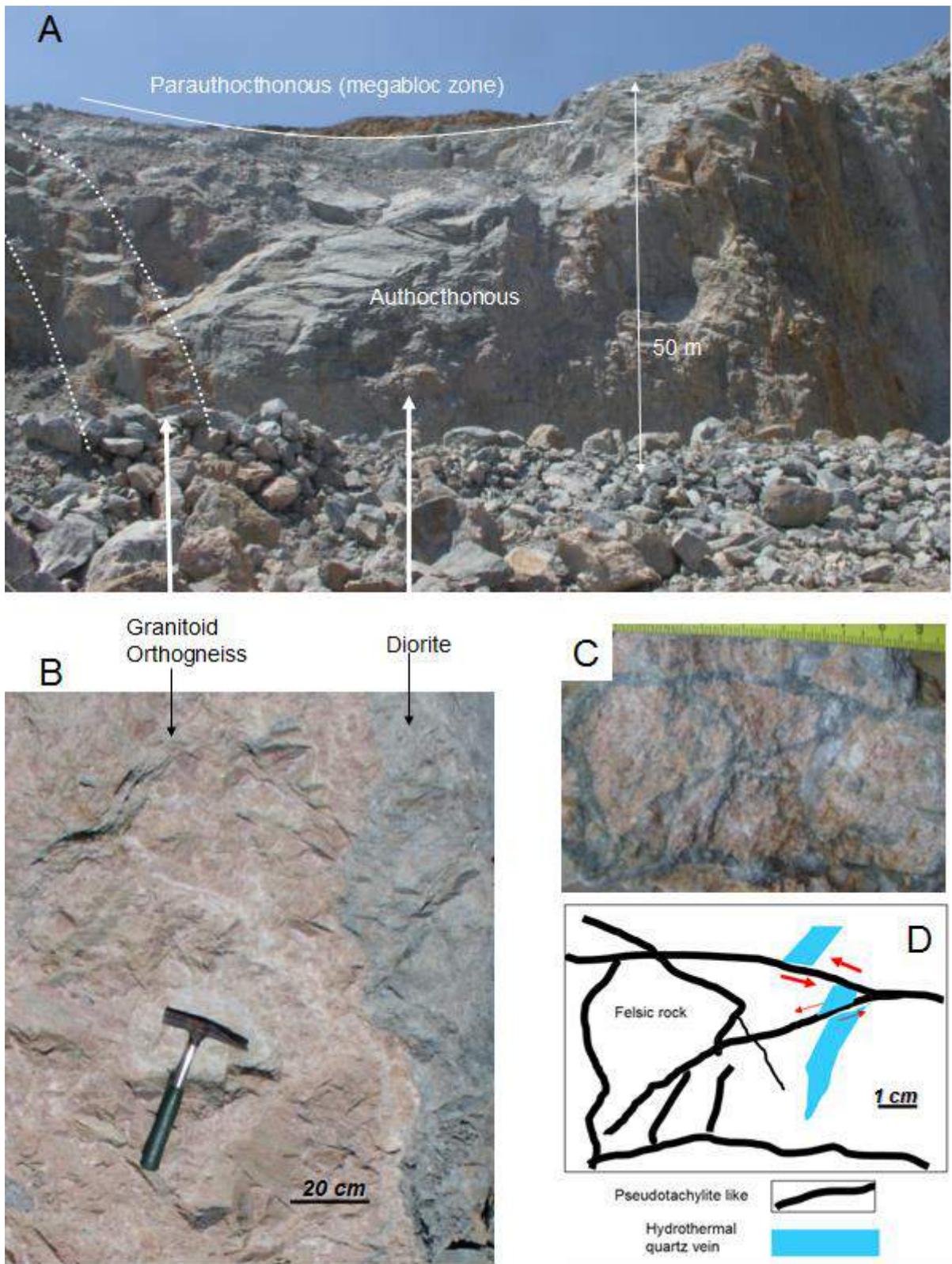


Figure 121- Stop 19c: A- Champagnac active quarry from the bottom at stop 19c looking W-SW to the main wall. B- View of the weavy contact between the diorite and a felsic intercalation, C- Dark veins in the felsic rock. D- Interpretative diagram of C showing the relative displacement of hydrothermal veins by dark veins.

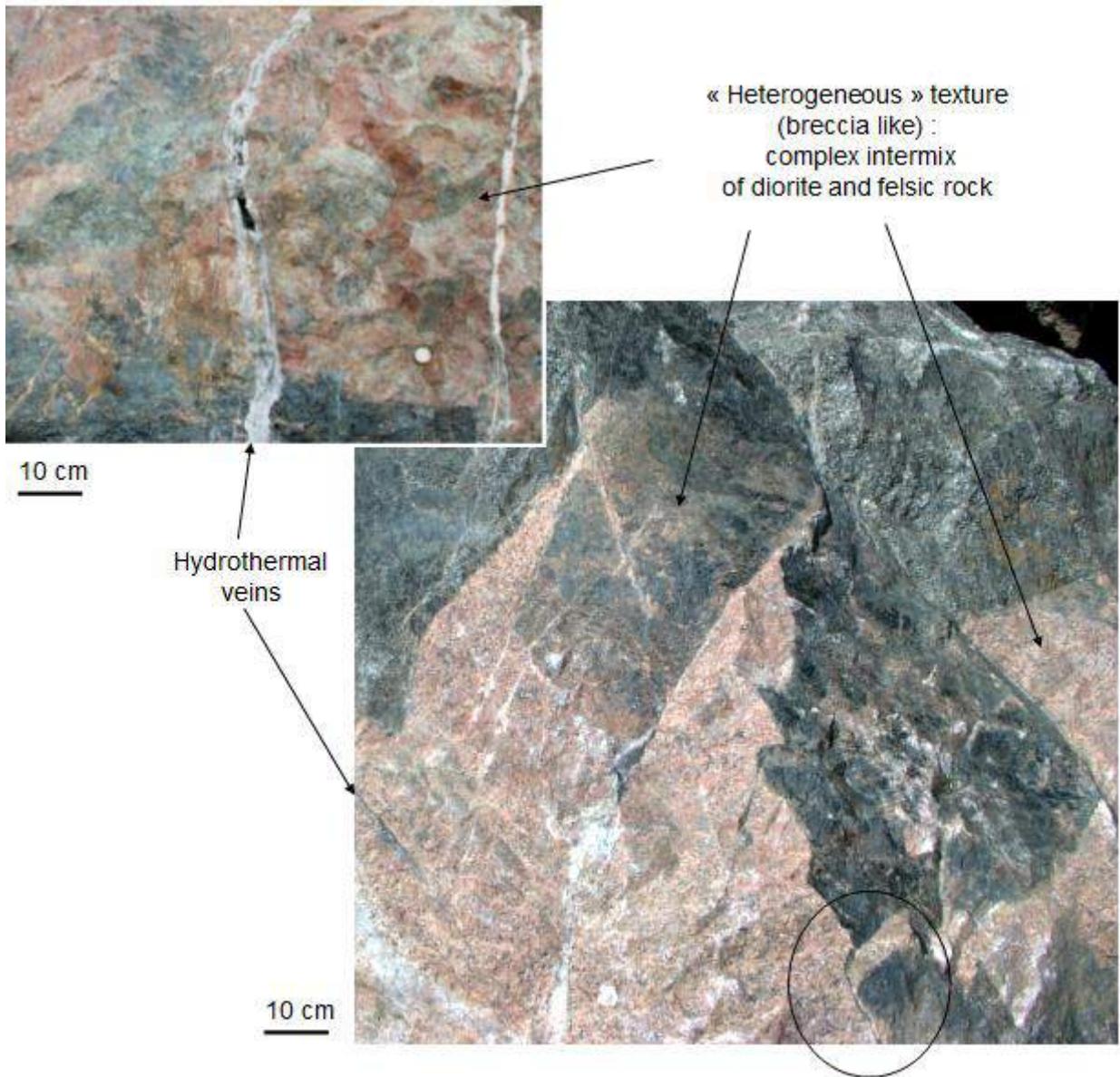


Figure 122- Stop 19c: Champagnac active quarry from the bottom at stop 19c. Detail of the pre-impact breccia like texture and the hydrothermal veining.

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