Accurate dating of Gallipoli Terrace (Ionian Sea) sediments: Historical eruptions and climate records

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The radiometric and tephro-analysis dating of shallow-water Ionian Sea cores is summarized. The 2-kyr series of volcanic pyroxene grains provides information on the volcanic activity of the Campanian area for the period that precedes detailed documentation of eruptions.

The key to gaining information on climate analogs and periodicities, on decadal to centennial timescales, is the measurement of proxy records over the recent millennia with multi-annual resolution and matching accuracy in dating. Accurate dating of non-laminated sediment records is difficult but crucial in achieving meaningful climate reconstructions. Here we describe an approach for constraining the chronology of shallow marine sediment cores from the Ionian Sea with an accuracy of better than 1%.

The cosmogeophysics group in Torino (founded by Giuliana Cini Castagnoli) has been studying sediment cores collected from the Tyrrhenian and Ionian Seas for many years; in particular the group has performed the absolute dating of shallow-water cores drilled on the Gallipoli Terrace (Gulf of Taranto, Ionian Sea). Due to the proximity of the volcanically active Campanian area (Fig. 1), the Gallipoli Terrace is well situated for accurate sediment dating: tephra layers correspond to historically documented eruptions, thus allowing accurate dating and determination of the sedimentation rate. Figure 1 show the locations of four gravity cores, collected from 200 m water depth. By applying the methods described in the following paragraphs, we demonstrated that the sedimentation rate has remained constant to a very good approximation over the last two millennia and across the whole Gallipoli Terrace.

Sedimentation rates were first deduced from the top 20 cm of the four cores by measuring the excess ^{210}Pb activity with respect to the ^{226}Ra isotope. This method showed that 1 cm of sediment was deposited in about 15.5 years. Moreover, the ^{210}Pb dates were in agreement with the ^{137}Cs peaks produced by nuclear bomb testing in 1963-64 AD. This result indicates that the sediments in the upper parts of the cores remained undisturbed during the extraction process (Bonino et al., 1993; Cini Castagnoli et al., 1990).

Using the sedimentation rate obtained by the ^{210}Pb method, we searched in the deeper sections of the cores for the presence of volcanic material corresponding to historically documented volcanic events. Peaks in the number density of pyroxene grains that were clearly of volcanic origin, as shown by a characteristic morphology (Bonino et al., 1993), were considered as markers for volcanic eruption events. In the 2 kyr-long pyroxene series measured in core GT89-3, we identified 22 peaks that correspond to known historical eruptions that occurred in the Campanian area over the last two millennia, starting with the 79 AD eruption that buried Pompeii and ending with the documented eruption of 1944 (Arno' et al., 1987). The very sharp

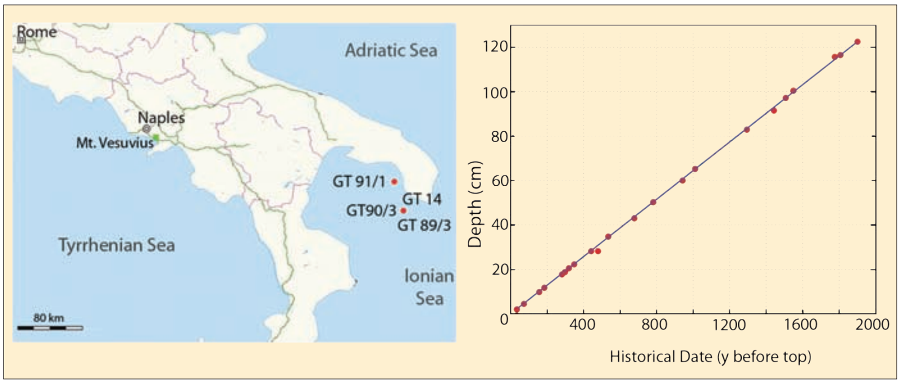

*Figure 1: **a**) Map showing location of drilling sites (red circles) and location of Mt. Vesuvius (green square). **b**) Time-depth relationship over the last 2 kyr. The depth at which a volcanic peak is found in the sediment is plotted versus the historical date of the corresponding eruption, expressed in years before 1979 AD, the date of the core top.*

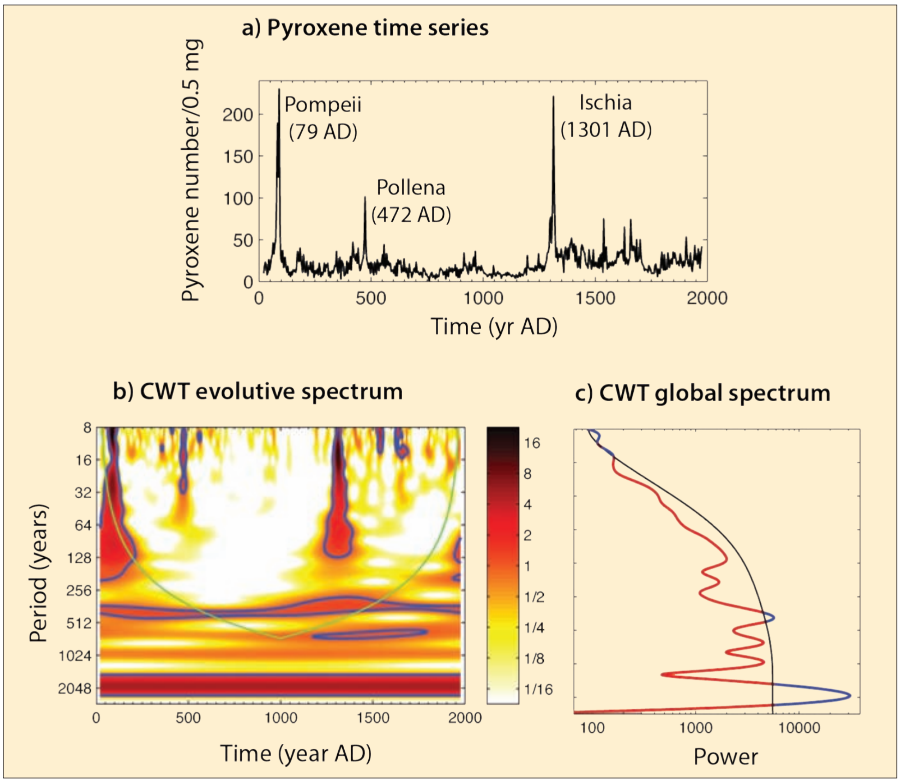

*Figure 2: **a**) Pyroxene series measured in the GT89-3 shallow-water Ionian core. **b**) Evolutive spectrum of pyroxene series by Continuous Wavelet Transform (CWT) with complex Morlet wavelet (parameter $\omega_0 = 6$). Power is normalized dividing it by the level of significance at 90% confidence, computed according to the statistical test described by Torrence and Compo (1998). Blue lines correspond to normalized power equal to 1. The green line represents the cone of influence, outside which power values are affected by zero padding at the edge of the series; such padding is performed before computing the CWT convolution in the frequency domain via a Fast Fourier Transform (FFT), in order to avoid aliasing in the time domain. **c**) Global wavelet spectrum (colored line) and corresponding significance level at 90% confidence (black line). Blue color highlights portions of the spectrum above this level.*

pyroxene peaks indicate that bioturbation by bottom-dwelling organisms is limited. Through pyroxene measurements performed in the cores extracted at different locations on the Gallipoli Terrace and through the remarkable coincidence among $CaCO_3$ profiles in all the cores, Cini Castagnoli et al. (1990; 1992) provided evidence that the sedimentation rate is uniform across the Terrace. This result supports the high reliability of the dates for the climate records from this area.

Figure 1 shows the time-depth relationship over the last two millennia. Each pyroxene peak corresponds to a historical volcanic eruption. The linear regression gives $h = (0.0645 \pm 0.0002)yr_{BT}$, where h is depth (in cm), yr_{BT} means year-before-top (top = 1979 AD) and the correlation coefficient is $r = 0.99$; the slope of this straight line is the sedimentation rate. The highly linear relationship demonstrates that the sedimentation rate has remained constant over the last two millennia to a very good approximation. The pyroxene series, covering the last two millennia with a temporal resolution of 3.87 yr (corresponding to a sampling interval of 2.5 mm), is shown in Fig. 2a. The three largest peaks correspond to the eruptions of Pompeii (Mt. Vesuvius; 79 AD), Pollena (Mt. Vesuvius; 472 AD) and Ischia (Mt. Arso; 1301 AD). In a recent paper (Taricco et al., 2008), we focused on the long-term variability of this series and, using several advanced spectral methods, identified both a millennial trend and a 400-y oscillation, with a high confidence level.

Here we investigate the decadal variability in the volcanic record, possibly related to the length of the activity cycles of Mt. Vesuvius. Detailed information on these cycles is available from 1638 AD and is documented in the catalogue of Arnò et al. (1997). Each cycle ends with an explosive eruption of moderate-to-violent intensity, followed by a dormancy phase of variable duration; the average interval between successive explosive eruptions is roughly 15 ± 3 years. Such cyclic build-ups of pressure, followed by rapid releases, are called relaxation oscillations, which are suspected to occur in the multi-phase (liquid-solid) environment of magma chambers under a volcano. For different volcanoes, the activity cycles can be fairly regular, as is the case for Mt. Vesuvius, or very irregular (Barmin, 2002). The qualitative regularity and mean period between successive eruptions can help diagnose the regime in which the volcano's hidden dynamics operates and possibly help predict future eruptions (e.g., Palumbo, 1997).

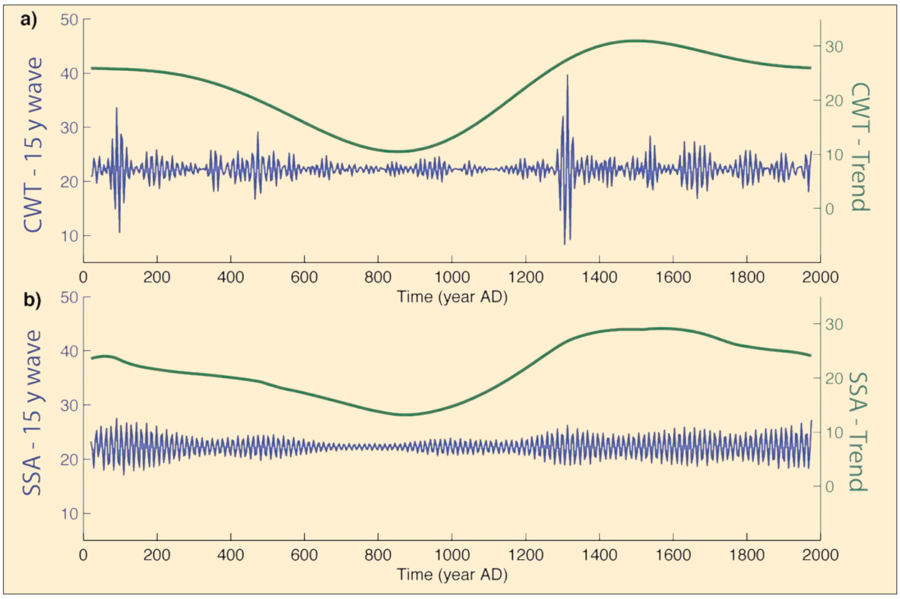

*Figure 3: Reconstructed high-frequency (~ 1/15 yr^{-1}) component (purple lines) and trend (green lines) of the pyroxene series. The reconstructions are obtained by **a**) Continuous Wavelet Transform (CWT) and **b**) Singular Spectrum Analysis (SSA).*

In Figures 2b and c we show the results of the spectral analysis of the pyroxene series, performed by Continuous Wavelet Transform (CWT). Figure 2b shows the CWT evolutive spectrum as a function of time and period (1/frequency). By averaging power over time at each period, the global wavelet spectrum, shown in Fig. 2c, is obtained. Besides the long-term components (trend and 400-yr oscillation), we notice significant power (with a 90% confidence level) in the high-frequency region and in particular around periods of ~15 yr; this periodicity could be connected to the average interval between the explosive eruptions of the Vesuvius. The presence and statistical significance of the 15-yr component is confirmed by Singular Spectrum Analysis (SSA; Ghil et al., 2002; Ghil and Taricco, 1997) and Monte-Carlo SSA (not shown).

Having revealed such regularity in this long time series allows one to study it prior to 1638 AD, when detailed information about recurring eruptions of Mt. Vesuvius is not available. The 15-yr oscillation, reconstructed by Inverse CWT, is shown in Figure 3a. The CWT's high temporal resolution at high frequencies captures strong amplitude modulations. The amplitude modulations obtained in Figure 3b by SSA are consistent with those in Figure 3a but are much smoother.

In the last 2 kyr we can distinguish three intervals (Figs. 3a, b): the intervals prior to 600 AD and post 1200 AD exhibit higher amplitudes of the 15-yr cycle, and are separated by an interval (600 – 1200 AD) of lower amplitudes. The same three regimes are also present in the long-term trend revealed in the record by both CWT and SSA (Figs. 3a, b) and are also visible in the evolutionary wavelet spectrum (Fig. 2b). Higher levels of overall volcanic activity of Mt. Vesuvius, concomitant with an increased pyroxene background level, are thus accompanied by higher-amplitude 15-yr cycles, both before 600 AD and after 1200 AD.

The pyroxene measurements performed by the Torino cosmogeophysics group in the Ionian sediments are thus the basis of a very accurate dating of multi-proxy records over the last two millennia. Moreover, this high-resolution pyroxene series can provide information about the volcanic activity in the Campanian area before the period for which detailed documentation of eruptions is available.

These well-dated sediments are also providing climate information over the last two millennia. Currently, we are preparing for publication the results obtained from a high-resolution record of foraminiferal $\delta^{18}O$ that exhibits highly significant centennial and decadal oscillatory components of climate variability.

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Change at the Poles: A Paleoscience Perspective

Editors:

Julie Brigham-Grette, Ross Powell, Louise Newman and Thorsten Kiefer

Rugged yet modern technology is necessary in the remote polar regions to recover world-class geoscientific datasets that are critical for reconstructing global paleoclimate and constraining climate models. (Cover design by Tom Naughton; image credits on back page).