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On the occurrence of the Neapolitan Yellow Tuff tephra in the Northern Phlegraean Fields offshore (Eastern Tyrrhenian margin; Italy)

Sulla presenza del tefra del Tufo Giallo Napoletano nell'offshore settentrionale dei Campi Flegrei (margine tirrenico orientale, Italia).

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ABSTRACT

A main volcanic marker has been identified for the first time on the continental shelf of the northern Phlegraean Fields in the Gaeta Gulf (Campania region, eastern Tyrrhenian margin, Italy) by means of Subbottom Chirp profile grid and stratigraphic analysis of a core collected on the slope. In the seismic sections, the core bottom corresponds to the top of a continuous and parallel reflector (*V*) interbedded within the transgressive deposits of the Late Quaternary-Holocene depositional sequence. The Transgressive System Tract deposits are particularly thick compared to the majority of the transgressive deposits of other shelf settings. This might be due to the input of pyroclastic and volcanoclastic deposits related to the intense eruptive activity of the Campania Plain during the Late Pleistocene-Holocene time span. Undulations and pockmarks are the main morphological features of the sea floor and they might be linked to gas uprising, widely detected in the study area. The *V* reflector is located on the shelf from northeast to southwest at different depths, ranging from 10 ms (about 8 m) to 30 ms (about 25 m) below sea floor and it can be mapped down to the continental slope. The geological calibration of this continuous reflector coupled with tephrostratigraphic analysis, allowed to correlate it with the Neapolitan Yellow Tuff deposits emplaced at Phlegraean Fields at ca. 15 ka.

Key words: Neapolitan Yellow Tuff, Gaeta Gulf, Phlegraean Fields, coastal volcanism, seismic stratigraphy.

1. INTRODUCTION

Coastal volcanism along the Campania margin plays a key role in the stratigraphic architecture of adjacent marine settings since it leads to several types of processes that supply large volumes of pyroclastic and volcanoclastic deposits over wide sectors of the continental shelf-slope-basin system during short time spans (INSINGA *et alii*, 2006; MILIA *et alii*, 2007; DE ALTERIIS *et alii*, 2010, BUDILLON *et alii*, 2012). Pyroclastic deposits, in particular, are delivered to the sedimentary environment following a variety of transport processes such as fallout, flows and surges which can evolve across the continental shelf and slope in sediment failure or hyperpicnal flows (SACCHI *et alii*, 2005, 2009; MILIA *et alii*, 2008). As a result of their synchronous deposition over large areas, pyroclastics (tephra) form important stratigraphic markers and event signals in the marine record (e.g. LOWE, 2011; ZANCHETTA *et alii*, 2011; INSINGA *et alii*, 2014 and references therein) and such findings are particularly frequent along the Campania margin in the Naples and Salerno gulfs and offshore Cilento (e.g.; BUCCHERI *et alii*, 2002; IORIO *et alii*, 2004; SACCHI *et alii*, 2005; INSINGA *et alii*, 2008; LIRER *et alii*, 2013; IORIO *et alii*, 2014a). A detailed geological literature exists on the structural and stratigraphic relationships between marine and volcanic units in the Gaeta Gulf since the Quaternary, however it is mainly based on seismic interpretations and onshore borehole data (AIELLO *et alii*, 2000; MILIA *et alii*, 2013; TORRENTE & MILIA, 2013; MILIA & TORRENTE, 2015). Core data regarding the marine stratigraphic record and the tephra deposits interbedded within are still very few and mainly related to the Holocene deposits (IORIO *et alii*, 2014b; MARGARITELLI *et alii*, 2016).

In this paper we report, for the first time, on the occurrence of the Neapolitan Yellow Tuff deposit in the southern sector of the Gaeta Gulf, between the Volturno mouth and the Cuma town, offshore the Northern Phlegraean Fields (Fig. 1). Based on gravity core data and high-resolution seismic profiles, the Neapolitan Yellow Tuff deposit was characterized both in terms of lithology and chemistry and its seismic signature was described and mapped. The obtained results aim to provide a contribution to the tephrostratigraphic framework of the southern Gaeta Gulf and highlight the significant role of this tephra in regards to the stratigraphic architecture of Northern Phlegraean offshore.

2.GEOLOGIC SETTING

The study area represents the seaward extension of the northern sector of the Campania Plain (Fig. 1), a coastal plain of southern Italy located along the Latium-Campania margin. This latter is characterized by Plio-Pleistocene tectonically-downthrown areas genetically related to normal and strike-slip faults linked to the geological evolution of the Eastern Tyrrhenian margin ("peri-tyrrhenian basins"; FABBRI *et alii*, 1981 BARTOLE *et alii*, 1984; MALINVERNO & RYAN, 1986; MARIANI & PRATO, 1988; FLORIO *et alii*, 1999; BRUNO *et alii*, 2000; AIELLO *et alii*, 2000, 2011a; 2011b; CASCIELLO *et alii*, 2006) and filled by coastal and marine deposits reaching thicknesses of several thousand of meters. In particular, in the Gaeta basin, extensional tectonics has been active along systems of ESE-WNW, E-W and NE-SW trending normal faults, related to strike-slip tectonic movements that took place mainly during the Late Pliocene-Early Pleistocene time interval (BARTOLE *et alii,* 1984, AIELLO *et alii*, 2000, BRUNO *et alii*, 2000).

The depositional geometries of strata pertaining to the Plio-Quaternary basin fill are similar to those recognized in the adjacent Terracina basin (AIELLO *et alii*, 2000). The lower seismic sequences are characterized by parallel horizons and are strongly affected by wedging and growth as a consequence of synsedimentary tectonics. The upper seismic sequences show progradational geometries led by sedimentary feeding from the Garigliano and Volturno rivers and controlled by eustatic sea-level fluctuations during Quaternary times (AIELLO *et alii*, 2000).

Regional geological evidence, coupled with seismo-stratigraphic interpretations, has suggested that the Volturno basin represents a half-graben structure, characterized by blocks downthrown along normal faults and filled by four main seismic units (identified as D1-D4; AIELLO *et alii*, 2011a; 2011b). Rapid flooding of coastal Volturno Plain culminated at 6.5 cal. ka B.P. (AMOROSI *et alii*, 2012 and references therein), leading to a narrowing of the shelf to a maximum width of 16 km in correspondence to Volturno river mouth and a minimum width in the Cuma offshore (about 10 km). The shelf break occurs at water depths ranging between 120-125 m.

The stratigraphic architecture of the continental shelf during the Late Pleistocene – Holocene time interval is an incomplete 4th order depositional sequence, that shows an inner strata organization with minor downlap surfaces and erosional truncations separating different phases of progradation (MARANI *et alii*, 1986; AIELLO *et alii*, 2000, 2011a; 2011b; IORIO *et alii*, 2014b). The last progradation started at about 130 ka and ended at about 18 ka (CATTANEO *et alii*, 2002; LOFI *et alii*, 2003; DUVAIL *et alii*, 2005; LISIECKI & RAYMO, 2005; PELLEGRINI *et alii*, 2010; CAPRARO *et alii*, 2011; MASELLI & TRINCARDI, 2013; MASELLI *et alii*, 2014). An abrupt erosional surface separates the forced regression and lowstand deposits from the overlying sediments, that were formed between 18 ka and 5 ka during the last sea level rise (transgressive deposits; FABBRI *et alii*, 2002; CATTANEO & STEEL, 2003; TRINCARDI *et alii*, 1994) and from about 5 ka to present times during the recent sea level highstand (highstand deposits; HUNT & TUCKER, 1992; COPPA *et alii*, 1996; BUCCHERI *et alii*, 2002). Since ca. 6.5 cal. ka, the highstand phase has marked the onset of the present-day Volturno delta and the progradation of the adjacent coastal plain, ranging between 3 and 6 km (BARRA *et alii*, 1996; BELLOTTI, 2000; ROMANO *et alii*, 2004; AMOROSI *et alii*, 2012; SACCHI *et alii*, 2014b). Holocene wedge decreases in thickness towards the shelf edge. The continental slope is characterized by a uniform profile and is incised by several submarine gullies (CHIOCCI & CASALBORE, 2011; PETRUCCIONE *et alii*, 2011).

2.1 THE NEAPOLITAN YELLOW TUFF

Intense volcanism took place at several centers of the Campania Plain since at least the middle Pleistocene (DE VIVO *et alii*, 2001; ROLANDI *et alii*, 2003; DI VITO *et alii*, 2008; INSINGA *et alii*, 2014) as a consequence of the extensional tectonics that affected the eastern Tyrrhenian margin. During the Late Pleistocene, caldera-forming eruptions occurred inside the Campania Plain at Phlegraean Fields district with the most recent event of the Neapolitan Yellow Tuff (NYT) at 14.9±0.4 ka (DEINO *et alii*, 2004). It erupted an estimated volume of about 45 km^3 DRE (Dense Rock Equivalent) covering an area of more than 1000 km^2 and producing a caldera collapse of about 10 km in diameter (SCARPATI *et alii*, 1993; ORSI *et alii*, 1995). On the periphery of Phlegraean Fields and in the Campania Plain, the NYT exhibits high thickness and is characterized by a succession of pyroclastic fall and flow deposits (Lower and Upper Member, respectively; ORSI *et alii*, 1992, 1995). The Lower Member is compositionally bimodal (trachytic and trachyphonolitic) whereas the Upper Member spans the full compositional range between the two Lower Member populations (TOMLINSON *et alii*, 2012). Distal ash-fall deposits spread over wide areas up to northern Europe in marine and continental archives (e.g. PATERNE *et alii*, 1986; CALANCHI *et alii*, 1998; SIANI *et alii*, 2004; BOURNE *et alii*, 2010; LANE *et alii*, 2015 and references therein). By contrast, far from the vent on land, such as in the Volturno coastal plain, the NYT is absent due to the removal-burial by fluvial processes (AMOROSI *et alii*, 2012). The NYT products had a strong impact on the sedimentary processes and, ultimately, on the stratigraphic record of adjacent marine settings, as documented in the Pozzuoli Bay (AIELLO *et alii*; 2012; SACCHI *et alii*, 2014a; AIELLO *et alii*, in press.)

3. DATASET AND METHODS

3.1 GRAVITY CORE C1161

The core C1161 was recovered at 144 m below the sea level on the right side of an upper slope gully in the northern sector of Phlegraean Fields offshore (Fig. 1) using a 6 m long gravity corer with liners of 9 cm in diameter. Core recovery was about 50% with an estimated compaction of about 15%. The stratigraphic record consists of ca. 2.62 m-thick Holocene deposits which have been studied in detail with respect to their lithological, sedimentological, petrophysical and seismic aspects (IORIO *et alii*, 2014b). The sediments are mainly represented by silty and clayey deposits. A grain-size variation occurs at about 1.60 m below sea floor down to the core bottom, where sandy and gravelly fractions, mainly made up of bioclastic and pumiceous clasts, occur. Sedimentological analysis suggested a high energy depositional environment (IORIO *et alii*, 2014b), in agreement with the location of the core on a submarine channel levee. The integrated petrophysical (high magnetic susceptibility values) and seismic analysis correlated the bottom of the core to the top of a seismic reflector interpreted as being of volcanic origin (*V* in IORIO *et alii*, 2014b). The sediment was sampled and chemically analysed for the purposes of this work.

3.1.1 TEPHRA ANALYSIS

The non visible-tephra (cryptotephra) found at the core bottom and corresponding to the top of the reflector *V* in IORIO *et alii* (2014b), was sampled, disaggregated in distilled water and wet sieved at 63, 90, 125 and 250 μm in order to remove the fine-grained sediment. The sieved material was cleaned with an ultrasonic probe, dried at 60°C and then it was observed at the optical microscope in order to describe the lithology and to pick up fresh glasses for the chemical characterization. At least 25 juvenile fragments (pumiceous and glass shards) were mounted on epoxy resin and suitably polished for microprobe analysis.

Energy Dispersive Spectrometric (EDS) analyses were performed using JEOL JSM-5310 SEM at CISAG (Centro Interdipartimentale di Servizio per Analisi Geomineralogiche) of the University of

Napoli “Federico II” through Oxford Instruments Microanalysis Unit, equipped with an INCA X-act detector. The operating conditions were 15 kV primary beam voltage, 50-100 m. A filament current, 50 sec acquisition time with variable spot size was adopted during the data elaboration. A correction for matrix effect was performed using INCA version 4.08 software that used the XPP correction routine, based on a Phi-Ro-Zeta approach. Moreover, a primary calibration was performed using international mineral and glass standards USMN reference samples according to the following scheme: Anorthoclase 133868 for Si and Na, Microcline 143966 for Al and K, Fayalite 85276 for Mn, Anorthite 137041 for Ca, Hornblende 143965 for Fe, Mg and Ti, Scapolite 6600-1 for Cl, and Apatite 104021 for P.

Precision and accuracy were assessed using the rhyolitic glass USMN 75854 as secondary standard. Mean precision was <5% for SiO_2, Al_2O_3, K_2O, CaO and FeO, and around 10% for the other elements.

3.2 SEISMIC DATA ACQUISITION

Six Chirp profiles, collected in the frame of research projects on marine geological mapping on the continental shelf off the Campania region (penetration between 25 and 50 m below the sea bottom using an average velocity of 1.550 m/sec for time-to-depth conversion), provided the stratigraphic framework to recognize the volcanic marker (Tab. 1). High resolution seismic stratigraphy has been described in detail as a valuable technique of analysis of seismic profiles (MITCHUM *et alii*, 1977; VAIL *et alii*, 1977; VAN WAGONER *et alii*, 1988; CATUNEANU *et alii*, 2009; ZECCHIN & CATUNEANU, 2013) and has been herein applied in the geological interpretation of seismic profiles. Positioning was established through the Starfix differential GPS. The software IHS Kingdom® was used for the processing, management and interpretation of the seismic lines. The seismo-stratigraphic results were integrated with stratigraphic results previously obtained on the same dataset (PETRUCCIONE *et alii*, 2011; IORIO *et alii*, 2014b) and with new data from core samples

(tephrostratigraphy)

4. RESULTS

4.1 TEPHROSTRATIGRAPHY

The analyzed cryptotephra, here labelled as C1161/1, is represented by medium- to fine-grained ash made up of light grey elongated pumices, light-grey glass shards with fibrous and bubble wall junction morphologies and brown blocky glass shards. Loose crystals of feldspar, biotite and clinopyroxene occur in the deposit along with rare lithics and bioclasts. According to the TAS (Total Alkali/Silica; LE MAITRE, 2005) classification diagram, glasses from C1161/1 straddle the trachyte/phonolite (hence being trachyphonolites) and the tephriphonolite/latite boundary forming a continuum of compositions (Fig. 3a). A few points fall within the trachyte and phonolite fields. The silica values range from 54.90 wt.% to 62.90 wt.%, CaO and FeO_{tot} from 1.70 wt.% to 5.55 wt.% and from 2.50 wt.% to 6.66 wt.% respectively, MgO from 0.27 wt% to 2.36 wt% whereas Al_2O_3 is approximately constant. The alkali content ranges from 10.78 wt.% to 14.20 wt.% (Tab. 2).

4.2 HIGH RESOLUTION SEISMIC STRATIGRAPHY

The seismo-stratigraphic interpretation of six Chirp seismic profiles, significant for the stratigraphic architecture of the northern Phlegraean offshore (Tab.1), has been carried out in order to map the trend of the seismic horizon *V*.

The oldest seismic unit is represented by the Falling Stage System Tract (FSST; Figs. 4, 5 and 6). It is characterized by seismic reflectors in offlap, grading seawards into a wedge-shaped seismic unit, interpreted as the Shelf Margin System Tract (SMST). Due to the limited penetration of the seismic sections, the FSST and the SMST are not well detectable. In the M198 seismic profile (Fig. 5), the SMST has not been recognized, because the present-day shelf break is shallower than the one corresponding to the last phase of sea level lowstand (120 m bsl; CHAPPELL AND SHACKLETON, 1986; LAMBECK AND CHAPPELL, 2001; LAMBECK *et alii*, 2014). In the M196 seismic profile, the FSST and the SMST are bounded upwards by the transgressive surface (T), marking the first major flooding of the continental shelf following the lowstand phase (Fig. 5). In this case the transgressive surface coincides with the 4th order sequence boundary. The transgressive paralic deposits have been observed mainly on NW-SE trending seismic profiles and they are characterised by variable thickness (Fig. 4). They rest in downlap on the T surface and are separated from the overlying marine deposits by the ravinement surface (RS). Both the transgressive surface (T) and the ravinement surface (RS) appear as marked irregular erosional surfaces, gently deepening seawards (Figs. 4, 5 and 6). The FSST has been interpreted as Upper Pleistocene prograding deposits and it is overlaid by a very thick Transgressive System Tract (TST). The TST marine deposits onlap onto the RS (Figs. 4 and 5). They are characterized by parallel and continuous seismic reflectors with moderate to low amplitude. The TST upper boundary is the maximum flooding surface (MFS), which is often interrupted by shallow gas pockets (Figs. 4, 5 and 6). Above the MFS surface, the Highstand System Tract (HST) is represented by a wedge-shaped seismic unit thickening landwards. It is distinguished by discontinuous seismic reflectors with a moderate high amplitude.

The *V* reflector is parallel and displays a high amplitude. It has been continuously detected from the shelf to the slope within the transgressive marine deposits (Figs. 4, 5 and 6). On the inner shelf its continuity is interrupted by shallow gas pockets. The *V* depths ranges from 2 ms bsf on the slope to 28 ms bsf on south-eastern sector of the continental shelf. The overlying TST and HST deposits are affected by undulations, often downthrown by small-scale normal faults having a limited offset (IORIO *et alii*, 2014b). Undulations mainly occur in the outer shelf controlling the thickening of sediments.

5. DISCUSSION

5.1 TEPHRA CORRELATION

The major element features of cryptotephra C1161/1 are typical of mildly silica undersaturated to saturated potassic products of Phlegraean activity occurred during the Late Pleistocene-Holocene time interval (SMITH *et alii*, 2011; TOMLINSON *et alii*, 2012). The wide chemical composition ranging from trachyphonolites to less evolved portions and the finding of the tephra within the transgressive marine deposits, indicate the correlation of C1161/1 to the NYT products dated via the ^{40}Ar/^{39}Ar method at 14.09±0.4 ka (DEINO *et alii*, 2004) and later refined to 14.11± 0.21 cal. ka B.P. (BLOCKLEY *et alii*., 2008). In detail, chemistry of our tephra is well within the NYT-Upper Member population but a contribution of the Lower Member cannot be discarded (Fig. 3a-b-c). The NYT has been correlated to marine tephra C-2 up to 250 km from the Phlegraean Fields in the Tyrrhenian and Adriatic seas and it likely records both the Lower and Upper Member composition (e.g. PATERNE *et alii*., 1986; CALANCHI *et alii*., 1998; SIANI *et alii*, 2004, BOURNE *et alii*, 2010; MORABITO *et alii*, 2014). At very distal sites in northern Europe, the NYT tephra records only the bi-modal Lower Member (LANE *et alii*, 2015 and references therein). However, in the Tyrrhenian and Adriatic seas the correlation is not straightforward since a number of tephras with strong chemical similarity to the NYT immediately underlies tephra C-2 (SIANI *et alii*, 2004; BOURNE *et alii*, 2010; MORABITO *et alii*, 2014). This tephra framework may be the result of a complex stratigraphy on land that led some authors to propose different hypotheses about the origin of the NYT deposits: 1) they were emitted at different times from different eruptive centers (e.g. ROSI & SBRANA, 1987); 2) they were the result of a single event on land perhaps from multiple vents (e.g. ORSI *et alii*, 1992, 1995, SCARPATI *et alii*, 1993). According to data from the southern Adriatic, SIANI *et alii* (2004) suggested that the NYT could represent the last event of a series of eruptions closely spaced in time (ca. 600 years), thus aiming to solve the volcanological issue. This might be in agreement with our finding of the NYT tephra at the top of the *V* main volcanic reflector. It is possible, in fact, that the *V* marker correlates with other pyroclastic and volcanoclastic deposits from eruptions closely spaced in time to the NYT and immediately underlying it. However, the need to improve the stratigraphic analysis of the whole *V* reflector at other sites of the Gulf is required to confirm or deny the above hypothesis.

5.2 Stratigraphy and *V*/NYT marker

The seismostratigraphic data obtained from the measurements of depths allowed to construct sketch diagrams which show the pattern of the NYT tephra in relation with the depth calculated from both the sea level and the sea floor (Figs. 7 and 8, respectively). Three-dimensional views of the NYT/seismic reflector are also reported (insets in Figs. 7 and 8).

The depth pattern of the NYT seismic reflector measured from the sea level depicts a surface regularly dipping towards south-west, proceeding from the shelf to the basin (Fig. 7). The thickness of sediments overlying the NYT deposits is very high on the shelf (Fig 8) and, in detail, ranges from 10 ms (about 8 m) to 30 ms (about 25 m) (Fig. 8). Greater depths, between 26 ms and 30 ms are reached along a NE-SW trending area located in the central part of the shelf where sediment undulations, gas charged sediments, and pockmarks, identified in Iorio *et alii* (2014 b), have been mapped (Fig. 8). These features are typical of other examples where undulated reflectors characterize thick prodelta wedges on the Mediterranean shelves (e.g., TRINCARDI & NORMARK 1988; CORREGGIARI *et alii*, 2001; LYKOUSIS *et alii*, 2003). The origin of undulations in the study area has been largely debated in Iorio *et alii* (2014b). The authors related them mainly to shear-dominated failure with limited downslope displacement rather than erosional/depositional processes. The displacement was likely favored by high sediment supply, high-water content, fluid escapes and shelf gradient deepening.

In this study case, the seismic facies related to undulations are discontinuous, probably due to frequent occurrence of gas within the sediments (ERCILLA *et alii,* 1994, 1995; CORREGGIARI *et alii*, 2001). In fact, in correspondence of each undulation we can observe, on the seismic profiles, the typical transparent seismic facies correlated to the presence of gas (Figs. 4, 5 and 6).

The NYT is interlayered in the TST marine deposits (Figs. 4, 5 and 6) which are particularly developed in this area compared to the majority of TST deposits on the continental shelves of other settings (TRINCARDI *et alii*, 1994; CATTANEO & STEEL, 2003; MARTORELLI *et alii*, 2010; PELLEGRINI *et alii*, 2010; ZECCHIN & CATUNEANU, 2013), such as in the Salerno Gulf where the TST is characterized by a thin succession of sediments in spite of active fluvial supply during that time span (BUCCHERI *et alii*, 2002). However, in the Naples Gulf the TST is difficult to be defined in terms of thickness and distribution due to the complex interplay among volcanism, tectonics and sedimentary processes (e.g. MILIA, 1998a). So far, the high thickness of the TST deposits in the study area, which reaches the maximum value of about 40 ms (30 m), might be related to the input of large amounts of pyroclastic and volcanoclastic materials associated to the NYT eruption and to the subsequent eruptive periods of the Phlegraean Fields (DI VITO *et alii*, 1999) before the deposition of the HST deposits (from ca. 6.5 cal ka B.P.; AMOROSI *et alii,* 2012). In particular, volcanoclastic deposits were delivered to the shelf and slope by the fluvial erosion, transportation and depositional system of the Volturno coastal plain where the NYT is found only in correspondence to the morpho-structural highs (AMOROSI *et alii*, 2012, SACCHI *et alii*, 2014b). The HST deposits are quite thin if compared with the HST deposits of the adjacent Pozzuoli and Naples gulfs where the active volcanic vents located along the coastline continuously acted as significant sediment sources (pyroclastic, volcanoclastic and epiclastic) to the marine depositional system (e.g. MILIA, 1998b; AIELLO *et alii*, 2001; SACCHI *et alii,* 2005) irrespective of the size of the eruption.

6. CONCLUSION

Core data and seismic profiles allowed to recognize and map for the first time the NYT deposits in southern Gaeta Gulf. The data presented in this work point to a relevant role that the NYT deposition had on the stratigraphic architecture and morphological evolution of the study area. According to its wide distribution, it can be considered an excellent marker horizon for the basin and, hence, used as a tool for future stratigraphic, volcanological and marine hazard studies. The NYT is interbedded within the TST succession which has a considerable thickness likely due to the supply of pyroclastic and volcanoclastic deposits related to the intense eruptive activity from the close volcanoes during the Late Pleistocene-Holocene. Undulations and pockmarks are the main morphological features at the sea floor in the study area and they might be mainly related to the intense gas uprising through the TST and HST deposits. The presented results are part of a wider study which currently focuses on the Upper Pleistocene-Holocene evolution of the overall Gaeta Gulf, a pery-Tyrrhenian basin located at mid-position from the Campania Plain eruptive vents.

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FIGURE CAPTIONS

Figure 1: Location of the study area in the northern Phlegraean Fields offshore, along the eastern Tyrrhenian margin. The seismic lines and the C1161 core used in this study are reported.

Figure 2. (I) Grain size, (II) Lithology and (III) Raw Volume Magnetic susceptibility logs of core C1161. Black star and label *V* indicate the stratigraphic height of tephra sample and the top of the volcanic marker, respectively (modified from Iorio *et alii,* 2014b).

Figure 3: a) TAS (Total Alkali/Silica) classification diagram (Le Maitre, 2005) of C1161/1 tephra. b) FeO vs SiO_2 and c) CaO vs SiO_2 variation diagrams with composition of the analysed tephra. Single glass data (WDS) of the NYT proximal deposits (Upper Member and Lower Member) are reported for comparison (from Tomlinson *et alii*, 2012).

Figure 4: ChirpProfile (trasf_0; modified from Iorio *et alii*, 2014b) showing the seismo-stratigraphic architecture of the area (see location in Fig. 1). Notice the volcanic marker (V) marked in red. See text for explanation.

Figure 5: Chirp Profiles M196, M197 and M198 (see location in Fig. 1). Notice the volcanic marker (V) marked in red. See text for the explanation.

Figure 6: Chirp Profiles M198A (modified from Iorio *et alii*, 2014b), M199 and M200 (see location in Fig. 1). Notice the volcanic marker (V) marked in red. See text for the explanation.

Figure 7: Map of the depth trend of the *V* reflector (NYT) from the sealevel. The colorimetric scale represents the variation of the depth in milliseconds with the corresponding values in meters. The inset on the top right shows a 3D model of the NYT trend.

Figure 8: Map of the depth trend of the *V* reflector (NYT) from the seafloor. The colorimetric scale represents the variation of the depth in milliseconds with the corresponding values in meters. The inset on the top right shows a 3D model of the NYT trend.

TABLE CAPTIONS

Table 1: Location, orientation, and average water-depths details of the analyzed Subbottom Chirp lines.

Table 2: Major element content of single glass (wt. %) in sample C1161/1. All analyses are recalculated water-free to 100.

On the occurrence of the Neapolitan Yellow Tuff tephra in the Northern Phlegraean Fields offshore (Eastern Tyrrhenian margin; Italy)

Sulla presenza del tefra del Tufo Giallo Napoletano nell'offshore settentrionale dei Campi Flegrei (margine tirrenico orientale, Italia).

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ABSTRACT

A main volcanic marker has been identified for the first time on the continental shelf of the northern Phlegraean Fields in the Gaeta Gulf (Campania region, eastern Tyrrhenian margin, Italy) by means of Subbottom Chirp profile grid and stratigraphic analysis of a core collected on the slope. In the seismic sections, the core bottom corresponds to the top of a continuous and parallel reflector (*V*) interbedded within the transgressive deposits of the Late Quaternary-Holocene depositional sequence. The Transgressive System Tract deposits are particularly thick compared to the majority of the transgressive deposits of other shelf settings. This might be due to the input of pyroclastic and volcanoclastic deposits related to the intense eruptive activity of the Campania Plain during the Late Pleistocene-Holocene time span. Undulations and pockmarks are the main morphological features of the sea floor and they might be linked to gas uprising, widely detected in the study area. The *V* reflector is located on the shelf from northeast to southwest at different depths, ranging from 10 ms (about 8 m) to 30 ms (about 25 m) below sea floor and it can be mapped down to the continental slope. The geological calibration of this continuous reflector coupled with tephrostratigraphic analysis, allowed to correlate it with the Neapolitan Yellow Tuff deposits emplaced at Phlegraean Fields at ca. 15 ka.

Key words: Neapolitan Yellow Tuff, Gaeta Gulf, Phlegraean Fields, coastal volcanism, seismic stratigraphy.

1. INTRODUCTION

Coastal volcanism along the Campania margin plays a key role in the stratigraphic architecture of adjacent marine settings since it leads to several types of processes that supply large volumes of pyroclastic and volcanoclastic deposits over wide sectors of the continental shelf-slope-basin system during short time spans (INSINGA *et alii*, 2006; MILIA *et alii*, 2007; DE ALTERIIS *et alii*, 2010, BUDILLON *et alii*, 2012). Pyroclastic deposits, in particular, are delivered to the sedimentary environment following a variety of transport processes such as fallout, flows and surges which can evolve across the continental shelf and slope in sediment failure or hyperpicnal flows (SACCHI *et alii*, 2005, 2009; MILIA *et alii*, 2008). As a result of their synchronous deposition over large areas, pyroclastics (tephra) form important stratigraphic markers and event signals in the marine record (e.g. LOWE, 2011; ZANCHETTA *et alii*, 2011; INSINGA *et alii*, 2014 and references therein) and such findings are particularly frequent along the Campania margin in the Naples and Salerno gulfs and offshore Cilento (e.g.; BUCCHERI *et alii*, 2002; IORIO *et alii*, 2004; SACCHI *et alii*, 2005; INSINGA *et alii*, 2008; LIRER *et alii*, 2013; IORIO *et alii*, 2014a). A detailed geological literature exists on the structural and stratigraphic relationships between marine and volcanic units in the Gaeta Gulf since the Quaternary, however it is mainly based on seismic interpretations and onshore borehole data (AIELLO *et alii*, 2000; MILIA *et alii*, 2013; TORRENTE & MILIA, 2013; MILIA & TORRENTE, 2015). Core data regarding the marine stratigraphic record and the tephra deposits interbedded within are still very few and mainly related to the Holocene deposits (IORIO *et alii*, 2014b; MARGARITELLI *et alii*, 2016).

In this paper we report, for the first time, on the occurrence of the Neapolitan Yellow Tuff deposit in the southern sector of the Gaeta Gulf, between the Volturno mouth and the Cuma town, offshore the Northern Phlegraean Fields (Fig. 1). Based on gravity core data and high-resolution seismic profiles, the Neapolitan Yellow Tuff deposit was characterized both in terms of lithology and chemistry and its seismic signature was described and mapped. The obtained results aim to provide a contribution to the tephrostratigraphic framework of the southern Gaeta Gulf and highlight the significant role of this tephra in regards to the stratigraphic architecture of Northern Phlegraean offshore.

2.GEOLOGIC SETTING

The study area represents the seaward extension of the northern sector of the Campania Plain (Fig. 1), a coastal plain of southern Italy located along the Latium-Campania margin. This latter is characterized by Plio-Pleistocene tectonically-downthrown areas genetically related to normal and strike-slip faults linked to the geological evolution of the Eastern Tyrrhenian margin ("peri-tyrrhenian basins"; FABBRI *et alii*, 1981 BARTOLE *et alii*, 1984; MALINVERNO & RYAN, 1986; MARIANI & PRATO, 1988; FLORIO *et alii*, 1999; BRUNO *et alii*, 2000; AIELLO *et alii*, 2000, 2011a; 2011b; CASCIELLO *et alii*, 2006) and filled by coastal and marine deposits reaching thicknesses of several thousand of meters. In particular, in the Gaeta basin, extensional tectonics has been active along systems of ESE-WNW, E-W and NE-SW trending normal faults, related to strike-slip tectonic movements that took place mainly during the Late Pliocene-Early Pleistocene time interval (BARTOLE *et alii,* 1984, AIELLO *et alii*, 2000, BRUNO *et alii*, 2000).

The depositional geometries of strata pertaining to the Plio-Quaternary basin fill are similar to those recognized in the adjacent Terracina basin (AIELLO *et alii*, 2000). The lower seismic sequences are characterized by parallel horizons and are strongly affected by wedging and growth as a consequence of synsedimentary tectonics. The upper seismic sequences show progradational geometries led by sedimentary feeding from the Garigliano and Volturno rivers and controlled by eustatic sea-level fluctuations during Quaternary times (AIELLO *et alii*, 2000).

Regional geological evidence, coupled with seismo-stratigraphic interpretations, has suggested that the Volturno basin represents a half-graben structure, characterized by blocks downthrown along normal faults and filled by four main seismic units (identified as D1-D4; AIELLO *et alii*, 2011a; 2011b). Rapid flooding of coastal Volturno Plain culminated at 6.5 cal. ka B.P. (AMOROSI *et alii*, 2012 and references therein), leading to a narrowing of the shelf to a maximum width of 16 km in correspondence to Volturno river mouth and a minimum width in the Cuma offshore (about 10 km). The shelf break occurs at water depths ranging between 120-125 m.

The stratigraphic architecture of the continental shelf during the Late Pleistocene – Holocene time interval is an incomplete 4th order depositional sequence, that shows an inner strata organization with minor downlap surfaces and erosional truncations separating different phases of progradation (MARANI *et alii*, 1986; AIELLO *et alii*, 2000, 2011a; 2011b; IORIO *et alii*, 2014b). The last progradation started at about 130 ka and ended at about 18 ka (CATTANEO *et alii*, 2002; LOFI *et alii*, 2003; DUVAIL *et alii*, 2005; LISIECKI & RAYMO, 2005; PELLEGRINI *et alii*, 2010; CAPRARO *et alii*, 2011; MASELLI & TRINCARDI, 2013; MASELLI *et alii*, 2014). An abrupt erosional surface separates the forced regression and lowstand deposits from the overlying sediments, that were formed between 18 ka and 5 ka during the last sea level rise (transgressive deposits; FABBRI *et alii*, 2002; CATTANEO & STEEL, 2003; TRINCARDI *et alii*, 1994) and from about 5 ka to present times during the recent sea level highstand (highstand deposits; HUNT & TUCKER, 1992; COPPA *et alii*, 1996; BUCCHERI *et alii*, 2002). Since ca. 6.5 cal. ka, the highstand phase has marked the onset of the present-day Volturno delta and the progradation of the adjacent coastal plain, ranging between 3 and 6 km (BARRA *et alii*, 1996; BELLOTTI, 2000; ROMANO *et alii*, 2004; AMOROSI *et alii*, 2012; SACCHI *et alii*, 2014b). Holocene wedge decreases in thickness towards the shelf edge. The continental slope is characterized by a uniform profile and is incised by several submarine gullies (CHIOCCI & CASALBORE, 2011; PETRUCCIONE *et alii*, 2011).

2.1 THE NEAPOLITAN YELLOW TUFF

Intense volcanism took place at several centers of the Campania Plain since at least the middle Pleistocene (DE VIVO *et alii*, 2001; ROLANDI *et alii*, 2003; DI VITO *et alii*, 2008; INSINGA *et alii*, 2014) as a consequence of the extensional tectonics that affected the eastern Tyrrhenian margin. During the Late Pleistocene, caldera-forming eruptions occurred inside the Campania Plain at Phlegraean Fields district with the most recent event of the Neapolitan Yellow Tuff (NYT) at 14.9±0.4 ka (DEINO *et alii*, 2004). It erupted an estimated volume of about 45 km^3 DRE (Dense Rock Equivalent) covering an area of more than 1000 km^2 and producing a caldera collapse of about 10 km in diameter (SCARPATI *et alii*, 1993; ORSI *et alii*, 1995). On the periphery of Phlegraean Fields and in the Campania Plain, the NYT exhibits high thickness and is characterized by a succession of pyroclastic fall and flow deposits (Lower and Upper Member, respectively; ORSI *et alii*, 1992, 1995). The Lower Member is compositionally bimodal (trachytic and trachyphonolitic) whereas the Upper Member spans the full compositional range between the two Lower Member populations (TOMLINSON *et alii*, 2012). Distal ash-fall deposits spread over wide areas up to northern Europe in marine and continental archives (e.g. PATERNE *et alii*, 1986; CALANCHI *et alii*, 1998; SIANI *et alii*, 2004; BOURNE *et alii*, 2010; LANE *et alii*, 2015 and references therein). By contrast, far from the vent on land, such as in the Volturno coastal plain, the NYT is absent due to the removal-burial by fluvial processes (AMOROSI *et alii*, 2012). The NYT products had a strong impact on the sedimentary processes and, ultimately, on the stratigraphic record of adjacent marine settings, as documented in the Pozzuoli Bay (AIELLO *et alii*; 2012; SACCHI *et alii*, 2014a; AIELLO *et alii*, in press.)

3. DATASET AND METHODS

3.1 GRAVITY CORE C1161

The core C1161 was recovered at 144 m below the sea level on the right side of an upper slope gully in the northern sector of Phlegraean Fields offshore (Fig. 1) using a 6 m long gravity corer with liners of 9 cm in diameter. Core recovery was about 50% with an estimated compaction of about 15%. The stratigraphic record consists of ca. 2.62 m-thick Holocene deposits which have been studied in detail with respect to their lithological, sedimentological, petrophysical and seismic aspects (IORIO *et alii*, 2014b). The sediments are mainly represented by silty and clayey deposits. A grain-size variation occurs at about 1.60 m below sea floor down to the core bottom, where sandy and gravelly fractions, mainly made up of bioclastic and pumiceous clasts, occur. Sedimentological analysis suggested a high energy depositional environment (IORIO *et alii*, 2014b), in agreement with the location of the core on a submarine channel levee. The integrated petrophysical (high magnetic susceptibility values) and seismic analysis correlated the bottom of the core to the top of a seismic reflector interpreted as being of volcanic origin (*V* in IORIO *et alii*, 2014b). The sediment was sampled and chemically analysed for the purposes of this work.

3.1.1 TEPHRA ANALYSIS

The non visible-tephra (cryptotephra) found at the core bottom and corresponding to the top of the reflector *V* in IORIO *et alii* (2014b), was sampled, disaggregated in distilled water and wet sieved at 63, 90, 125 and 250 μm in order to remove the fine-grained sediment. The sieved material was cleaned with an ultrasonic probe, dried at 60°C and then it was observed at the optical microscope in order to describe the lithology and to pick up fresh glasses for the chemical characterization. At least 25 juvenile fragments (pumiceous and glass shards) were mounted on epoxy resin and suitably polished for microprobe analysis.

Energy Dispersive Spectrometric (EDS) analyses were performed using JEOL JSM-5310 SEM at CISAG (Centro Interdipartimentale di Servizio per Analisi Geomineralogiche) of the University of

Napoli "Federico II" through Oxford Instruments Microanalysis Unit, equipped with an INCA X-act detector. The operating conditions were 15 kV primary beam voltage, 50-100 m. A filament current, 50 sec acquisition time with variable spot size was adopted during the data elaboration. A correction for matrix effect was performed using INCA version 4.08 software that used the XPP correction routine, based on a Phi-Ro-Zeta approach. Moreover, a primary calibration was performed using international mineral and glass standards USMN reference samples according to the following scheme: Anorthoclase 133868 for Si and Na, Microcline 143966 for Al and K, Fayalite 85276 for Mn, Anorthite 137041 for Ca, Hornblende 143965 for Fe, Mg and Ti, Scapolite 6600-1 for Cl, and Apatite 104021 for P.

Precision and accuracy were assessed using the rhyolitic glass USMN 75854 as secondary standard. Mean precision was <5% for SiO_2, Al_2O_3, K_2O, CaO and FeO, and around 10% for the other elements.

3.2 SEISMIC DATA ACQUISITION

Six Chirp profiles, collected in the frame of research projects on marine geological mapping on the continental shelf off the Campania region (penetration between 25 and 50 m below the sea bottom using an average velocity of 1.550 m/sec for time-to-depth conversion), provided the stratigraphic framework to recognize the volcanic marker (Table 1). High resolution seismic stratigraphy has been described in detail as a valuable technique of analysis of seismic profiles (MITCHUM *et alii*, 1977; VAIL *et alii*, 1977; VAN WAGONER *et alii*, 1988; CATUNEANU *et alii*, 2009; ZECCHIN & CATUNEANU, 2013) and has been herein applied in the geological interpretation of seismic profiles. Positioning was established through the Starfix differential GPS. The software IHS Kingdom® was used for the processing, management and interpretation of the seismic lines. The seismo-stratigraphic results were integrated with stratigraphic results previously obtained on the same dataset (PETRUCCIONE *et alii*, 2011; IORIO *et alii*, 2014b) and with new data from core samples

(tephrostratigraphy)

4. RESULTS

4.1 TEPHROSTRATIGRAPHY

The analyzed cryptotephra, here labelled as C1161/1, is represented by medium- to fine-grained ash made up of light grey elongated pumices, light-grey glass shards with fibrous and bubble wall junction morphologies and brown blocky glass shards. Loose crystals of feldspar, biotite and clinopyroxene occur in the deposit along with rare lithics and bioclasts. According to the TAS (Total Alkali/Silica; LE MAITRE, 2005) classification diagram, glasses from C1161/1 straddle the trachyte/phonolite (hence being trachyphonolites) and the tephriphonolite/latite boundary forming a continuum of compositions (Fig. 3a). A few points fall within the trachyte and phonolite fields. The silica values range from 54.90 wt.% to 62.90 wt.%, CaO and FeO_{tot} from 1.70 wt.% to 5.55 wt.% and from 2.50 wt.% to 6.66 wt.% respectively, MgO from 0.27 wt% to 2.36 wt% whereas Al_2O_3 is approximately constant. The alkali content ranges from 10.78 wt.% to 14.20 wt.% (Tab. 2).

4.2 HIGH RESOLUTION SEISMIC STRATIGRAPHY

The seismo-stratigraphic interpretation of six Chirp seismic profiles, significant for the stratigraphic architecture of the northern Phlegraean offshore (Tab.1), has been carried out in order to map the trend of the seismic horizon *V*.

The oldest seismic unit is represented by the Falling Stage System Tract (FSST; Figs. 4, 5 and 6). It is characterized by seismic reflectors in offlap, grading seawards into a wedge-shaped seismic unit, interpreted as the Shelf Margin System Tract (SMST). Due to the limited penetration of the seismic sections, the FSST and the SMST are not well detectable. In the M198 seismic profile (Fig. 5), the SMST has not been recognized, because the present-day shelf break is shallower than the one corresponding to the last phase of sea level lowstand (120 m bsl; CHAPPELL AND SHACKLETON, 1986; LAMBECK AND CHAPPELL, 2001; LAMBECK *et alii*, 2014). In the M196 seismic profile, the FSST and the SMST are bounded upwards by the transgressive surface (T), marking the first major flooding of the continental shelf following the lowstand phase (Fig. 5). In this case the transgressive surface coincides with the 4th order sequence boundary. The transgressive paralic deposits have been observed mainly on NW-SE trending seismic profiles and they are characterised by variable thickness (Fig. 4). They rest in downlap on the T surface and are separated from the overlying marine deposits by the ravinement surface (RS). Both the transgressive surface (T) and the ravinement surface (RS) appear as marked irregular erosional surfaces, gently deepening seawards (Figs. 4, 5 and 6). The FSST has been interpreted as Upper Pleistocene prograding deposits and it is overlaid by a very thick Transgressive System Tract (TST). The TST marine deposits onlap onto the RS (Figs. 4 and 5). They are characterized by parallel and continuous seismic reflectors with moderate to low amplitude. The TST upper boundary is the maximum flooding surface (MFS), which is often interrupted by shallow gas pockets (Figs. 4, 5 and 6). Above the MFS surface, the Highstand System Tract (HST) is represented by a wedge-shaped seismic unit thickening landwards. It is distinguished by discontinuous seismic reflectors with a moderate high amplitude.

The *V* reflector is parallel and displays a high amplitude. It has been continuously detected from the shelf to the slope within the transgressive marine deposits (Figs. 4, 5 and 6). On the inner shelf its continuity is interrupted by shallow gas pockets. The *V* depths ranges from 2 ms bsf on the slope to 28 ms bsf on south-eastern sector of the continental shelf. The overlying TST and HST deposits are affected by undulations, often downthrown by small-scale normal faults having a limited offset (IORIO *et alii*, 2014b). Undulations mainly occur in the outer shelf controlling the thickening of sediments.

5. DISCUSSION

5.1 TEPHRA CORRELATION

The major element features of cryptotephra C1161/1 are typical of mildly silica undersaturated to saturated potassic products of Phlegraean activity occurred during the Late Pleistocene-Holocene time interval (SMITH *et alii*, 2011; TOMLINSON *et alii*, 2012). The wide chemical composition ranging from trachyphonolites to less evolved portions and the finding of the tephra within the transgressive marine deposits, indicate the correlation of C1161/1 to the NYT products dated via the ^{40}Ar/^{39}Ar method at 14.09±0.4 ka (DEINO *et alii*, 2004) and later refined to 14.11± 0.21 cal. ka B.P. (BLOCKLEY *et alii*., 2008). In detail, chemistry of our tephra is well within the NYT-Upper Member population but a contribution of the Lower Member cannot be discarded (Fig. 3a-b-c). The NYT has been correlated to marine tephra C-2 up to 250 km from the Phlegraean Fields in the Tyrrhenian and Adriatic seas and it likely records both the Lower and Upper Member composition (e.g. PATERNE *et alii*., 1986; CALANCHI *et alii*., 1998; SIANI *et alii*, 2004, BOURNE *et alii*, 2010; MORABITO *et alii*, 2014). At very distal sites in northern Europe, the NYT tephra records only the bi-modal Lower Member (LANE *et alii*, 2015 and references therein). However, in the Tyrrhenian and Adriatic seas the correlation is not straightforward since a number of tephras with strong chemical similarity to the NYT immediately underlies tephra C-2 (SIANI *et alii*, 2004; BOURNE *et alii*, 2010; MORABITO *et alii*, 2014). This tephra framework may be the result of a complex stratigraphy on land that led some authors to propose different hypotheses about the origin of the NYT deposits: 1) they were emitted at different times from different eruptive centers (e.g. ROSI & SBRANA, 1987); 2) they were the result of a single event on land perhaps from multiple vents (e.g. ORSI *et alii*, 1992, 1995, SCARPATI *et alii*, 1993). According to data from the southern Adriatic, SIANI *et alii* (2004) suggested that the NYT could represent the last event of a series of eruptions closely spaced in time (ca. 600 years), thus aiming to solve the volcanological issue. This might be in agreement with our finding of the NYT tephra at the top of the *V* main volcanic reflector. It is possible, in fact, that the *V* marker correlates with other pyroclastic and volcanoclastic deposits from eruptions closely spaced in time to the NYT and immediately underlying it. However, the need to improve the stratigraphic analysis of the whole *V* reflector at other sites of the Gulf is required to confirm or deny the above hypothesis.

5.2 Stratigraphy and *V*/NYT marker

The seismostratigraphic data obtained from the measurements of depths allowed to construct sketch diagrams which show the pattern of the NYT tephra in relation with the depth calculated from both the sea level and the sea floor (Figs. 7 and 8, respectively). Three-dimensional views of the NYT/seismic reflector are also reported (insets in Figs. 7 and 8).

The depth pattern of the NYT seismic reflector measured from the sea level depicts a surface regularly dipping towards south-west, proceeding from the shelf to the basin (Fig. 7). The thickness of sediments overlying the NYT deposits is very high on the shelf (Fig 8) and, in detail, ranges from 10 ms (about 8 m) to 30 ms (about 25 m) (Fig. 8). Greater depths, between 26 ms and 30 ms are reached along a NE-SW trending area located in the central part of the shelf where sediment undulations, gas charged sediments, and pockmarks, identified in Iorio *et alii* (2014 b), have been mapped (Fig. 8). These features are typical of other examples where undulated reflectors characterize thick prodelta wedges on the Mediterranean shelves (e.g., TRINCARDI & NORMARK 1988; CORREGGIARI *et alii*, 2001; LYKOUSIS *et alii*, 2003). The origin of undulations in the study area has been largely debated in Iorio *et alii* (2014b). The authors related them mainly to shear-dominated failure with limited downslope displacement rather than erosional/depositional processes. The displacement was likely favored by high sediment supply, high-water content, fluid escapes and shelf gradient deepening.

In this study case, the seismic facies related to undulations are discontinuous, probably due to frequent occurrence of gas within the sediments (ERCILLA *et alii,* 1994, 1995; CORREGGIARI *et alii*, 2001). In fact, in correspondence of each undulation we can observe, on the seismic profiles, the typical transparent seismic facies correlated to the presence of gas (Figs. 4, 5 and 6).

The NYT is interlayered in the TST marine deposits (Figs. 4, 5 and 6) which are particularly developed in this area compared to the majority of TST deposits on the continental shelves of other settings (TRINCARDI *et alii*, 1994; CATTANEO & STEEL, 2003; MARTORELLI *et alii*, 2010; PELLEGRINI *et alii*, 2010; ZECCHIN & CATUNEANU, 2013), such as in the Salerno Gulf where the TST is characterized by a thin succession of sediments in spite of active fluvial supply during that time span (BUCCHERI *et alii*, 2002). However, in the Naples Gulf the TST is difficult to be defined in terms of thickness and distribution due to the complex interplay among volcanism, tectonics and sedimentary processes (e.g. MILIA, 1998a). So far, the high thickness of the TST deposits in the study area, which reaches the maximum value of about 40 ms (30 m), might be related to the input of large amounts of pyroclastic and volcanoclastic materials associated to the NYT eruption and to the subsequent eruptive periods of the Phlegraean Fields (DI VITO *et alii*, 1999) before the deposition of the HST deposits (from ca. 6.5 cal ka B.P.; AMOROSI *et alii,* 2012). In particular, volcanoclastic deposits were delivered to the shelf and slope by the fluvial erosion, transportation and depositional system of the Volturno coastal plain where the NYT is found only in correspondence to the morpho-structural highs (AMOROSI *et alii*, 2012, SACCHI *et alii*, 2014b). The HST deposits are quite thin if compared with the HST deposits of the adjacent Pozzuoli and Naples gulfs where the active volcanic vents located along the coastline continuously acted as significant sediment sources (pyroclastic, volcanoclastic and epiclastic) to the marine depositional system (e.g. MILIA, 1998b; AIELLO *et alii*, 2001; SACCHI *et alii,* 2005) irrespective of the size of the eruption.

6. CONCLUSION

Core data and seismic profiles allowed to recognize and map for the first time the NYT deposits in southern Gaeta Gulf. The data presented in this work point to a relevant role that the NYT deposition had on the stratigraphic architecture and morphological evolution of the study area. According to its wide distribution, it can be considered an excellent marker horizon for the basin and, hence, used as a tool for future stratigraphic, volcanological and marine hazard studies. The NYT is interbedded within the TST succession which has a considerable thickness likely due to the supply of pyroclastic and volcanoclastic deposits related to the intense eruptive activity from the close volcanoes during the Late Pleistocene-Holocene. Undulations and pockmarks are the main morphological features at the sea floor in the study area and they might be mainly related to the intense gas uprising through the TST and HST deposits. The presented results are part of a wider study which currently focuses on the Upper Pleistocene-Holocene evolution of the overall Gaeta Gulf, a pery-Tyrrhenian basin located at mid-position from the Campania Plain eruptive vents.

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FIGURE CAPTIONS

Fig. 1: Location of the study area in the northern Phlegraean Fields offshore, along the eastern Tyrrhenian margin. The seismic lines and the C1161 core used in this study are reported.

Figure 2. (I) Grain size, (II) Lithology and (III) Raw Volume Magnetic susceptibility logs of core C1161. Black star and label *V* indicate the stratigraphic height of tephra sample and the top of the volcanic marker, respectively (modified from Iorio et al 2014).

Fig. 3: a) TAS (Total Alkali/Silica) classification diagram (Le Maitre, 2005) of C1161/1 tephra. b) FeO vs SiO_2 and c) CaO vs SiO_2 variation diagrams with composition of the analysed tephra. Single glass data (WDS) of the NYT proximal deposits (Upper Member and Lower Member) are reported for comparison (from Tomlinson et al., 2012).

Fig. 4: ChirpProfile (trasf_0; modified from Iorio et al., 2014b) showing the seismo-stratigraphic architecture of the area (see location in Fig. 1). Notice the volcanic marker (V) marked in red. See text for explanation.

Fig. 5: Chirp Profiles M196, M197 and M198 (see location in Fig. 1). Notice the volcanic marker (V) marked in red. See text for the explanation.

Fig. 6: Chirp Profiles M198A (modified from Iorio et al., 2014b), M199 and M200 (see location in Fig. 1). Notice the volcanic marker (V) marked in red. See text for the explanation.

Fig. 7: Map of the depth trend of the *V* reflector (NYT) from the sealevel. The colorimetric scale represents the variation of the depth in milliseconds with the corresponding values in meters. The inset on the top right shows a 3D model of the NYT trend.

Figure 8: Map of the depth trend of the *V* reflector (NYT) from the seafloor. The colorimetric scale represents the variation of the depth in milliseconds with the corresponding values in meters. The inset on the top right shows a 3D model of the NYT trend.

TABLE CAPTIONS

Table1: Location, orientation and average water-depths details of the analyzed Subbottom Chirp lines.

Table 2: Major element content of single glass (wt. %) in sample C1161/1. All analyses are recalculated water-free to 100.

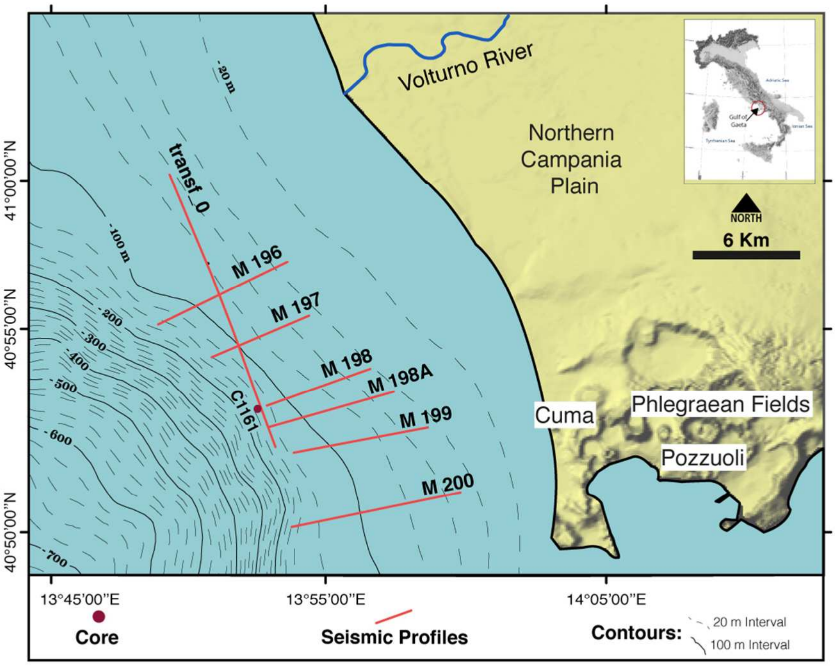

Figure 1: Location of the study area in the northern Phlegraean Fields offshore, along the eastern Tyrrhenian margin. The seismic lines and the C1161 core used in this study are reported.

111x80mm (300 x 300 DPI)

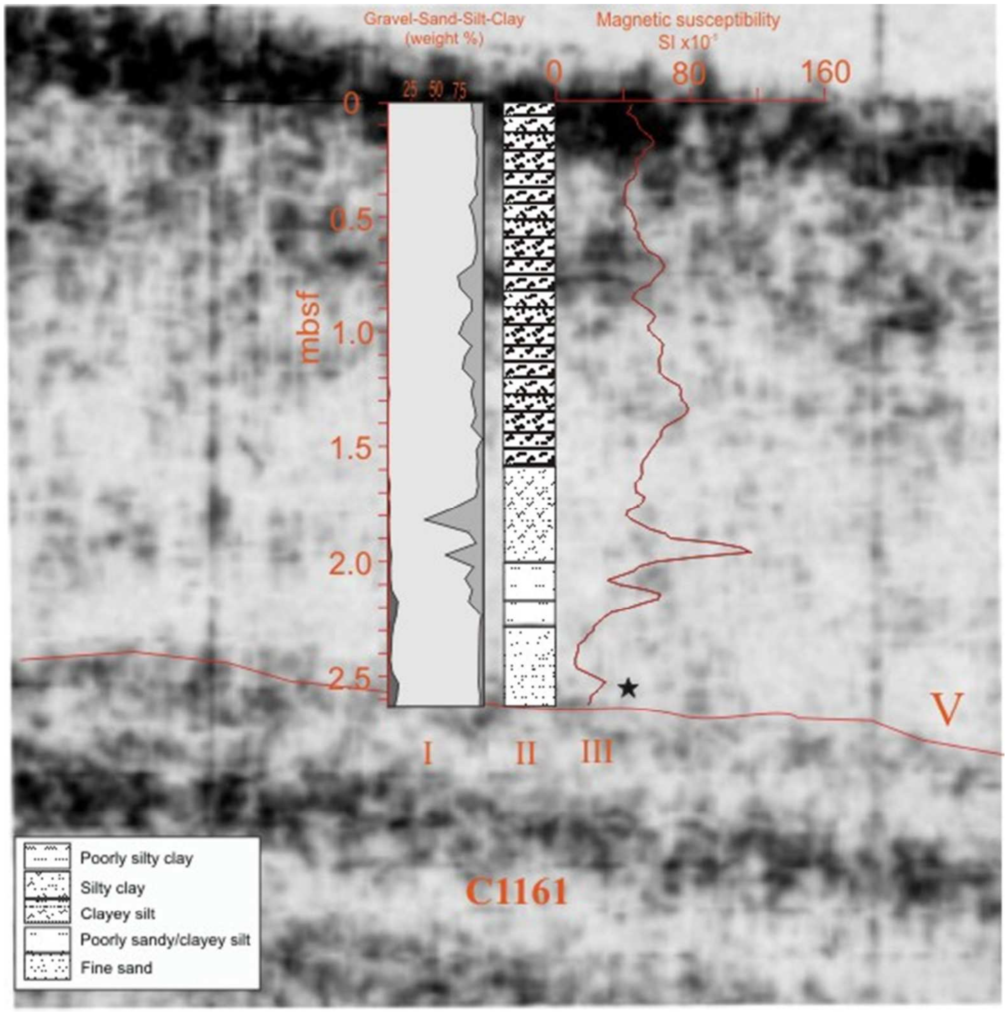

Figure 2. (I) Grain size, (II) Lithology and (III) Raw Volume Magnetic susceptibility logs of core C1161. Black star and label V indicate the stratigraphic height of tephra sample and the top of the volcanic marker, respectively (modified from Iorio et alii, 2014b).

145x146mm (100 x 100 DPI)

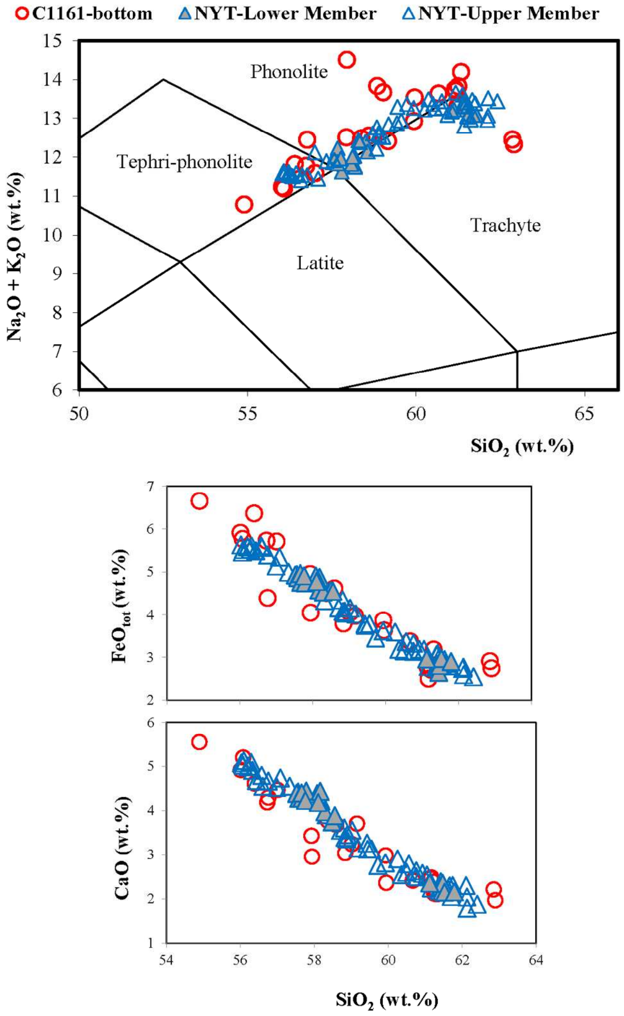

Figure 3: a) TAS (Total Alkali/Silica) classification diagram (Le Maitre, 2005) of C1161/1 tephra. b) FeO vs SiO2 and c) CaO vs SiO2 variation diagrams with composition of the analysed tephra. Single glass data (WDS) of the NYT proximal deposits (Upper Member and Lower Member) are reported for comparison (from Tomlinson et alii, 2012).

210x297mm (200 x 200 DPI)

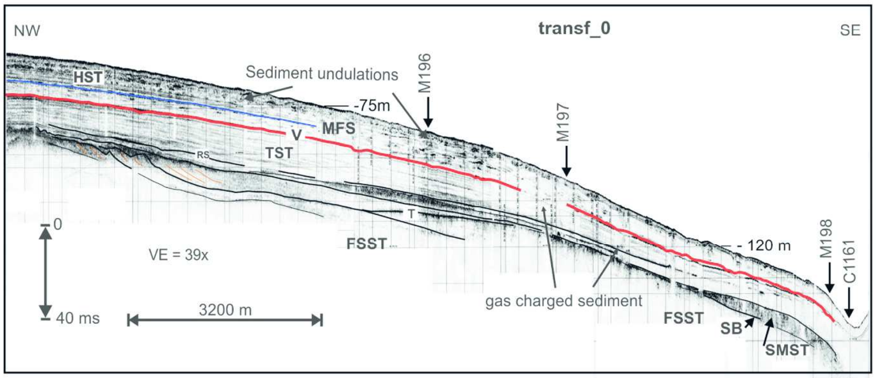

Figure 4: ChirpProfile (trasf_0; modified from Iorio et alii, 2014b) showing the seismo-stratigraphic architecture of the area (see location in Fig. 1). Notice the volcanic marker (V) marked in red. See text for explanation.

199x150mm (300 x 300 DPI)

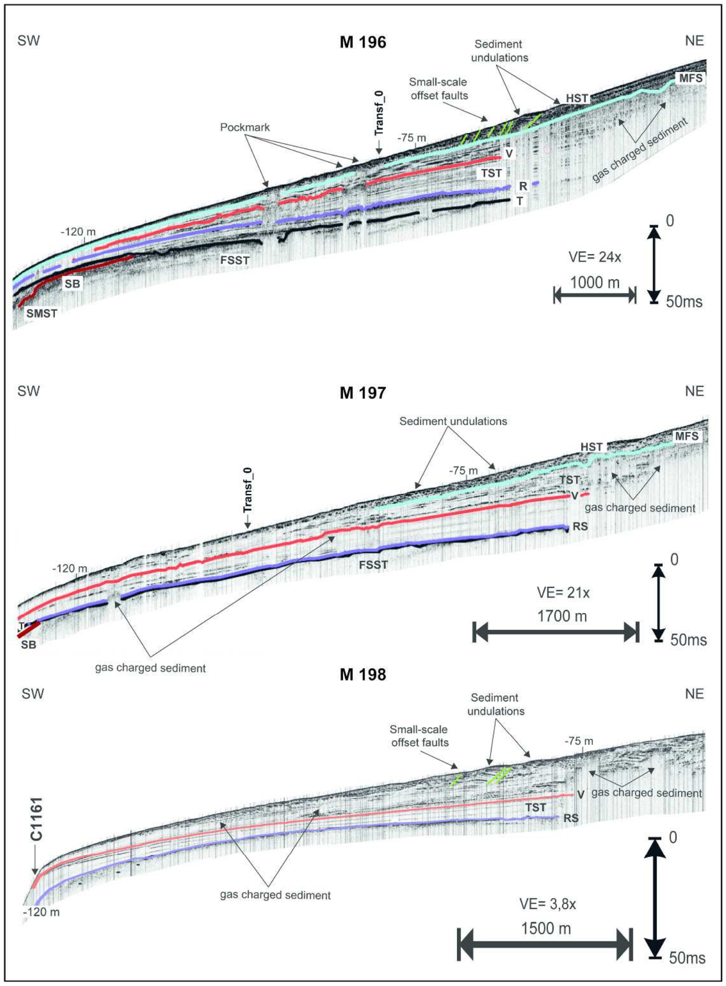

Figure 5: Chirp Profiles M196, M197 and M198 (see location in Fig. 1). Notice the volcanic marker (V) marked in red. See text for the explanation.

214x300mm (300 x 300 DPI)

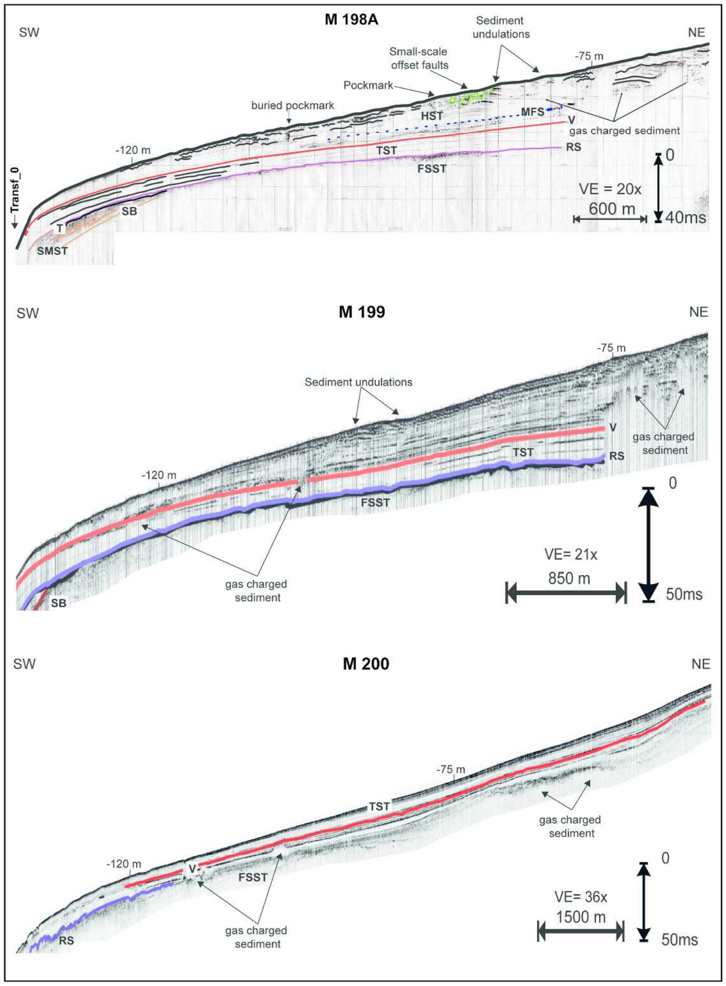

Figure 6: Chirp Profiles M198A (modified from Iorio et alii, 2014b), M199 and M200 (see location in Fig. 1). Notice the volcanic marker (V) marked in red. See text for the explanation.

214x300mm (300 x 300 DPI)

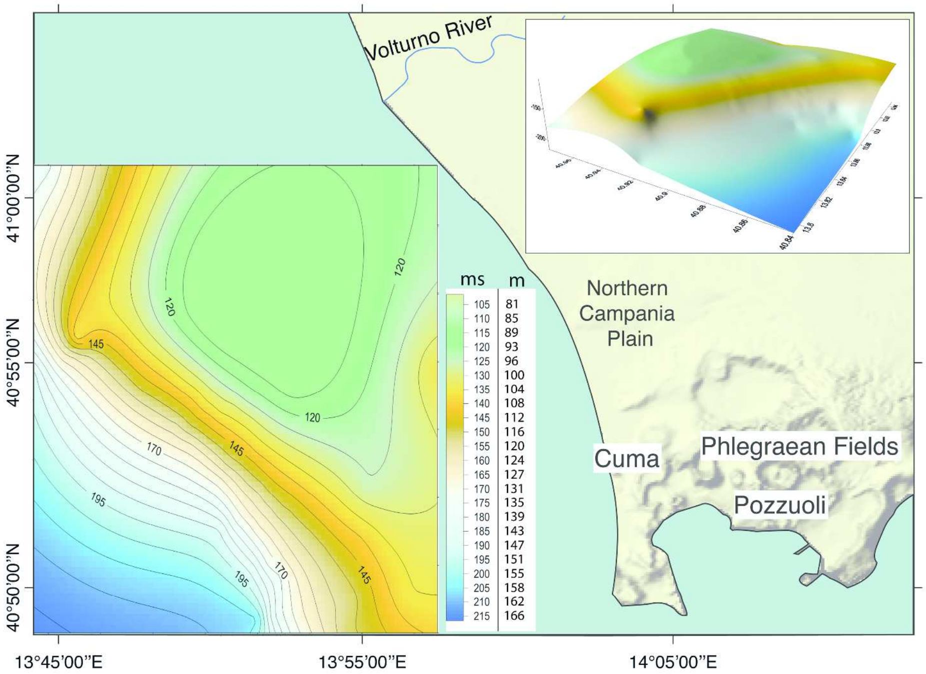

Figure 7: Map of the depth trend of the V reflector (NYT) from the sealevel. The colorimetric scale represents the variation of the depth in milliseconds with the corresponding values in meters. The inset on the top right shows a 3D model of the NYT trend.

300x214mm (300 x 300 DPI)

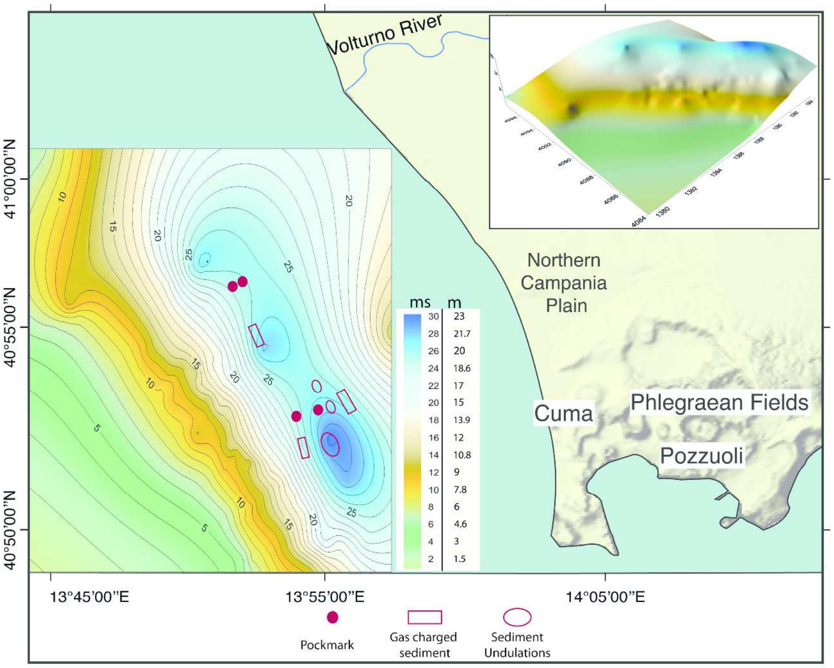

Figure 8: Map of the depth trend of the V reflector (NYT) from the seafloor. The colorimetric scale represents the variation of the depth in milliseconds with the corresponding values in meters. The inset on the top right shows a 3D model of the NYT trend.

300x214mm (300 x 300 DPI)

TAB 1

Seismic line	**Orientation**	**Location**	**Average water depths**
M200	WNW-ESE	Southern Tyrrhenian sea,extending from the Torregaveta offshore (WNW) to the Tyrrhenian sea northwards Ischia island (ESE)	18m (WNW) 435 m (ESE)
M199	WNW-ESE	Southern Tyrrhenian sea, extending from the Cuma offshore (WNW) to the Tyrrhenian sea (ESE)	22 m (WNW) 400 m (ESE)
M198A	WNW-ESE	Southern Tyrrhenian sea, extending from the Licola offshore (WNW) to the Tyrrhenian sea (ESE)	16 m (WNW) 250 m (ESE)
M198	WNW-ESE	Southern Tyrrhenian sea, extending from the Patria Lake offshore (WNW) to the Tyrrhenian sea (ESE)	17 m (WNW) 400 m (ESE)
M197	WNW-ESE	Southern Tyrrhenian sea, extending from the Ischitella offshore (WNW) to the Tyrrhenian sea (ESE)	18 m (WNW) 320 m (ESE)
TRANS0	S-N	Southern Tyrrhenian sea, extending from the Cuma offshore (S) to the Ischitella offshore (N)	120 m (S) 22 m (N)

tephra/sample	C1161/1																								
SiO_2	56.03	60.83	58.01	57.57	55.67	55.75	56.71	57.56	59.56	60.85	60.85	60.79	58.81	56.51	59.55	60.75	58.61	58.42	56.38	54.60	60.16	58.22	62.43	62.47	60.73
TiO_2	0.28	0.50	0.53	0.42	0.77	0.44	0.34	0.86	0.54	0.35	0.43	0.58	0.67	0.60	0.55	0.14	0.53	0.65	0.43	0.85	0.63	0.23	0.54	0.45	0.36
Al_2O_3	18.01	18.90	18.60	19.13	18.18	18.19	18.25	18.0	18.60	18.57	18.81	18.85	18.34	18.94	18.26	18.75	18.76	18.48	18.33	18.23	1826,00	18.83	18.28	18.28	18.50
FeOtot	6.32	2.69	4.48	4.02	5.88	5.74	5.68	4.92	3.1	3.16	2.79	2.48	3.95	4.37	3.84	2.74	4.02	3.77	5.69	6.62	3.3	4.58	2.72	2.89	2.79
MnO	0.26	0.17	0.10	0.22	0.25	0.56	0.31	0.10	0.28	0.36	0.00	0.07	0.15	0.62	0.23	0.45	0.00	0.23	0.16	0.12	0.13	0.00	0.59	0.14	0.45
MgO	1.64	0.38	1.24	0.59	1.99	2.05	1.68	1.10	0.79	0.37	0.53	0.41	1.29	1.49	0.80	0.37	0.59	0.75	1.79	2.36	0.64	1.18	0.31	0.42	0.27
CaO	4.58	2.10	3.75	2.93	4.88	5.17	4.44	3.41	2.35	2.08	2.37	2.46	.68	4.28	2.96	2.44	3.22	3.01	4.16	5.52	2.39	3.66	1.95	2.19	1.68
Na_2O	3.45	4.52	3.56	4.22	3.53	3.27	3.36	3.62	3.82	5.78	4.43	4.27	3.53	3.72	4.22	4.25	3.81	3.90	3.57	3.38	4.75	3.77	4.31	3.82	6.63
K_2O	8.29	9.21	8.85	10.19	7.63	7.86	8.18	8.81	9.63	7.53	8.79	9.36	8.80	8.67	8.63	9.41	9.77	9.83	8.13	7.35	8.78	8.70	7.93	8.56	7.43
P_2O_5	0.49	0.0	0.27	0.05	0.59	0.38	0.52	0.49	0.16	0.18	0.38	0.09	0.17	0.36	0.31	0.03	0.00	0.24	0.73	0.44	0.07	0.18	0.20	0.16	0.17
Cl	0.64	0.69	0.61	0.65	0.62	0.59	0.53	0.63	0.65	0.76	0.61	0.63	0.60	0.45	0.63	0.66	0.7	0.71	0.62	0.54	0.84	0.64	0.75	0.62	0.98
Original Total	100.53	101.09	98.72	99.45	97.71	97.36	97.76	98.84	97.90	96.04	96.26	97.18	101.57	99.60	101.91	99.04	94.98	99,365952	99.90	100.66	99.51	99.58	92.80	93.12	100.10
alk	11.74	13.73	12.40	14.41	11.17	11.13	11.53	12.43	13.45	13.31	13.23	13.63	12.34	12.39	12.85	13.67	13.58	13.74	11.70	10.72	13.53	12.47	12.24	12.38	14.06