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SURFACE TEXTURES OF PYROCLASTIC PRODUCTS OF THE M. GUARDIA SURGE SEQUENCE, LIPARI

ROSANNA DE ROSA
Dip. Scienze della Terra, Univ, della Calabria, 87030 Castiglione Cosentino Stazione (Cosenza)

ABSTRACT. — The surface textures of pyroclasts from the Monte Guardia surge deposits have been examined by S.E.M. in order to identify and quantify the most significant aspects of each grain-type. The objective was to identify features that distinguish primary textures related to the physical disruption of magma during crater formation from secondary features related to the physical and chemical history of ejecta, either during transport or after emplacement. Therefore, criteria to distinguish genetic and temporal relationships were developed in this analysis. Crystal and glass particles from surge beds show distinctive primary surface features related to their origin and composition. With the exception of pumice, primary features of grains are modified during transport and after deposition. Pre-depositional features that reflect the physical history of pyroclast transport are mainly due to eruption energy and particle concentration in the surge cloud. Post-depositional textures that reflect the degree of chemical alteration are related to the emplacement « wetness » of surge deposits.

RIASSUNTO. — Sono stati esaminati al microscopio elettronico granuli piroclastici relativi a depositi di « surge » connessi con la messa in posto del duomo endogeno di M. Guardia, affiorante nella parte meridionale dell'isola di Lipari. Scopo del lavoro è stato quello di identificare le principali tessiture di superficie di questi granuli e di distinguere tra tessiture primarie, legate alla rottura fisica del magma durante la formazione del cratere, e tessiture secondarie legate alla storia fisica e chimica del materiale eiettato, sia durante il trasporto che dopo la messa in posto.

Le osservazioni eseguite hanno permesso di effettuare le seguenti considerazioni:

— cristalli e granuli vetrosi mostrano caratteristiche tessiture primarie legate alla diversa origine e composizione;
— le tessiture primarie dei granuli, ad eccezione delle pomici, subiscono sensibili modificazioni durante il trasporto e dopo la deposizione;
— le tessiture pre-deposizionali riflettono la storia fisica del materiale eiettato e dipendono dall'energia dell'eruzione e dalla concentrazione di particelle nella nuvola di « surge »;
— le tessiture post-deposizionali riflettono il grado di alterazione chimica dei prodotti eiettati e sono funzione del contenuto di acqua presente.

Introduction

The scanning electron microscope (SEM) is widely used in textural analysis to characterize and quantify the surface features of detrital quartz particles (KRINSLEY and MARGOLIS, 1971; KRINSLEY and DOORNKAMP, 1973; KRINSLEY, 1978). Recently, this technique has been used to interpret the origin, transport, and alteration of both glass (WOHLETZ and KRINSLEY, 1982) and crystal (DE RITA et al., 1982) particles in specific volcanic environments. The great diversity in the surface features of heterogeneous particles from pyroclastic deposits can be related to the origin of the clasts, to the type of transport and to diagenetic processes (SHERIDAN and MARSHALL, 1982).

The purpose of this paper is to examine samples from surge deposits in the Monte Guardia sequence on Lipari in order to relate the effects of emplacement and diagenesis on the surface textures of different grain-types collected at varying distances from the vent.

Geologic setting

The island of Lipari is entirely composed of volcanic products. According to PICHLER (1980), there were four main periods of activity; the first and second periods (100,000 to 60,000 y) produced andesitic composition materials, whereas the third and fourth periods (up to the sixth century a.D.) are represented by rhyolitic products.

The Monte Guardia pyroclastic sequence, which erupted during the third period described by PICHLER (1980), is related to the emplacement of the endogeneous Monte Guardia dome in the souther part of the

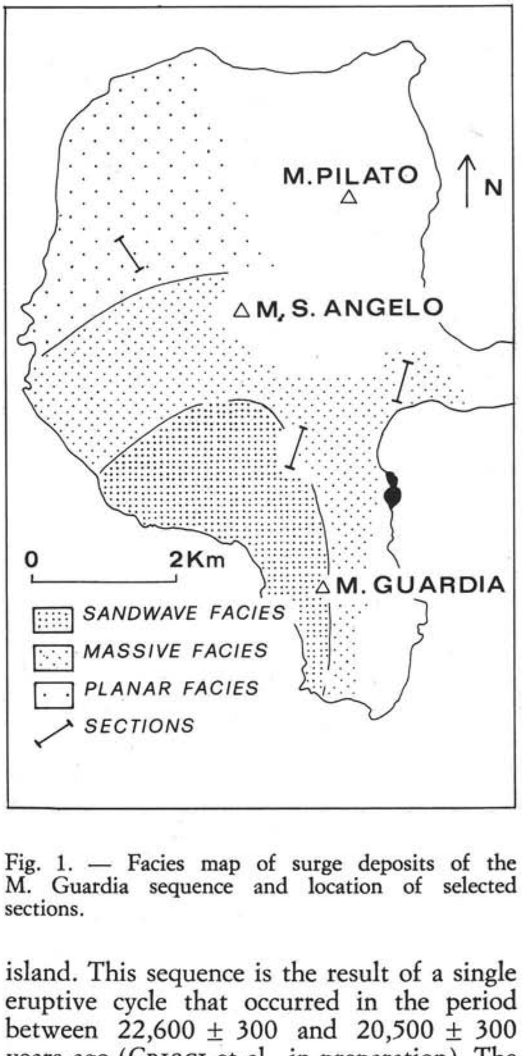

Fig. 1. — Facies map of surge deposits of the M. Guardia sequence and location of selected sections.

island. This sequence is the result of a single eruptive cycle that occurred in the period between 22,600 ± 300 and 20,500 ± 300 years ago (CRISCI et al., in preparation). The stratigraphy of these deposits (CRISCI et al., 1981) allows a reconstruction of volcanic events. The eruption began with a vent-opening explosion that produced a widespread breccia. Alternating subplinian lapilli-fall and surges events continued until a lava dome plugged the vent.

According to field investigations (CRISCI et al., 1981), the Monte Guardia products follow the Markov surge-emplacement model that was proposed by WOHLETZ and SHERIDAN (1979) for basaltic tuff rings in the western United States. The Markov analysis, based on subdivision of the pyroclastic-surge deposits into sandwave, massive and planar beeds, shows that the Monte Guardia surge sections are characterized by a dominance of sandwave and massive beds (sandwave facies) near the vent; planar, massive, and sandwave beds (massive facies) in sections at an intermediate distance from the vent; planar and massive beds (planar facies) far from the vent (fig. 1).

Methodology

The samples in this study were chosen to test the effect of distance, bedform, grain size, and composition on surface textures of the pyroclasts from the surge deposits. The collection followed a detailed field investigation of facies and stratigraphic variation in the deposit. The samples were thus collected from sandwave, massive, and planar beds at three sections representing proximal, medial and distal position from the vent. In all cases the sample represent a thin, single bed or bedding set.

A petrographic study of these samples (DE ROSA and SHERIDAN, 1983) indicate that the Monte Guardia surge beds contain a wide variety of crystal and glass particles. The glassy clasts include rhyolitic pumice and blocky, non-vesicular grains of either trachytic or rhyolitic composition. The crystals are represented by clinopyroxene, orthopyroxene and plagioclase.

Because the surface textures of particles collected from similar bed-types may depend on their grain-size and composition, care must be taken in selection of particles for analysis (SHERIDAN and MARSHALL, 1982). Hence, the entire grain-size distribution of each sample was determined using 1/2 Ø screen intervals. Textural SEM analysis was carried out on crystals and glass grains which were pre-selected from the 0.35-0.25 mm size population using a stereomicroscope. This size range encompasses a major part of one prominent mode of all of the samples in the study. Thus, grains can be competed on a uniform basis with respect to size.

Low magnification (100 to 150 x) SEM images were used to analyze textural features of 40 single grains for each sample. The most significant surface characteristics of each grain-type were then characterized and quantified, according to a recent classification system (SHERIDAN and MARSHALL, in press).

TABLE 1

Summary of occurrence of the main surface features of pyroclastic grains of surge beds from the M. Guardia sequence in Lipari

Symbols: █ Abundant; ■ Common; ▪ Rare; – Absent

SAND WAVES

Origin		Surface features	Proximal Cr	Proximal Pu	Proximal Og	Proximal Tg	Intermediate Cr	Intermediate Pu	Intermediate Og	Intermediate Tg	Distal Cr	Distal Pu	Distal Og	Distal Tg
Secondary – Pre depositional	General features	Adhering particles	▪	▪	–	▪	▪	▪	–	▪	■	■	▪	▪
Secondary – Pre depositional	General features	Edge modification	▪	▪	▪	▪	▪	▪	▪	■	▪	▪	▪	■
Secondary – Pre depositional	General features	Hydration cracks	▪	–	–	–	–	–	▪	–	–	–	–	–
Secondary – Pre depositional	General features	Frozen melt textures	▪	–	■	–	▪	–	■	–	▪	–	■	–
Secondary – Pre and/or post deposit.	General features	Pitting	■	–	■	▪	■	–	■	■	■	–	■	▪
Secondary – Pre and/or post deposit.	General features	Overgrowth	▪	▪	–	▪	▪	–	–	■	▪	–	–	▪
Primary	Pumice features	Tubular vesicles		▪				■				█		
Primary	Pumice features	Dish-like vesicles		■				■				▪		
Primary	Pumice features	Sub-spherical vesicles		■				▪				▪		
Primary	Pumice features	Angular vesicles		–				–				–		
Primary	Pumice features	Sponge-like vesicles		–				–				▪		
Primary	Pumice features	Coalescing bubbles		–				–				–		
Primary	Pumice features	Fraction of void-space												
Primary	Pumice features	Fraction of phenocrysts		–				–				–		
Primary and secondary – Pre-depositional	Crystals features	Cleavage surface	■				■				■			
Primary and secondary – Pre-depositional	Crystals features	Concentric fractures	▪				▪				–			
Primary and secondary – Pre-depositional	Crystals features	Radial fractures	–				▪				–			
Primary and secondary – Pre-depositional	Crystals features	Steep-like parallel fra.	■				■				■			
Primary and secondary – Pre-depositional	Crystals features	Hertzian cracks	■				–				–			
Primary and secondary – Pre-depositional	Crystals features	Concave dish-shape surface	▪				▪				▪			
Primary and secondary – Pre-depositional	Glass feat.	Smooth surface			–	█			–	█			–	█
Primary and secondary – Pre-depositional	Glass feat.	Rough surface			█	–			█	–			█	–
Primary and secondary – Pre-depositional	Glass feat.	Smooth convex fract.			–	■			–	■			–	■

MASSIVE

Origin		Surface features	Proximal Cr	Proximal Pu	Proximal Og	Proximal Tg	Intermediate Cr	Intermediate Pu	Intermediate Og	Intermediate Tg	Distal Cr	Distal Pu	Distal Og	Distal Tg
Secondary – Pre depositional	General features	Adhering particles	▪	▪	–	▪	▪	■	█	■	█	█	█	█
Secondary – Pre depositional	General features	Edge modification	■	▪	■	▪	■	▪	■	▪	■	▪	■	■
Secondary – Pre depositional	General features	Hydration cracks	–	–	■	–	–	–	–	–	–	–	–	–
Secondary – Pre depositional	General features	Frozen melt textures	■	–	▪	–	■	–	■	–	█	–	■	–
Secondary – Pre and/or post deposit.	General features	Pitting	■	–	█	■	■	–	■	■	■	▪	■	█
Secondary – Pre and/or post deposit.	General features	Overgrowth	▪	–	–	■	▪	–	–		▪	–	–	█
Primary	Pumice features	Tubular vesicles		■				■				█		
Primary	Pumice features	Dish-like vesicles		▪				–				▪		
Primary	Pumice features	Sub-spherical vesicles		■				▪				–		
Primary	Pumice features	Angular vesicles		–				–				–		
Primary	Pumice features	Sponge-like vesicles		▪				■				▪		
Primary	Pumice features	Coalescing bubbles		–				▪				–		
Primary	Pumice features	Fraction of void-space												
Primary	Pumice features	Fraction of phenocrysts		–				–				–		
Primary and secondary – Pre-depositional	Crystals features	Cleavage surface	■				■				■			
Primary and secondary – Pre-depositional	Crystals features	Concentric fractures	–				–				–			
Primary and secondary – Pre-depositional	Crystals features	Radial fractures	▪				–				–			
Primary and secondary – Pre-depositional	Crystals features	Steep-like parallel fra.	█				■				▪			
Primary and secondary – Pre-depositional	Crystals features	Hertzian cracks	–				–				–			
Primary and secondary – Pre-depositional	Crystals features	Concave dish-shape surface	▪				▪				–			
Primary and secondary – Pre-depositional	Glass feat.	Smooth surface			–	█			–	■			–	■
Primary and secondary – Pre-depositional	Glass feat.	Rough surface			█	–			█	–			█	–
Primary and secondary – Pre-depositional	Glass feat.	Smooth convex fract.			–	█			–	■			–	▪

PLANAR

Origin		Surface features	Proximal Cr	Proximal Pu	Proximal Og	Proximal Tg	Intermediate Cr	Intermediate Pu	Intermediate Og	Intermediate Tg	Distal Cr	Distal Pu	Distal Og	Distal Tg
Secondary – Pre depositional	General features	Adhering particles	▪	■	–	▪	▪	■	■	▪	■	■	▪	▪
Secondary – Pre depositional	General features	Edge modification	■	▪	■	▪	■	▪	■	■	▪	▪	■	■
Secondary – Pre depositional	General features	Hydration cracks	–	–	▪	–	–	–	–	–	▪	–	–	▪
Secondary – Pre depositional	General features	Frozen melt textures	–	–	–	–	▪	–	–	–	▪	–	▪	–
Secondary – Pre and/or post deposit.	General features	Pitting	■	▪	■	■	■	▪	■	▪	■	▪	█	■
Secondary – Pre and/or post deposit.	General features	Overgrowth	▪	–	–	■	▪	–	–	■	▪	▪	–	▪
Primary	Pumice features	Tubular vesicles		■				■				█		
Primary	Pumice features	Dish-like vesicles		▪				■				▪		
Primary	Pumice features	Sub-spherical vesicles		▪				▪				–		
Primary	Pumice features	Angular vesicles		–				–				–		
Primary	Pumice features	Sponge-like vesicles		–				▪				–		
Primary	Pumice features	Coalescing bubbles		–				–				–		
Primary	Pumice features	Fraction of void-space												
Primary	Pumice features	Fraction of phenocrysts		–				–				–		
Primary and secondary – Pre-depositional	Crystals features	Cleavage surface	▪				■				■			
Primary and secondary – Pre-depositional	Crystals features	Concentric fractures	–				–				–			
Primary and secondary – Pre-depositional	Crystals features	Radial fractures					▪				–			
Primary and secondary – Pre-depositional	Crystals features	Steep-like parallel fra.	■				■				■			
Primary and secondary – Pre-depositional	Crystals features	Hertzian cracks	–				–				–			
Primary and secondary – Pre-depositional	Crystals features	Concave dish-shape surface	■				■				▪			
Primary and secondary – Pre-depositional	Glass feat.	Smooth surface			–	█			–	■			–	■
Primary and secondary – Pre-depositional	Glass feat.	Rough surface			█	–			█	–			█	–
Primary and secondary – Pre-depositional	Glass feat.	Smooth convex fract.			–	█			–	█			–	█

(Cr) Crystals (Pu) Pumices (Og) Opaque glass (Tg) Transp. glass

Results

The objective in selecting specific features for analysis was to distinguish textures related to the primary physical rupture of magma during crater formation from secondary aspects related to the physical and chemical history of ejecta during transport and after emplacement. Therefore, the textural criteria from analysis of surge pyroclasts provide both genetic and temporal information.

The results of the SEM examination are presented in table 1. Glass and crystal particles from surge beds have some common secondary features which can be used to interpret their history. Edge modification and adhering particles can be related to transport mechanism. Pyroclastic grains from sandwave beds show a low degree of edge-modification and few adhering particles, whereas particles from planar beds have a high degree of edge modification and abundant adhering particles. Pyroclasts from massive beds were expected to have an intermediate development of these secondary features, but samples from massive beds at Lipari are generally characterized by a high degree of edge modification and abundant adhering particles. This supports the hypothesis of WOHLETZ and SHERIDAN (1979) that sandwave grains are transported in a dilute surge and suffer few impacts.

Generally edge-modification and the abundance of adhering particles increase with the distance from the vent. Massive deposits at distal locations show maximum development of these surface features. Agglutination of small particles on the wet surface of larger grains may be related to the electrostatic charging due to breakage (KRINSLEY and LEACH, 1979). Frozen melt texture (achneliths) are mostly present on trachytic grains from massive and sandwave beds and on glass adhering to crystal faces. This feature is probably related to optimum interaction of fluid magma with water inside the vent (WOHLETZ, 1983). The sparce frequency of hydration cracks, which are formed by an excess of water, also attests to a relatively « dry » hydrovolcanic system.

Pits and overgrowths are present in samples from sandwave, massive and planar beds. The greater abundance of secondary mineral overgrowths that typifies massive beds testifies to a higher water or steam content at the time of their deposition (DE RITA et al., 1982). According to SHERIDAN and MARSHALL (1982) pits are produced by solution phenomena that occur during transport or after deposition. This hypothesis is supported by our samples for which the abundance of pits increases with distance from the vent. This increase suggests that the active agent (a condensed film of water on the grain surface) becomes more effective with distance.

Besides the main features given above, each grain shows specific surface characteristics related to its origin, composition, and (with the exception of pumice grains) duration and type of transport.

Crystal pyroclasts (fig. 2 *a, b,* and *c*) are generally characterized by large cleavage surfaces with step-like parallel fractures. Some grains from planar beds also have concave dish-shaped features. Step fractures are considered to be related to high-energy impacts in a dilute flow, whereas dish-shaped concavities are thought to be due to low-energy impacts in a dense flow where the grain contact is frequent. The degree of grain interaction depends upon the concentration of particles in the surge cloud. Following the model of WOHLETZ and SHERIDAN (1979), grain concentration in the basal surge increases with distance from the vent as reflected by the progression from sandwave through massive to planar bedforms. Consequently, the number of impacts for grains from planar beds is greater than for grains from sandwave beds. However, pyroclasts from sandwave beds should have experienced higher-energy collisions.

Pumice from the Monte Guardia sequence are characterized by tubular vesicles (fig. 2, *d, e,* and *f*). Vesicularity (the fraction of void-space) is greatest in pumice from sandwave beds. According to SHERIDAN and MARSHALL (1982), the number of vesicles depends on the viscosity of the magma and the concentration of magmatic volatiles. Vesicle shape is a function of the external stresses on the magma at the time of exolution and growth of bubbles. The prevalence of pumice grains with tubular vesicles in our samples testifies to their formation in a conduit while the magma was subject to lateral shear (SHERIDAN and MARSHALL, 1982).

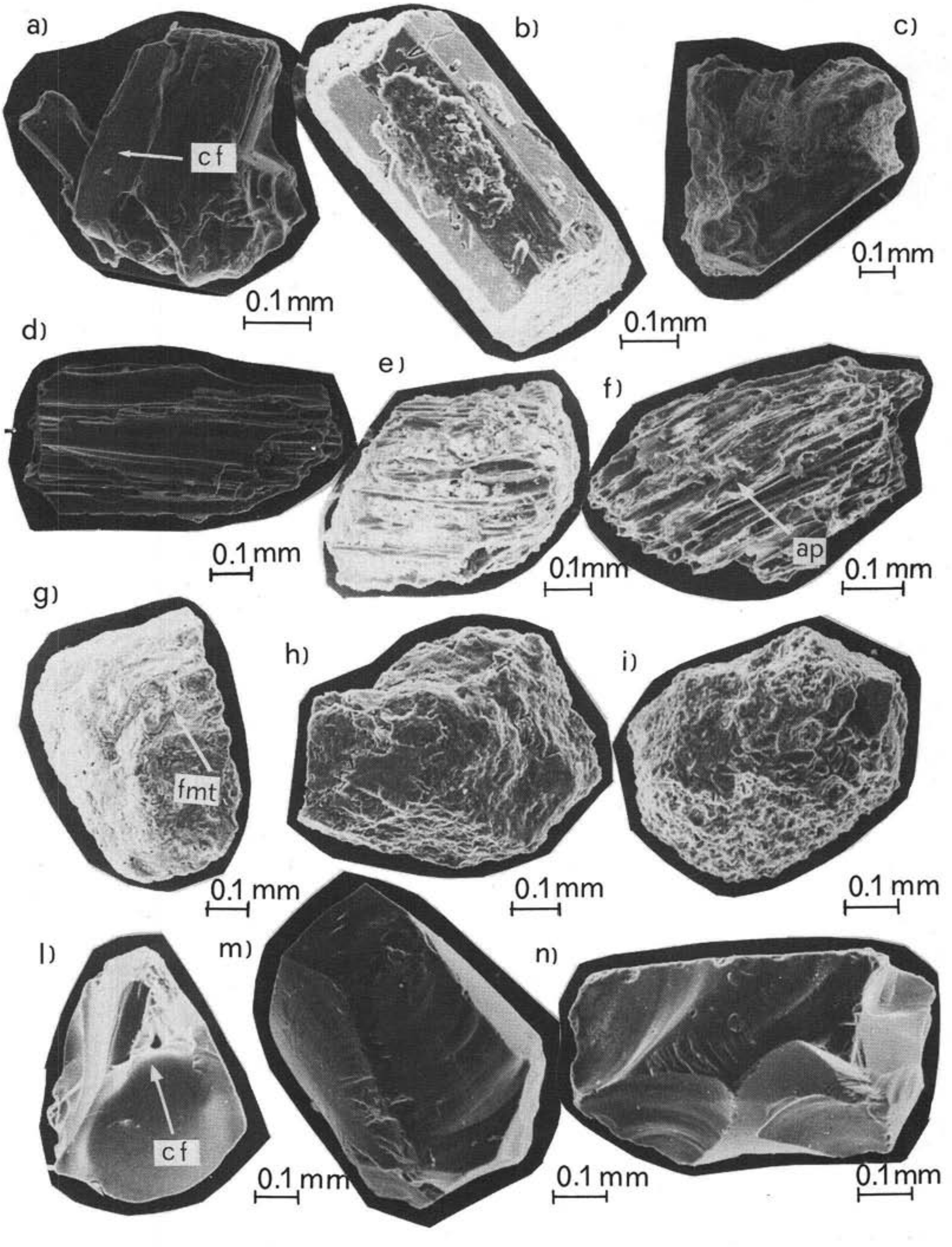

Fig. 2. — Some surface features of crystal and glass particles from sand-wave, massive and planar beds as seen by SEM: *a, b, c* = crystal grains showing cleavage surface (*cf*); *d, e, f* = pumice grains showing tubular vesicles and a maximum in the amount of adhering particles (*ap*) in massive beds; *g, h, i* = opaque glass showing rough surface and frozen melt texture (*fmt*); *l, m, n* = transparent glass showing smooth surface and convex fractures (*cf*).

Besides pumice, magma fragments are present either in the form of opaque microcrystalline clasts (fig. 2, *g, h,* and *i*) or blocky transparent glass (fig. 2, *j, k,* and *l*), each with different textural features and composition. The microcrystalline opaque pyroclasts of trachytic composition (DE ROSA and SHERIDAN, 1982) are characterized by a rough surface due to the projection of microlites that crystallized after eruption. The transparent glass of rhyolitic composition has a smooth surface caused by spalling that occurred during transport or after deposition. Smooth convex fractures on these glassy grains are most abundant in planar beds. This suggests that the large number of impacts in high-concentration laminar (grain) flow induces spalling in the planar beds.

Conclusions

The surface textures of pyroclastic particles from the Monte Guardia surge deposits have been examined by SEM in order to identify and quantify the significant features of each grain-type. The objective of the study was to select specific characteristics that distinguish primary features that related to the physical history of pyroclast formation from secondary features that related to the physical and chemical history of ejecta during transport and after emplacement.

Crystals and glass particles from surge beds have distinctive surface features that relate to their origin and composition. These features, with the exception of those on pumice, are modified during transport and after deposition. The physical history of pyroclasts during transport, deduced by examining variations in surface features of grains collected from lateral and vertical surge bed facies, can be primarily related to eruption energy and particle concentration in the surge cloud. The post-depositional features observed on pyroclasts reflect the degree of chemical alteration related to the « wetness » of the surge deposits. The results obtained by this study suggest that:

1) The surface features of grains from surge deposits can be used to reconstruct the physical history of pyroclasts during their formation and transport.

2) A hydrovolcanic eruptive mechanism can be identified by the nature of ejecta.

3) The presence of water and/or steam during and after ejecta emplacement accounts for the development of secondary features on the surface of pyroclastic grains.

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