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The importance of coastal geomorphological setting as a controlling factor on microtextural signatures of the 2010 Maule (Chile) tsunami deposit

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ABSTRACT

Quartz grains collected from Arauco and Mataquito (central Chile) after the 2010 Maule tsunami presented an overwhelming dominance of dissolution textures. The analysis of superficial imprints proved that some grains were mechanically impacted before deposition. However, the percentage of grains with fresh surfaces and percussion marks was significantly lower than average values from other tsunami deposits elsewhere in the world. In this work, we discuss the reasons for such results in the context of the geomorphological setting of the areas analyzed and its influence on the microtextural signatures observed. The data presented in this study evidences a geographic dependence in the type of microtextures in the areas analyzed. For example, in Arauco the abundance of dissolution textures decreases rapidly towards the center of the embayment and increases towards the rocky headlands of its westernmost sector. By contrast, an increase of mechanical marks (*e.g.* fresh surfaces) is observed in the central region of the Arauco's embayment. Similarly, in Mataquito, dissolution features are more abundant in the headlands or small capes, while there is a higher presence of mechanical marks in sandy embayments. The results of this study demonstrate the importance of the geomorphological context as a controlling factor in the intensity of mechanical imprints on the surface of quartz grains transported by tsunamis and deposited in the inner shelf and coastal areas. Therefore, our results suggest that without a detailed geomorphological contextualization microtextural discrimination can lead to misleading interpretations. Hence, there is a need for more microtextural analysis on tsunami deposits in order to assess the variability in the geographic distribution and intensity of microtextures imprinted on the surface of quartz grains deposited during a tsunami event.

KEYWORDS **Quartz grains. Provenance studies. Dissolution. Principal Component Analysis. Exoscopy.**

INTRODUCTION

Sedimentary studies have used Scanning Electron Microscope (SEM) images to analyse microtextural changes on quartz grain surfaces from tsunami and palaeotsunami deposits (Bellanova *et al.*, 2016; Bruzzi and Prone, 2000; Costa *et al.*, 2009, 2012; Mahaney *et al.*, 2010; Mahaney and Dohm, 2011; Silva *et al.*, 2016). Even considering the ephemeral nature of the process and small transport distances involved in tsunami events, results revealed that tsunami grains tend to present higher percentage of mechanical imprints (*i.e.* fresh surfaces and percussion marks) when compared with their potential source sediment (Costa *et al*., 2012; Mahaney and Dohm, 2011). This was attributed to higher sediment concentration and higher flow velocities which are responsible for higher number of inter-grain impacts which cause the microtextural changes observed in tsunami and palaeotsunami samples from Portugal, Scotland and Indonesia (Costa *et al*., 2012). Earlier studies (Mahaney and Dohm, 2011) argued that steep offshore gradients and narrow embayments funnelled the energy and resulted in highly resurfaced grains during tsunamis.

Despite the advances in this field, there is not a unique microtexture or group of microtextures that could unequivocally identify a deposit caused by a tsunami event (Bellanova *et al*., 2016). This was observed on tsunami deposits from events such as the 27th of February 2010, Mw 8.8, earthquake off the coast of central Chile with the epicentre ca. 105km northwest of the city of Concepción (NOAA, 2012). Bellanova *et al.* (2016) used the tsunami deposit and the likely source-material samples from the Tirúa region and was unable to clearly differentiate the tsunami deposit from other sediments of diverse sources. Thus, these results raised questions on the widespread applicability of microtextural analysis to tsunami deposits. Here, we also assess the relevance of this morphological context and its importance in the microtextural signatures imprinted on quartz grains transported during a tsunami event.

In this work, we discuss the potential causes for the (non-)obliteration of a source signal in the microtextural compositions of the tsunami deposits. Results obtained from Arauco and Mataquito (Chile) (Fig. 1) provide further insights into the tsunami microtextural signatures.

METHODS

Microtextural analysis

A considerable number of papers described the application of SEM imagery in sedimentary studies (Mahaney, 2002 for summary). These studies have mainly focused in the establishment of provenance relationships in glacial, fluvial, aeolian and marine sediments with a few focusing in the study of tsunami deposits (*e.g*. Bellanova *et al*., 2016; Bruzzi and Prone, 2000; Costa *et al*., 2009, 2012; Mahaney and Dohm, 2011).

Grain surface microtexture (the micromorphological analysis of imprints carved on the surface of grains) is an analysis usually reserved for sandy quartz particles. Many quartz sand grains present microtextural features that can often be directly associated with specific transport processes or specific sedimentary environments. In order to recognize surface microtextures, a SEM was used to obtain high resolution images [JEOL JSM 5200 LV (Lisbon)].

Laboratory procedure

An average of 36 quartz grains per sample - minimum of 10 and a maximum of 60; total of 971 grains from 27 different samples, from the 5 to 1ϕ (31.5–500µm) size fraction were randomly selected under the binocular microscope and prepared for SEM analyses (Table 1). This involved particle mineralization with gold. SEM images were used to visually analyse each grain, focusing in the identification and semi-quantitative analysis of a group of microtextural characteristics.

Microtextural classification

A microtextural classification of quartz grains was conducted by three independent double-blind observers using the SEM images of the tsunamigenic samples and their likely sediment sources from Chile (Arauco and Mataquito). The classification clustered the grain features into two main microtextural families: Type A, grain surface dominated by chemical marks, and Type B, grain surface dominated by mechanical marks, described below and in Figure 2. As a result of the analysis, the percentage of each microtextural family within each sample was established. Median values for each microtextural family were calculated for each sample and used in the subsequent statistical analysis.

Furthermore, the semi-quantitative classification proposed by Costa *et al.* (2012) was applied. This classification is based on the percentage of the grain surface that is occupied by a specific microtextural feature (0: absent; 1: 0% to 10%; 2: 10 to 25%; 3: 25 to 50%; 4: 50 to 75% and 5: >75%). The microtextural features analysed were: fresh surfaces, percussion marks, dissolution and adhering particles. They can be characterized as follows:

Fresh surfaces: microtexture characterized by the presence of mechanical marks (*i.e.* fractures, abrasion marks, sharp edges) that resulted from the recent exposure of part, or the totality, of the grain surface. It is also indicative the absence of chemical dissolution or precipitation in these new surfaces.

Percussion marks: a V-shaped scar on a grain, typically the result of impact.

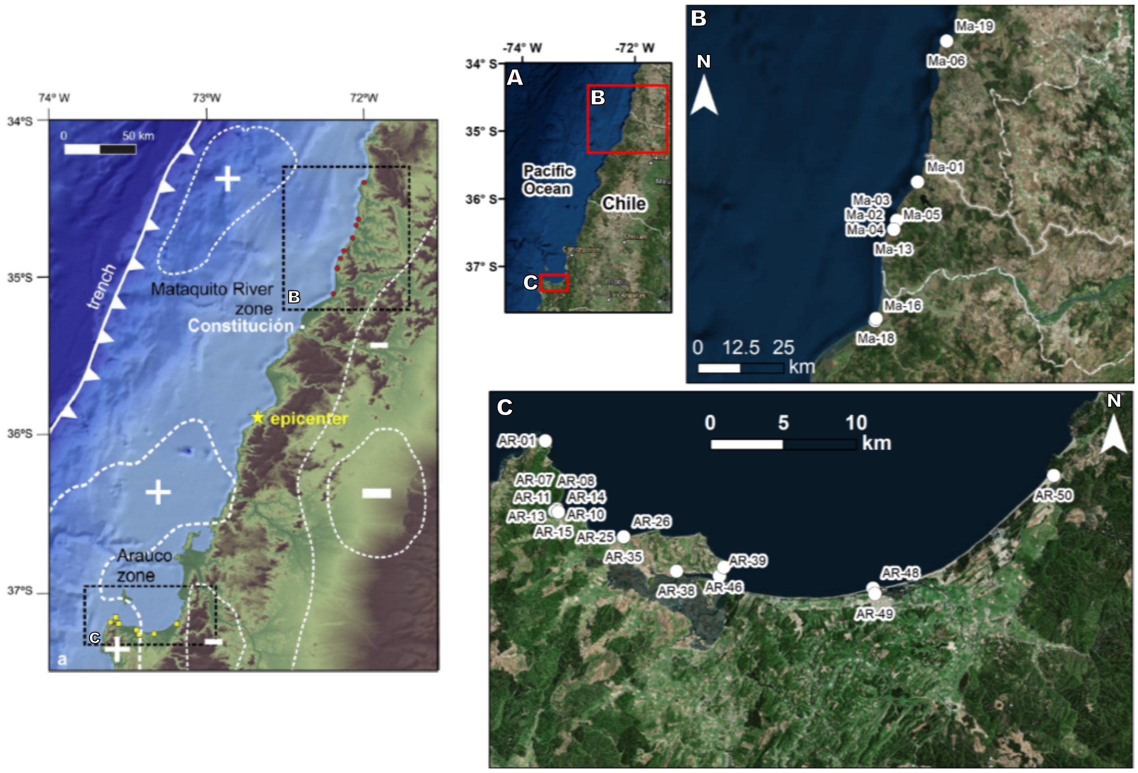

FIGURE 1. Location map of the two studied areas. Land deformation (uplift: +; subsidence: –) from surface deformation models published just after the earthquake by Sladen (2010) (adapted from Lario *et al.*, 2016). A) General overview of central Chilean coast. B) Sampling sites near Mataquito (sample Ma-3 was retrieved from the same location as sample Ma-2, but deeper in the trench). C) Sampling locations near Arauco (samples Ar-8 and Ar-7 were retrieved from the same location which was in the near vicinity (a few meters) of samples Ar-10, Ar-11, Ar-13 and Ar-14.

Adhering particles: microparticles on the surface of quartz grains. Usually, these microparticles are within grooves and many are attached to the surfaces of individual grains.

Dissolution: microtexture of chemical nature indicating the degree of dissolution on the surface of individual grains. The effects of dissolution on the grain surface are noticed by obliteration of fresh surfaces and sharp edges and by the formation of grooves.

STUDY AREA

On February 27th 2010 at 06:34:14 UTC an earthquake with epicentre situated 35Km depth in 35.909ºS, 72.733ºW (USGS, 2016) stuck the Maule Region. The Mw 8.8 earthquake deformed the ocean floor, setting off a tsunami along the fault-rupture area, that caused major damage to over 500km of mainland coastline of central Chile, as well as to several islands. The maximum water level observed in several places ranged from 10 to 12m and three to five waves reached the coast during the next four hours. Some days later, several ITST's (International Tsunami Survey Team), from UNESCO surveyed the effect of the tsunami, some focusing on the sedimentary record. In all cases tsunami run-up elevations and morphological changes were highly variable over short alongshore distances as a result local amplification effects due to alongshore variations in the tsunami wave heights, offshore bathymetry, shoreline orientations and onshore topography (Fritz *et al.*, 2011; Lario *et al.*, 2016; Morton *et al.*, 2011).

From 17th to 30th March a survey of the tsunami sedimentary record was carried out (Lario *et al.*, 2016). Water levels were established based on watermarks in buildings and vegetation and on local people reports. In order to study the tsunami impact, two different co-seismic deformation areas were selected from surface deformation models published by the California Institute of Technology just after the earthquake (Sladen, 2010). This model predicted uplift deformation in the Arauco Peninsula and stability in the Mataquito River area. With this premises, according to Lario *et al.* (2016) the two areas selected to survey were: i) the Arauco Gulf and surrounding coast, swept by the tsunami and affected by a co-seismic uplift of up to 2.5m, with emersion of the marine platform and tidal areas, and ii) Mataquito River area, where co-seismic subsidence was observed. In the uplifted Arauco sector, the co-seismic deformation seems to have increased backwash of remobilized sediments, leaving the observed thin deposits. Whereas in the stable and subsiding sites of the Mataquito River, sand deposits, pebble and cobble sediments are thicker (Lario *et al.*, 2016). The main tsunami parameters surveyed in both areas were a run-up to 12m in Arauco Gulf with nearly 1.2km of inundation in embayment areas and to 3.9km in tidal channels. In the Mataquito River area the run-up reached up to 8.5m in open areas and inland penetration up to 2.7km in streams.

Geomorphologically, the Arauco Gulf is a large embayment (approximately 35km long) with some rocky headlands mainly in its westernmost and easternmost sectors (Fig. 1). The central area of the bay is characterized by a sandy bay backed by incipient dunes. In this region of Chile the shelf edge lies at a water depth range of 150–300m and is well defined where the shelf is wider such as offshore the Arauco Gulf (Volker *et al.*, 2012, 2013). Offshore the Arauco Peninsula, the shelf edge is at some places indented by headscarps of ancient giant slope failures (Geersen *et al.*, 2011).

The upper continental slope shows a relatively smooth morphology and is inclined at low angles (2º–4º) to a water depth of 2,000m. On the other hand Mataquito (Fig. 1) is a roughly north-south stretch of the coast with small embayments separated by promontories. The largest bay is located in the central part of the study area (Fig. 1). Furthermore, offshore Mataquito, between latitude 34ºS and 34.7ºS, the Mataquito Canyon is a prominent feature of the inner shelf domain (Volker *et al.*, 2012, 2013).

RESULTS

Microtextural results are based on 971 SEM images of quartz grains (Fig. 2) collected in Arauco and Mataquito. Results are summarized in Figures 3, 4, 5, 6, 7 and Table 1.

In broad sense, a dominance of Type A grains (Fig. 3) was easily observed in the samples analysed. Chemical marks (dissolution and adhering particles), represent together >60% in 23 samples, and only 4 samples presented lower values (minimum of 44.4).

Using Costa *et al.* (2012) classification, fresh surfaces were present in all samples but essentially with low values (mean of 1.44). Nevertheless, values between 2.56 and 1.97 were observed in 6 samples – 5 from Arauco and 1 from Mataquito – (Ma-10-18, AR-10-10, AR-10-15, AR-10-07, AR-10-25, AR-10-48) (Fig. 6). Regarding percussion marks the mean value was 1.28 with 8 samples presenting the highest values (between 1.52 and 1.93) (Table 1). Adhering particles presented a mean value of 2.83, with 20 samples presenting values above 2. Similarly, regarding dissolution, the mean value was 2.70 and only 2 out of 27 samples displayed values >2 (Ma-10-18, AR-10-10) (Table 1).

DISCUSSION

Several attempts have been made in order to characterize microscopic signatures on the surface of quartz grains from

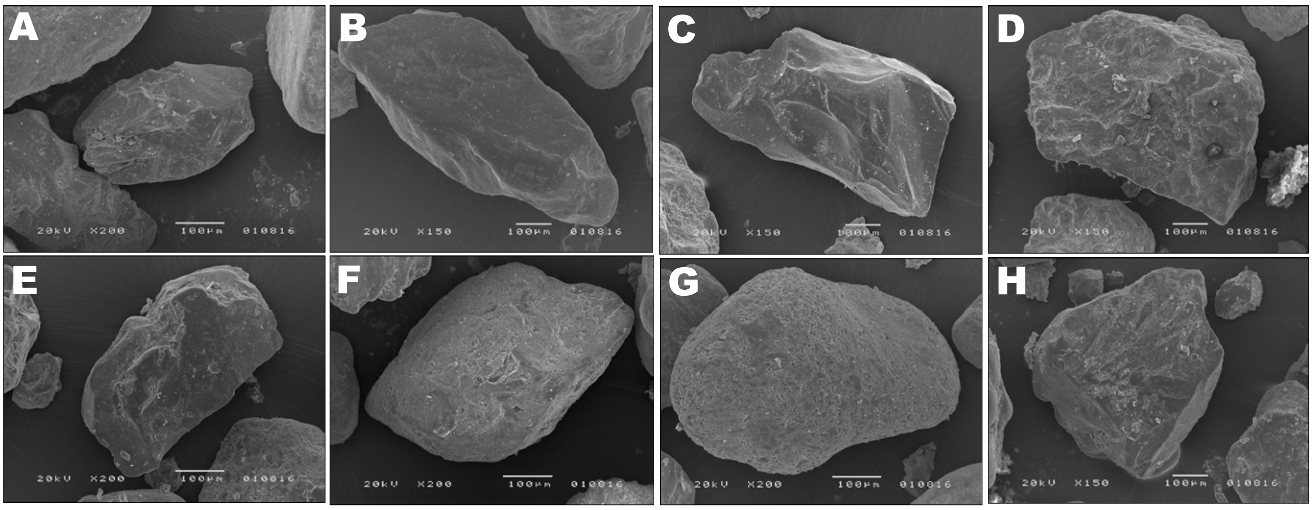

FIGURE 2. Mosaic with microtextural imprints representing the diversity of microtextural signatures observed in the Arauco and Mataquito samples. All images are from sample AR-10-39. A) Quartz grain displaying fresh surfaces and adhering particles (mainly in the top left part of the grain). It is possible to observe curved and linear fractures throughout the grain. B) Quartz grain that apparently did not suffer any major microtextural imprint syn-tsunami event. It presents a surface with mild dissolution and it is possible to identify craters on the lower section of the grain. C) Quartz grain covered with mechanical imprints (mainly fresh surfaces), with craters and a recently reworked surface. D) Quartz grain with strong dissolution (Type A), which makes difficult to assess the last mechanical imprint on the grain. E) Quartzgrains dominated by mechanical marks (indentations are visible and resulted from impacts with other grains) and, secondarily, with dissolution microtextures on the top right section. F and G) Grains with dominant chemical features and no relevant mechanical imprints. H) Grain with abundant fresh surfaces partially covered with adhering particles, which suggest that these surfaces precede chemical action on the grain's surface.

TABLE 1. Semi-quantitative microtextural analysis of 27 samples from Arauco and Mataquito. The results are derived from the individual classification of 971 grains and the calculation of mean values for each sample (average of 36 and maximum of 60 grains per sample). Microtextural features (dissolution, adhering particles, percussion marks and fresh surfaces) were classified according to Costa *et al*., (2012).from 0 (absent) to 5 (occupying >75% of the grain's surface). Grains we also grouped in two families, Type A (dissolution dominated) and Type B (mechanical features dominating)

Location	Sample	Sed Env	East	South	Number of grains	% of Grain Type A	% of Grain Type B	Fresh surfaces	Perc marks	Adhering particles	Dissolution
Arauco	AR-01	Beach	626325	5887551	28	92,86	7,14	0,43	0,57	4,00	4,04
Arauco	AR-07	Pre-tsunami sand	627141	5882925	28	85,71	14,29	0,39	0,46	4,46	3,68
Arauco	AR-08	Tsunami backwash	627141	5882925	54	98,21	1,79	0,95	0,63	4,70	3,46
Arauco	AR-10	Tsunami sand	627104	5882876	60	75,00	25,00	1,57	1,23	3,33	2,95
Arauco	AR-11	Tsunami sand	626960	5882755	46	78,26	21,74	1,17	1,52	2,43	2,87
Arauco	AR-13	Tsunami sand	626960	5882755	30	86,67	13,33	0,97	0,60	4,43	2,83
Arauco	AR-14	Tsunami sand	627219	5882688	56	77,78	22,22	1,28	1,19	3,30	2,80
Arauco	AR-15	Tsunami sand	627219	5882688	20	70,00	30,00	1,55	0,90	2,25	2,75
Arauco	AR-25	Post-tsunami beach	631691	5880991	60	71,67	28,33	1,85	1,38	2,47	2,67
Arauco	AR-26	Tsunami sand and cobbles	631691	5880991	28	71,43	28,57	1,32	1,32	3,93	2,64
Arauco	AR-35	Tsunami sand	631695	5880988	60	70,00	30,00	1,32	1,65	1,65	2,58
Arauco	AR-38	Tsunami sand	635314	5878641	30	66,67	33,33	1,53	1,40	1,67	2,53
Arauco	AR-39	Tsunami sand	638256	5878333	30	73,33	26,67	1,97	1,80	1,97	2,43
Arauco	AR-46	Tsunami sand	638545	5878911	30	73,33	26,67	1,00	0,97	3,40	2,40
Arauco	AR-48	Beach	648748	5877487	30	53,33	46,67	2,13	1,77	1,67	2,33
Arauco	AR-49	Tsunami sand	648873	5877093	60	66,67	33,33	2,20	1,53	2,60	2,17
Arauco	AR-50	Tsunami sand	661128	5885195	60	46,67	53,33	2,13	1,73	1,23	2,08
Mataquito	Ma-01	Tsunami sand	766972	6150231	28	60,71	39,29	2,21	1,93	2,11	1,86
Mataquito	Ma-02	Tsunami sand	760928	6139016	8	100,00	0,00	0,50	0,38	4,38	3,50
Mataquito	Ma-03	Beach	760928	6139016	60	81,67	18,33	1,42	1,28	3,80	3,05
Mataquito	Ma-04	Tsunami sand	760060	6136274	24	83,33	16,67	1,29	1,46	2,67	2,75
Mataquito	Ma-05	Tsunami sand	760060	6136274	18	66,67	33,33	1,50	1,22	3,28	2,67
Mataquito	Ma-06	Post-tsunami beach	775410	6191095	18	44,44	55,56	2,56	1,78	1,83	1,94
Mataquito	Ma-13	Tsunami sand	760032	6136452	24	83,33	16,67	0,88	1,38	3,04	2,63
Mataquito	Ma-16	Tsunami sand and cobbles	754620	6109873	26	57,69	42,31	1,62	1,35	2,46	2,58
Mataquito	Ma-18	Post-tsunami beach	754937	6110564	30	60,00	40,00	1,57	1,67	2,53	2,43
Mataquito	Ma-19	Tsunami sands	775410	6191095	26	65,38	34,62	1,62	1,38	0,85	2,38

distinct sedimentary environments (Costa *et al*., 2012; Vos *et al*., 2014 for a summary). These results, based solely on visual classification, yielded somewhat ambiguous identification of features, interpretation of imprinting mechanisms or processes, and association of specific microtextural signatures in quartz grains with specific sedimentary environments (*e.g*. Costa *et al*., 2012). This is a key issue in microtextural analyses, which is particularly amplified in the case of tsunami-driven sedimentary deposits because of the short transport distances and briefness of the events.

Interpretation of the results obtained in Arauco and Mataquito represent a challenge due to the overall dominance of dissolution and the low number of mechanical marks. If we regard a grain as a palimpsest, it is highly feasible that one can identify the last imprint (and therefore its transport and depositional mechanisms)

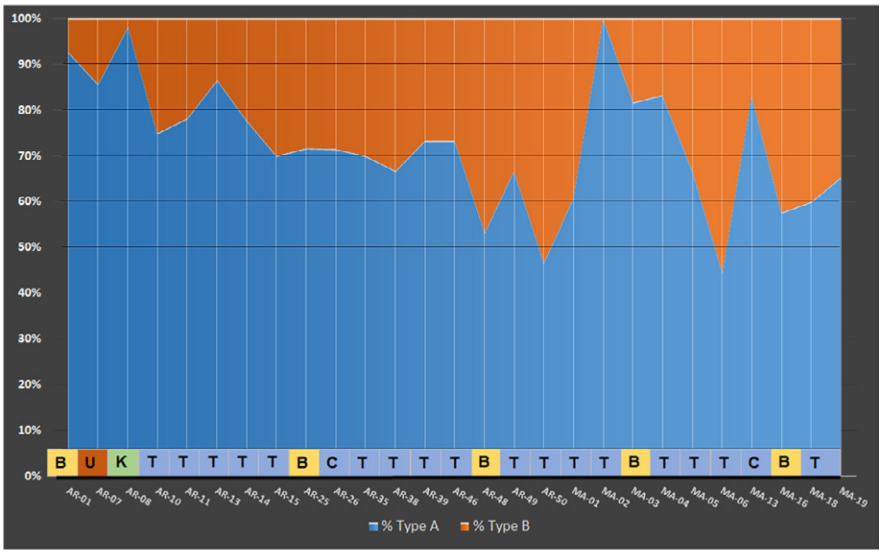

FIGURE 3. Histograms of the microtextural analysis. Note the different proportion of Type A (chemical) and Type B (mechanical) microtextures between different samples. B: Beach sample, K: Backwash sample, T: Tsunami sample, U: Underlying layer.

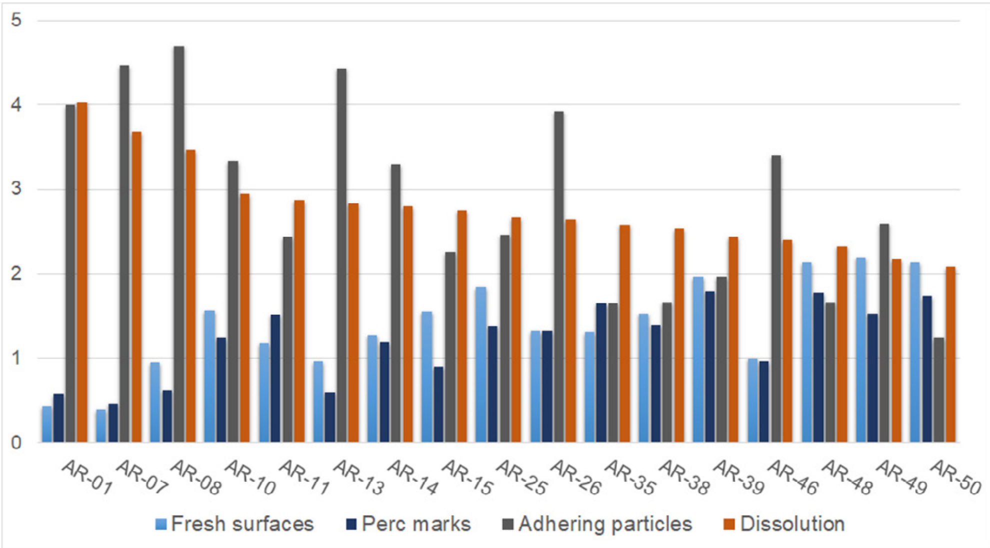

FIGURE 4. Intrasample variation of microtextural features from Arauco.

and infer other processes that affected the grain before the end of its last sedimentary cycle. In theory, in some cases, one could complete a full source-to-sink relationship and establish multi-cycle stages on the grain's evolution. However, this is only possible if preservation conditions are ideal. Therefore, if chemical agents are present they can contribute to dissolve the grain's surface or to precipitate materials (creating coating that will mask previous sedimentological episodes). In contrast, if the environment is highly dynamic and energetic, the grains could be totally resurfaced due to multiple impacts with other grains. These conclusions have been tested, and confirmed, empirically and with many field studies (*e.g*. Costa *et al*., 2017, 2018; Mahaney, 2002).

Although of unquestionable interest for provenance studies, high results for dissolution immediately question the reliability of microtextural analysis to study tsunamis mainly because (apparently) no syn-event imprints were registered. The high values of dissolution could raise the hypothesis of a major offshore sediment source, unfortunately not analysed here in the Chilean samples due to (field) sampling constrains. However, typically, tsunami deposits are fed by sediments that are available in the coastal fringe, even if contributions from offshore sediment have been (rarely) described (*e.g*. Paris *et al*., 2009).

As mentioned above, the dominant feature in the Chilean samples is the massive presence of chemical marks

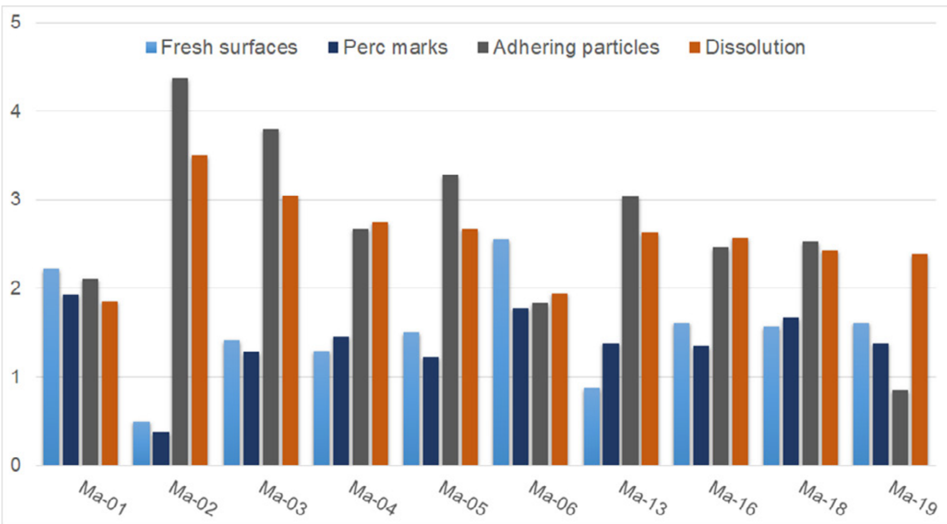

FIGURE 5. Intrasample variation of microtextural features from Mataquito.

(mostly dissolution). This is even clearer when we analyse the finer tsunami samples AR-10-50 and AR-10-11 or the one collected farther inland AR-10-35 (Table 1). These three samples present a sum of dissolution and adhering particles of 100% and are the only ones presenting such high values. The results from AR-10-50 and AR-10-11 could be a grain-size biass, as demonstrated by several studies (*e.g.* Costa *et al.*, 2012; Mahaney, 2002; Vos *et al.*, 2014), as silts are much more susceptible to chemical weathering and this derives into a stronger presence of dissolution. Confirming this line of reasoning, it is important to note that these are the samples presenting the highest values for adhering particles thus clearly suggesting precipitation of components that cover the grain's surface.

Mahaney and Dohm (2011) suggested that maximum grain mechanical damage is produced with steep offshore slope, maximum sand accumulations and narrow embayments. In the case of Arauco and Mataquito this model seems to be confirmed (Figs. 6; 7; check high-resolution detailed bathymetric mapping in Volker *et al.*, 2013). Maximum presence of fresh surfaces is observed in narrow embayments and where sand accumulation is at its maximum in the region analysed in this work (Table 1, Figs. 1; 6; 7). Moreover, in Figure 4, clear gradients can be observed in the fresh surfaces and percussion marks (increasing eastwards), while adhering particles and dissolution marks (decrease eastwards). This pattern is very likely associated with the degree of exposure of the coastal fringe in each location. The settings with a higher exposure tend to be impacted with higher energy thus are more prone to the presence (and increase) of mechanical marks. On the contrary, sheltered areas are less exposed to wave action and, thus, tend to present higher proportion of chemical marks.

Furthermore, the studied sites (Arauco and Mataquito, Fig. 1) were, essentially, in low (<10m above mean sea level) estuarine zones in central Chile. These coastal environments display contrasting features with the ones studied by Costa *et al.* (2012), namely the lack of robust dune fields adjacent to the coast. This factor is determinant for an even higher increase in mechanical marks (in particular, percussion marks) due to the sudden increase in sediment concentration when tsunami waves overtop the coastal dune and incorporate large volumes of aeolian coastal sand. The lack of this geomorphological feature has obvious consequences in the microtextural signatures observed in samples from Arauco and Mataquito. So, we have grounds to state that percussion marks were probably less present in the Chilean studied grains because of the very likely lower sediment concentration during the tsunami inundation (when compared, for instance, with the Portuguese sites studied by Costa *et al.*, 2012).

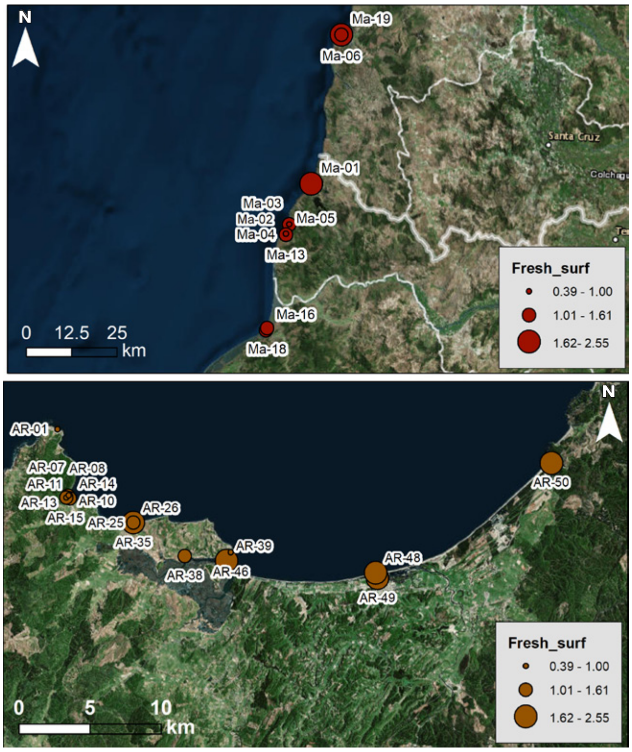

FIGURE 6. Geographic distribution of fresh surface microtextures along the study areas. Numbers according to the semi-quantitative microtextural classification of Costa *et al.* (2012).

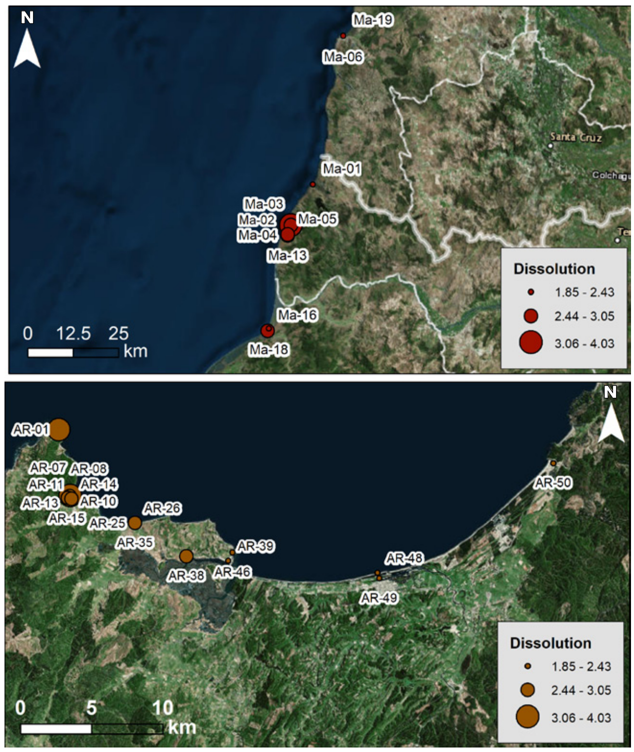

FIGURE 7. Geographic distribution of dissolution microtextures along the study areas. Numbers according to the semi-quantitative microtextural classification of Costa *et al.* (2012).

The observation that fresh surfaces increase in narrow embayments is in agreement with Mahaney and Dohm (2011) model. The formation of fresh surfaces has been determined empirically in open-channel tests (Costa *et al.*, 2017) showing that low sediment concentrations can produce increases in fresh surfaces. If we present results of fresh surfaces, dissolution and adhering particles in increasing order, it is easy to perceive that beach samples exhibit more fresh surfaces and less adhering particles, despite they still present very high dissolution values (Table 1). Regarding tsunami samples, it is clear that finer samples present more adhering particles while other tsunamigenic samples always present fresh surfaces (Table 1). It is also very interesting that the pre-tsunami sand and the backwash sample (AR-10-08) present one of the highest dissolution values (Table 1) thus, suggesting possible resurfacing of quartz grains during tsunami inundation.

In Figure 6 and 7, an overall and site-by-site analysis displays the correlation between the specific coastal and sedimentary settings with variations in the intensity of grain's microtextures. The spatial variation is obvious reflecting local conditioning factors (*i.e.* sand availability, accommodation space, nearshore slope, dune presence or absence). Despite huge difficulties (due to overall dissolution dominance), we conclude that it is possible to detect increases of mechanical marks (in this case fresh surfaces) on tsunami grains in the Central Chile.

Using PCA analysis, we can conclude that the two principal components are responsible for nearly 90% of the variation. Figure 8 shows the close relationship between mechanical marks (fresh surfaces and percussion marks) while they are orthogonally-related with dissolution. It is also interesting to see some contrast between dissolution and adhering particles. If we analyse the sample results (Table 1; Figs. 6; 7; 8) we can easily conclude that fine tsunami sediments are related with a stronger presence of adhering particles The large majority of tsunami samples (including backwash samples) show a strong relationship with dissolution however they also exhibit some mechanical marks. This is put in evidence in Figures 6 and 7, where a spatial distribution of fresh surfaces and dissolution can be observed. It is noted that fresh surfaces and dissolution tend to present symmetrical results and that this opposition is evident in 2 main geomorphological settings: headlands (lower fresh surfaces and higher dissolution) and embayment (higher fresh surfaces and lower dissolution).

The striking microtextural feature of the Chilean quartz grains, as stated above, is the dominance of dissolution. This can be also explained by the presence of pseudomorphic quartz (beta quartz, commonly associated with felsic volcanic rocks like rhyolite but also common in metamorphic and some igneous rocks). This type of quartz grains presents poor cleavage due to its crystalline structure and it is more easily weathered and chemically reacts more quickly with acidic and organic soils and with other minerals. It is important to consider that despite the siliciclastic (quartz) character of the Chilean littoral a strong presence of heavy minerals is noted. These minerals are more susceptible to chemical dissolution than quartz; thus, due to their larger presence they are able to introduce relative large amounts of chemical elements that will favour chemical dissolution of volcanic quartz. The microtextural features observed suggest that some of the quartz present in the sandy tsunami deposits could have an original source on andesitic rhyolitic rocks. These are present in the Chilean Andes (Pichler and Zeil, 1972) and the drainage basins bring these sediments to the coast making them available for cross shore transport during a tsunami.

Thus, results of Arauco and Mataquito point to the occurrence of a singular combination of the conditions described below:

i) Dominance of pre-event dissolution on grains surface (*e.g.* beach, pre-tsunami sand and backwash samples).

ii) Absence of relevant increases in percussion marks due to lack of available sediment source that causes a sudden increase in sediment concentration once the tsunami waves reach the coast.

iii) Slight increases in fresh surfaces (as described above) which are constrained by the local geomorphological setting (narrow embayments, steep offshore gradient).

iv) Presence of volcanic quartz in the tsunami quartz sands (reacting differently to weathering and dissolution).

The sum of these conditions creates a major challenge to sedimentological analysis of tsunami deposits, namely their microtextural identification. Nevertheless, it was possible to perceive the influence of the tsunami event on quartz grains surfaces, by the increase in fresh surfaces in areas with narrow embayments and sand availability. Conceptually, tsunami grains surface present more mechanical marks. Previous studies have suggested that these marks could be either fresh surfaces or percussion marks (Costa *et al.*, 2012). This study reveals a combination of factors that contribute to an increase of fresh surfaces in tsunami grains, despite the unfavourable sedimentological and microtextural context described above.

At the present state of research, results suggest that the sediment source had in origin high degrees of dissolution and it was those grains that were (slightly) resurfaced. Despite limitations revealed in this work, properly contextualized microtextural analysis can prove to be an interesting complementary tool in coastal provenance studies and also in the study of tsunami deposits

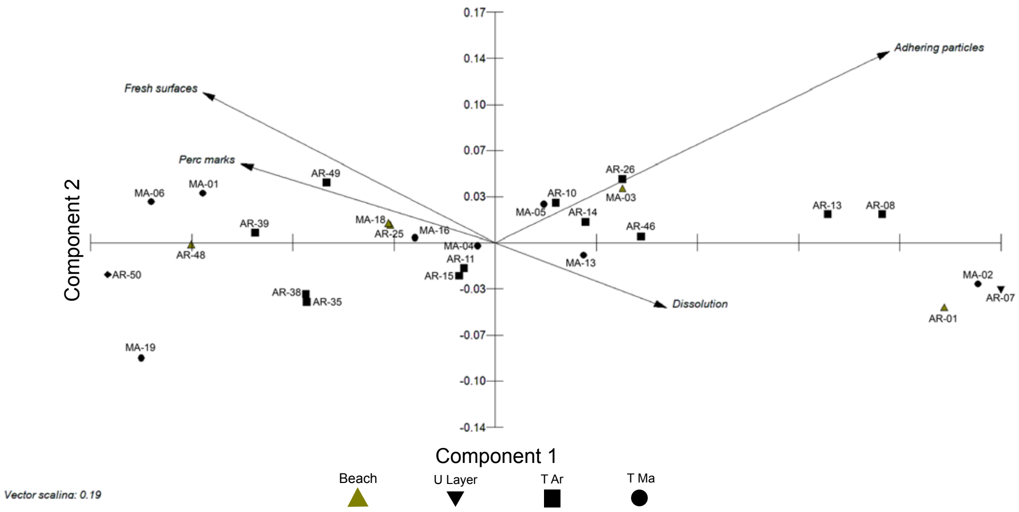

FIGURE 8. Principal component analysis of quartz grains microtextures. Samples are labelled in agreement with their sedimentary environment. B: Beach, T-Ar: Tsunami Arauco, T-Ma: Tsunami Mataquito, U: Underlying layer.

CONCLUSIONS

Results suggest poor syn-event depositional imprints and dominance of originally sourced microtextural features. Despite difficulties (dominance of dissolution, presence of volcanic quartz, absence of robust dune fields, limited sand availability), it was possible to perceive an increase in fresh surfaces mainly in areas with a favourable geomorphological setting (narrow embayments with steep offshore gradient). If, as expected, mechanical marks increased in tsunami deposits, we were able to conclude that the type of mark (percussion marks or fresh surfaces) depends on sediment availability. In the case of Arauco and Mataquito and in agreement with the model proposed by Mahaney and Dohm (2011), fresh surfaces increased in the tsunami deposits collected in sandy bays. By contrast, in headlands dissolution was overwhelming. Thus, results here demonstrated the site-specific character of this approach and displayed its main controlling factors (i.e. coastal geomorphology and sediment availability).

Finally, the case presented here stresses the need for a careful use of this technique and for an extensive effort to develop semi-automated observation methodologies that will favour: i) a less subjective quantification and ii) the increase of specific microtextures to analyse.

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