The consequences of hydrological events on steep coastal watersheds: the Costa d'Amalfi, eastern Tyrrhenian Sea

CRESCENZO VIOLANTE[1], CHIARA BISCARINI[2], ELIANA ESPOSITO[1], FLAVIA MOLISSO[1], SABINA PORFIDO[1] & MARCO SACCHI[1]

1 *Institute for Coastal Marine Environment, National Research Council, Calata Porta di Massa, Napoli, Italy*
crescenzo.violante@iamc.cnr.it

2 *WARREDOC, Water Resource Research and Documentation Centre, University for Foreigners, Perugia, Italy*

Abstract Mitigating the adverse impacts of extreme hydro-meteorological events such as floods requires a multi-hazard approach that integrates land and water resources development in a river basin. For this aim, geological data combined with historical and direct field investigations play a major role both for basin and flood analysis, especially in poorly monitored systems. In steep, rocky watersheds with ephemeral fluvial discharge, the scarcity of suitable networks of instrument stations and the importance of erosional processes claim the use of different data sources for predictive water models that include hydrological analyses. The advantages of an integrated approach is discussed within the case of the Costa d'Amalfi, a stretch of rocky coast with small and high-elevation drainage basins punctuated by rapid and catastrophic floods. The elevated bed load transport occurring in conjunction with rainstorms strictly associates with sediment supply by slope erosion that clearly excludes any kind of clear-water flows in favour of hyper-concentrated flows.

Key words multi-hazard approach; rain storm; stream flow; rocky coast

INTRODUCTION

The Mediterranean area, particularly Italy, is prone to extreme streamflows both inland and at the coast and their study can improve the overall quality of water resources management, by providing snapshots in the field. Short steep streams with very high urbanization rates, mostly concentrated at their mouths, are poorly monitored or not monitored at all, being often dry with long periods of apparent stability that turn rapidly into catastrophic events. For this reason, people and even authorities tend to forget the nature and the risks involved with these ephemeral streams, which are able to cause extensive damage and loss of life.

The main purpose of this study is to illustrate the contribution of different approaches, coming from different scientific disciplines, in water resources management. It particularly highlights the importance of direct field observations as a basis for predictive water models that include geological and historical investigations combined with hydrological data. This task is evaluated through the presentation of a pilot case study located along the eastern Tyrrhenian margin: the Costa d'Amalfi.

The selected case study deals with streamflow phenomena affecting the small watersheds of the Amalfi Coast, a famous coastal area that has been included in UNESCO's list of world heritage since 1997. The Amalfi Coast is a stretch of steep rocky coast that preserves, in an intact and visible form, many traces in terms of architecture, urban design, and agricultural use, principally for the occurrence of cultivated terraces, of its evolution since Roman times. Natural disasters resulting from streamflow events (flash floods) are an intimate part of such a landscape as testified by maritime Roman villas buried by flood deposits. In more recent times, heavy damage was produced by at least four catastrophic floods, documented both in the historical and environmental records. Geological and hydrological data point to elevated fluvial bed load transport strictly associated with sediment delivery from slope to streams in conjunction with rainstorm events. The slides involve a water saturated mass of materials rapidly flowing down slopes, that incorporates vegetated covers and man-made structures. This clearly excludes any kind of clear-water flow in favour of hyperconcentrated flow with significant catastrophic implications.

THE STUDY AREA

The Costa d'Amalfi consists of a steep mountain front that rises abruptly from the Tyrrhenian Sea. Steep topographic gradients forced human settlements to develop along the coast at the mouth of the main streams where low topographies, water resources, and natural embayment for ship recovery occur. Here, coastal landforms are created by deposition of alluvial sediments in the form of gentle sloping fan-shaped areas. This places local communities at high risk during intense and prolonged rainfall able to trigger catastrophic streamflows.

The study area is part of the Sorrento Peninsula, a major Quaternary morpho-structural unit of the western flank of the Southern Apennines consisting of a narrow and elevated mountain range (up to 1444 m) that separates two major embayments of the eastern Tyrrhenian margin, namely the Naples and Salerno bays (Fig. 1). It is mostly formed by a pile of Mesozoic carbonate rocks, covered by Tertiary to Quaternary siliciclastic and pyroclastic units, and is deeply cut by a complex pattern of bedrock rivers and channels characterized by small catchment areas that are very high relative to the base level. These rivers show a distinct seasonality and torrential behaviour (Esposito *et al*., 2004a,b; Budillon *et al*., 2005), with main delivery areas into the adjacent marine shelf.

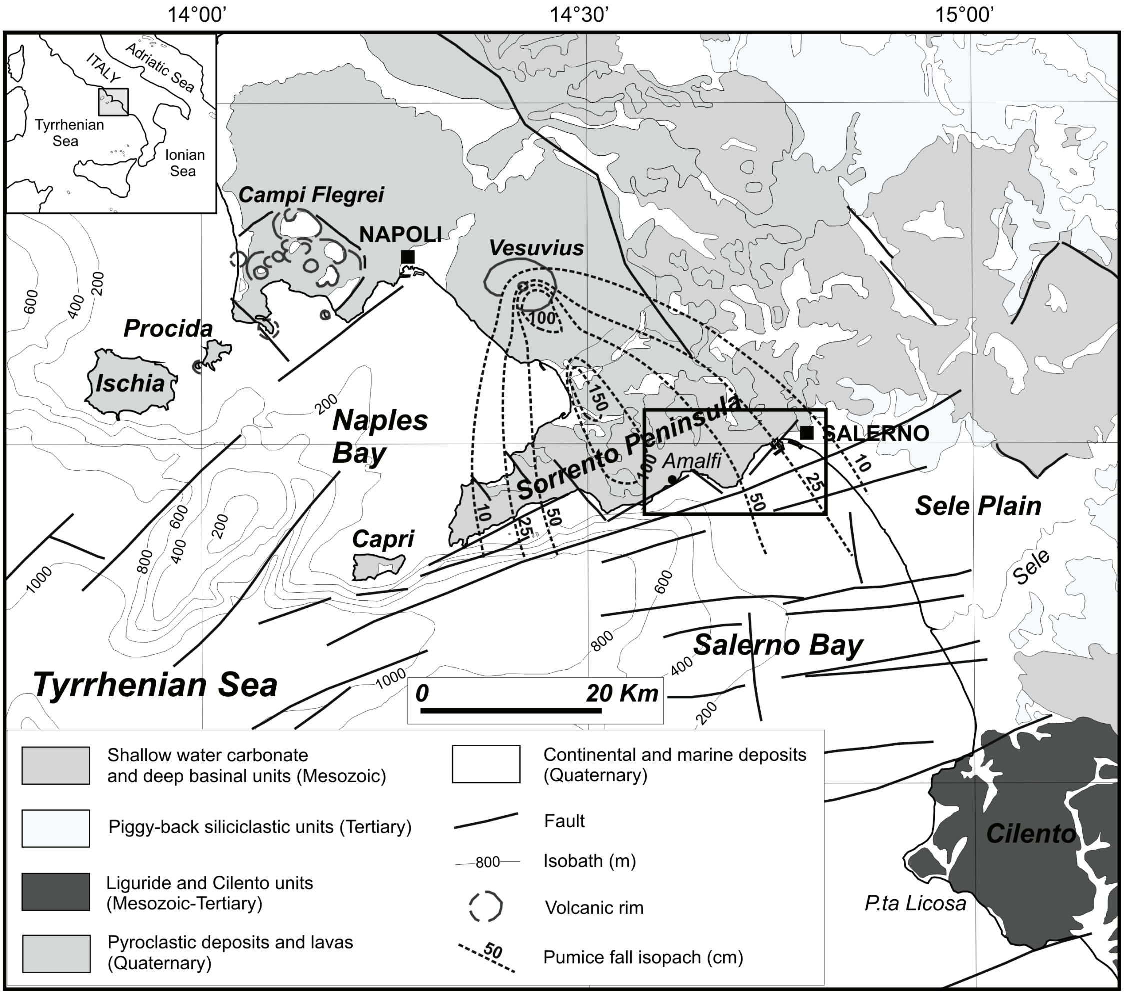

Fig. 1 Tectonic sketch-map of the Campania continental margin (Eastern Tyrrhenian Sea) and location of the study area (Amalfi coast of the Sorrento Peninsula).

The Costa d'Amalfi is located about 20 km south of the Somma-Vesuvius and has been repeatedly mantled during the last millennia by the pyroclastic products of the volcano. The most recent explosive eruptions of Vesuvius, particularly the AD 79 Plinian event, have accumulated loose pyroclastic material over large areas of the Campania region, thus creating favourable conditions for volcaniclastic debris to generate mass flows and flash floods in concomitance with rainy periods. In particular, during the Plinian eruption that destroyed the Roman cities of Pompei, Stabiae and Herculaneum in AD 79, the study area was covered by up to 2 m of pyroclastic air-fall tephra (Sigurdsson *et al*., 1985; Lirer *et al*., 1993; Cioni *et al*., 1999) now occurring as weathered levels up to a few metres thick or as deeply incised streamflow deposits (locally called *Durece*) up to 30 m thick along the stream valleys (Cinque & Robustelli, 2009).

THE COSTA D'AMALFI CULTURAL LANDSCAPE

On the steep slopes of the Amalfi coast, terracing is the only possible way for cultivation, as it allows sub-horizontal surfaces through deforestation and use of rocks to build retaining walls. These systems deeply modified both the geomorphic and hydrological features of the original slopes by varying the terrain profiles and diverting the flow of the rainfall runoff through construction of irrigation channels and water pools. Actually most of the managed terraces are used for lemon trees and as vineyards, as they are the more profitable cultivation practices.

In the study area terracing developed with different characters and typology according to slope steepness and morphology since Medieval Times (11th–12th century AD) generating an extraordinary territorial and cultural system. Their construction constituted a significant interference with the natural environment, introducing new equilibria in the geomorphic system and the water balance. However, these equilibria are necessarily based on the continued maintenance of irrigation channels, aqueducts and reservoirs that, when discarded, can cause a significant loss of productive land and biodiversity as well as increase of natural hazard and disappearance of a rich cultural heritage.

Terrace development on the Amalfi coast was implemented through social behaviour and the use of specific techniques. Traditionally the irrigation channels are managed jointly by the community and in the past the link between man and territory was established through religious events and associated traditions that involved clear obligations about land care, particularly those connected with management of surface waters. Such a cultural heritage of effective rules against land degradation, gradually disappeared and the maintenance of terraces and irrigation systems is at present significantly reduced. The abandonment of terraced areas was mainly due to reduced competitiveness and to dating of the traditional techniques only seldom replaced by new technologies.

If terracing constituted an interference with the natural environment, in the same way terrace abandonment can result in a new significant interference with a potential increase of the natural hazard. The lack of maintenance of a man-altered landscape implies a rapid restoration of the original geomorphic conditions by means of land degradation with diffuse problems of slope instability and consequent increase in the transport of solids in the rivers. This is particularly significant for the Costa d'Amalfi where the urbanization is mainly constrained at stream mouths, the only areas where the slopes are not too steep to build.

HISTORICAL FLOOD CHRONOLOGY

Streamflow events have produced severe impacts on the Amalfi coast throughout the centuries. The recurrence of such phenomena is well reported by local and national institutions as testified by historical sources (Esposito *et al*., 2003a,b). Historical archives, collecting administrative sources of high reliability, and public libraries, holding a lot of documentary sources (chronicles, diaries, newspapers, scientific publications, etc.), provide significant information that leads to the identification and characterization of the phenomena in terms of victims, damage and area involved.

The reconstruction of historical flood chronology of the Amalfi coast, is based on a great variety of historical sources concerning the period between the 16th and the 20th centuries, analysing both published and unpublished sources. The multiplicity of sources allows us to crosscheck the data. Because of the long time span, these data have also been influenced by social and cultural changes, therefore, while they represent the best possible data set, the description of the events may be still incomplete and much research work is necessary to obtain a complete overview of the historical floods (especially in the Middle Ages).

In order to obtain the best information *versus* the best data set quality, it was necessary to define an *ad hoc* scientific procedure in historical data collection that would take into account the completeness and reliability of documents within the historical context, considering the intrinsic quality of the document, and the historical reliability of the authors (Porfido *et al*., 2009). According to this procedure, we examined and analysed about 3000 documents, most of which fell in the *highest quality of reference* coming from original document sources that allowed the identification and classification of 106 floods occurring during the last five centuries within the Amalfi coast (Fig. 2). The information obtained from historical data concern the river locations, the exact dating and duration of flood events, the level of damages incurred by public and private structures, the number of victims, the flood extent, the geological-induced phenomena and the prevailing meteorological situation.

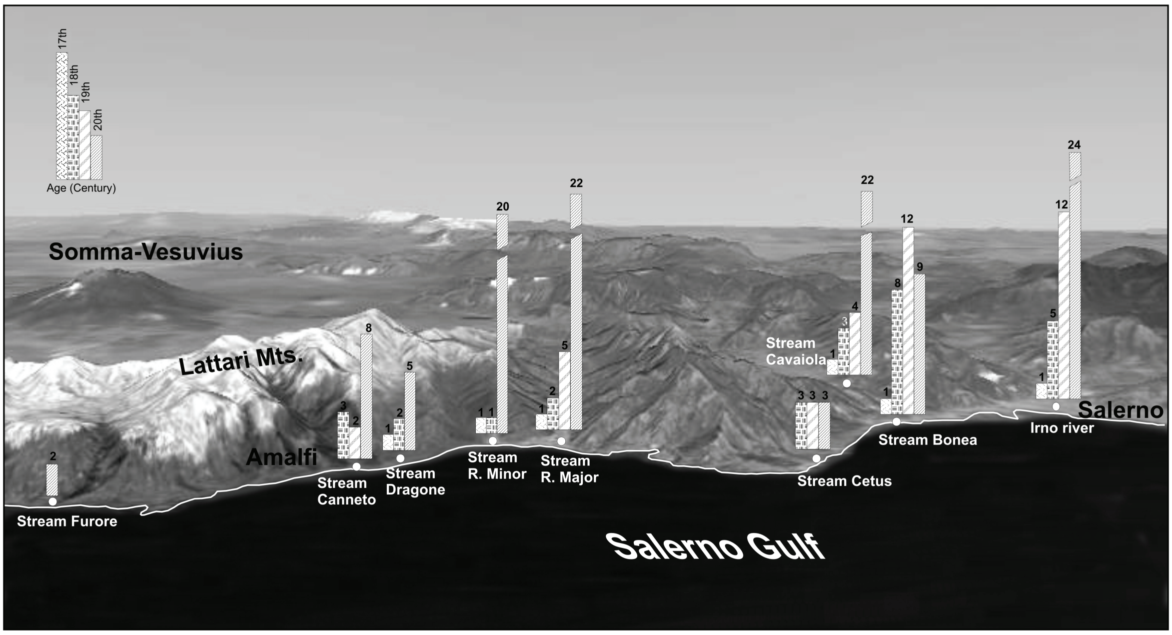

Fig. 2 Oblique view of the Amalfi coast, with an indication of the number of flood events that occurred along the main streams since AD 1581.

The systematic search for historic sources allowed estimation of the magnitude (Severity Class SC) of floods from the 16–17th centuries to the present (Table 1). On the basis of areal extent, the type of effects induced on the urban and physical environment and the recurrence intervals, the recognized events have been grouped in the following three levels:

– **SC 1** – *small flood* characterized by restricted area affected by streamflows, minor damage to buildings and no serious damage to the population. Recurrence interval <20 years.
– **SC 2** – *intermediate flood* characterized by large area affected by streamflows, severe damage/partial destruction to buildings. Infrastructures are destroyed along several hundred metres. Recurrence interval <100 years.
– **SC 3** – *catastrophic or large flood* characterized by large area affected by streamflows, severe damage or complete destruction of buildings and infrastructures. Recurrence interval >100 years.

Table 1 Flood events since the 16th century on the Amalfi coast and their classification in Severity Classes. The studied events are mainly concentrated in the autumn season, whereas the spring season has experienced seven floods out of a total of 106.

SEASON	1500–1600			1700			1800			1900			N. FLOOD
	SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3	
WINTER				4	1		6	1		13			25
SPRING				1			1			4	1		7
SUMMER		1		1			4			10			16
AUTUMN	2		1	6	1	1	7		1	28	2	1	50
UNKNOWN							6			2			8
TOTAL	2	1	1	12	2	1	24	1	1	57	3	1	106

In all, four events were estimated as *catastrophic or large flood* (SC3), seven as *intermediate flood* (SC2) and the rest as *small flood* (SC1). These events mainly hit the coastal areas in autumn and winter, with peak occurrences in October.

As regards the 16th and 17th century, the available data set allowed the identification of four events. Among these, the flood of 30 September 1581 has been classified as a *catastrophic or large flood* for the extensive damage produced in several localities distributed both on the coast and inland and for extensive inundations, high landslide activity and shoreline progradations. The number of victims was over 300.

The 31 August 1588 flood has been classified as an *intermediate flood* as severe damage to public and private property were recorded along with extensive inundation, medium landslide activity and localized shoreline progradation.

The 18th century was accompanied by 15 flood events. Among these the 23 November 1750 flood has been classified as an *intermediate flood.* The most destructive flood event occurred on 11 November 1773**,** and was classified as a *catastrophic or large flood* on the base of extensive inundation, high landslide activity and diffuse shoreline progradations. The fatalities were 400–450.

The 19th century was characterized by 22 flood events. An increase in the number of flood has been observed in the second half of the century. Beside the 1 January 1823 event, classified as *intermediate flood*, the 7 October 1899 flood produced a widespread pattern of destruction in almost 23 localities (Fumanti *et al*., 2001). The latter event caused massive destruction of thousands of houses, hydraulic mills, infrastructures such as aqueducts, main and secondary roads, bridges as well as railways, producing prolonged disorder in multiple productive activities of the coast. The final death toll was 86.

Of the 61 floods recorded in the 20th century the most significant occurred in the years 1910, 1924, 1954 and 1966. The 24–25 October 1910 flood hit a narrow costal area of about 70 km^2 located between Salerno and Conca dei Marini. Major damage (total and partial collapse of houses, roads and aqueducts) occurred in Cetara village where about 40 houses were completely buried by landslides, causing 200 deaths. It has been classified as an *intermediate flood*. The 1924**,** 26 March flood seriously damaged more than 20 localities along the Amalfi coast. Among these, Amalfi and surrounding villages were the most damaged, with the total or partial collapse of many houses, roads and bridges. In Vettica Minore village a wide landslide wiped out 25 buildings, killing at least 60 people. About 100 people died following extensive inundation and landslide activity. It has been classified as an *intermediate flood*. The 25–26 October 1954 flood, classified as a *catastrophic or large flood*, was produced by heavy rains that lasted 16 hours. The meteorological event is considered the most catastrophic one occurring on the Amalfi coast, with a maximum value of 504 mm (Esposito *et al*., 2004a,b) and a maximum intensity of 150 mm/hour (Frosini, 1955). A disaster of inestimable proportions affected 46 villages, causing the collapse of houses, and almost complete interruption of telegraph and telephone communications. Stream flows and landslides occurred over a wide areal extent, producing destructive flood waves. Twenty three localities lying along river banks suffered more severe damage; there were 318 victims and 350 were injured.

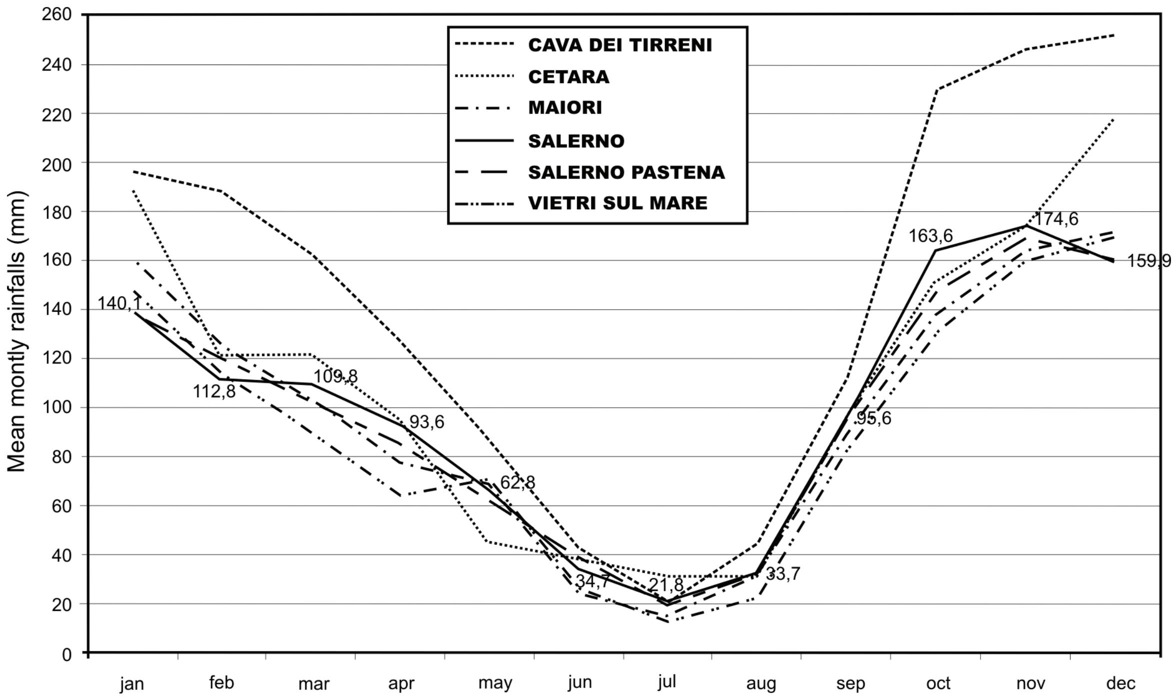

Fig. 3 Average monthly rainfall based on raingauges located around the Amalfi coast. The gauges refer to a time span lasting from 1862 to 2002 (from Tranfaglia & Braca, 2004).

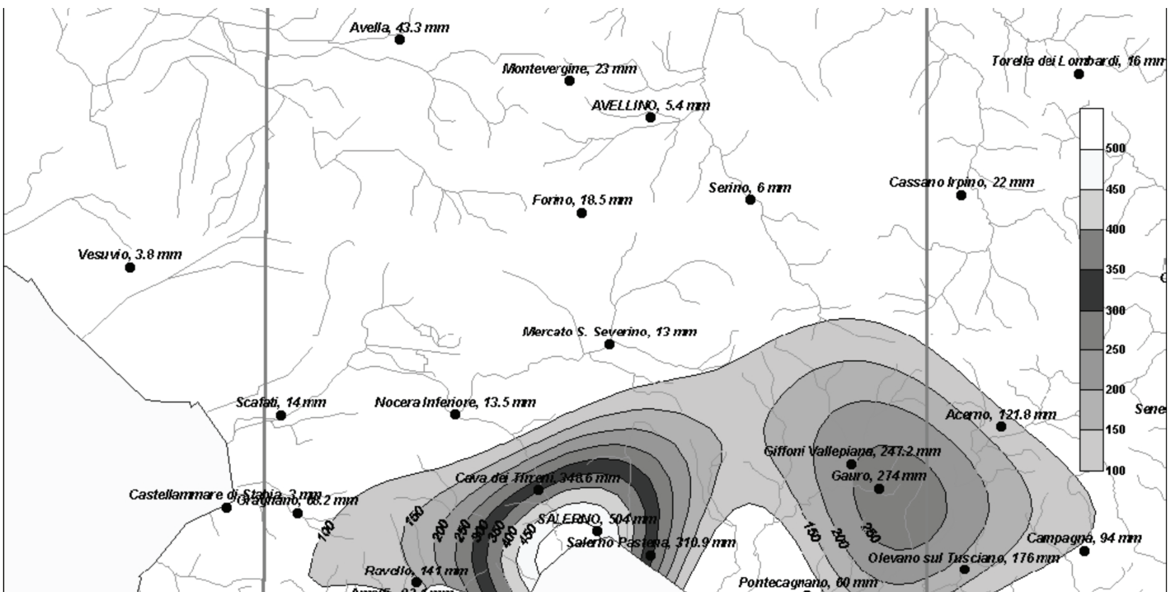

Fig. 4 Isohyets of the 24–25 October 1954 event. Data from Servizio Idrografico, 1958 (1954 annals of the Naples Hydrographic Service).

RAINSTORM-INDUCED ENVIRONMENTAL EFFECTS

The regime of precipitation on the Amalfi coastal range is strongly influenced by high topographic relief reaching more then 1400 m a.s.l. and by high temperatures of the coastal waters. Increase of rainfall with altitude and a *damming effect* associated with the steep coastal slopes produces intense cloudbursts of relatively short duration hitting zones of limited area. The analysis of the historical rainfall trend over a time-span ranging from 1920 to 1950 (Ruocco, 1957), indicates an annual average of 1200–1400 mm with peaks exceeding 1600–1800 mm in high elevation areas (>1000 m). Maximal precipitation occurs in spring and, most of all, in autumn (Fig. 3).

Hydrological features of flood-inducing rainstorms occurring on the Amalfi coast typically include a few days of steady rains, with anomalous high levels of daily totals, followed by a few hours of heavy rain commonly exceeding 200 mm. During the 1954 rain storm the spatial distribution of the rainfall (Fig. 4) shows a difference of more than 450 mm over a distance of only 15 km (Frosini, 1955) while the reconstruction of the storm hydrograph for the Bonea basin at Vietri sul Mare (Fig. 5) indicates a peak flow of more then 300 m^3/s occurred between 22:00 h and 23:00 h, and discharges of about 200 m^3/s in the following hours. Although significant, such values do not justify the pervasive pattern of damage and the number of fatalities (117) reported along the path and at the mouth of the main stream, the Bonea. Here heavy damage occurred to the building and industries, some 309 buildings were destroyed, 309 were damaged and 143 were rendered unfit for use, along with partial destruction of the state road, a bridge, the aqueduct, the sewer system and the railway. A local cemetery in the path of the water was totally destroyed, with several coffins transported about 1 km to the shore. A similar pattern of damage occurred in conjunction with concentrated burst of waters that hit the Amalfi coasts with both seasonal and larger recurrence intervals since the 16th century (see Table 1).

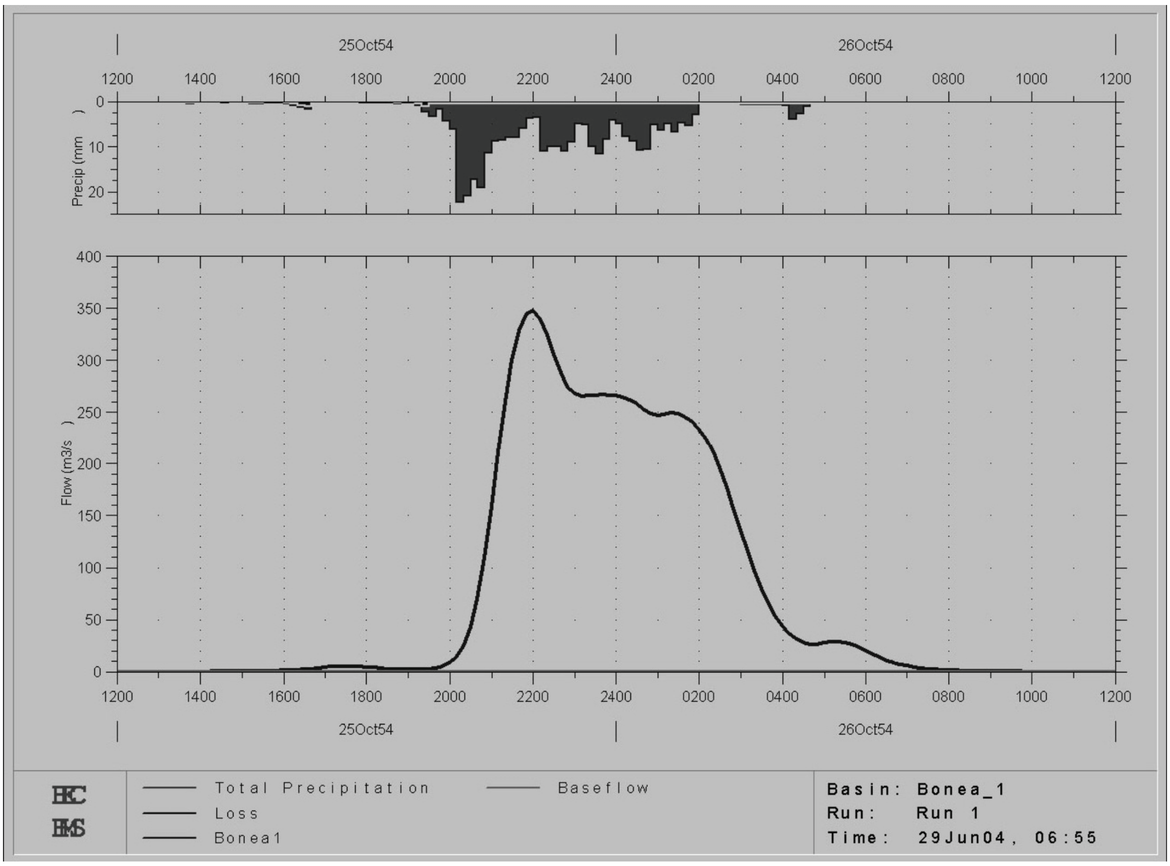

Fig. 5 The stream Bonea storm hydrograph reconstructed from data recorded in the Cava de Tirreni station (from Tranfaglia & Braca, 2004).

The damage analysis and information reported by witnesses clearly suggests the importance of the environmental effects produced by rain storms. Floods occurring in these types of settings are heavily influenced by sediment delivery from side slopes that produces intense erosion through a variety of mass-wasting phenomena. The slides are often shallow and very wide, extending all the way to the mountain ridge and crest, and largely ascribed to soil slip, debris/earth flow phenomena. In particular, debris flows may evolve from soil slips, or develop along linear paths and tributaries already flooded by rainfall. The mobilized materials are mainly composed of poorly consolidated pyroclastic deposits derived from late Quaternary activity of the Somma-Vesuvius directly overlaying carbonate bedrock (Esposito *et al.*, 2004a; Casciello *et al.*, 2004). Differential permeability and competence between sedimentary covers (Lazzari, 1954) along with high topographic gradients, creates conditions of elevated slope instability, with carbonate bedrock deposits being exposed over wide areas of hillsides during water events.

Besides hazards derived by sediment transport along slopes, landslide debris mixed with rising floodwaters along water paths can produce fast-moving large debris flows that in turn induce a positive reinforcement of slope instability due to strong bank erosion in the valley bottoms. Nevertheless, the more hazardous phenomenon associated with slope erosion results from the failure of temporary debris dams formed at narrow valley gorges where the flow backs up to a critical threshold, beyond which a translatory flood wave may be produced (Eliason *et al.*, 2007). Obstructions of the water paths by landslide deposits and consequent formation of ephemeral lakes have been described at different scales for both the 1924 and 1954 flood events (Passerini, 1924; Penta *et al.*, 1954). Abrupt draining of such temporary reservoirs can produce exceptional temporary discharges and highly destructive peak flows reaching depths as high as 8–10 m (Larsen *et al.*, 2001; Perez, 2001; Esposito *et al.*, 2004a,b; Violante, 2009).

MARINE SEDIMENTARY RECORD OF HYDROLOGICAL EVENTS

Rainstorm events occurring in the steep watersheds of the Amalfi coast typically imply accumulation of large volumes of sediment in the form of alluvial fan-deltas at the mouth of the main streams (Fig. 6). High topographic gradients and narrow, deeply incised v-shaped coastal valleys, strongly reduce deposition along the water paths, so that the alluvial materials are transported all the way down to the coast and stored as prograding foresets offshore. This was indeed the case of the catastrophic flood that hit the Amalfi coast in 1954, when the coastline shifted seaward for more than 100 m following the deposition of coarse terminal fans at river mouths (Fig. 7). Since fluvial discharges are of short duration, shoreline progradations are largely ephemeral as waves are free to erode alluvial deposits and restore the original conditions to a different extent.

As a main delivery area, the submerged part of the Amalfi coast preserves reliable sedimentary records of past hydrological events, only partly detectable along subaerial rocky slopes. Marine stratigraphic and sedimentologic investigations based on geophysical surveys and direct sampling of the delta bodies allowed identification of fluvial sedimentary sequences that coincide with a modification in sedimentation rate. Significant changes in river activity during hydrological events are recorded as successive phases of delta growths that, if dated, greatly improve flood modelling by extending back the hydrological record and providing environmental constraints to flood phenomena.

A recent geophysical survey, based on the use of a very high resolution (IKB-Seistec) seismic system calibrated with gravity core data, offshore from the Amalfi coast (see Fig. 6) has provided an extremely detailed image of the small coastal fan deltas fed by small alluvial fans, at the mouth of the main streams (Sacchi *et al.*, 2009). The individual deltaic bodies are about 1 km^2 wide and a few tens of metres thick (Fig. 8). They display a generally conical morphology with a delta front slope of approx. 20° and foreset inclination of between 15° and 30°. Gravity core data and subaqueous investigations showed that the fan deltas are mainly composed of volcaniclastic deposits deposited after the AD 79 Plinian eruption of the Somma-Vesuvius. During this time interval of approx. 2000 years, both sea-level oscillation and tectonic subsidence/uplift were

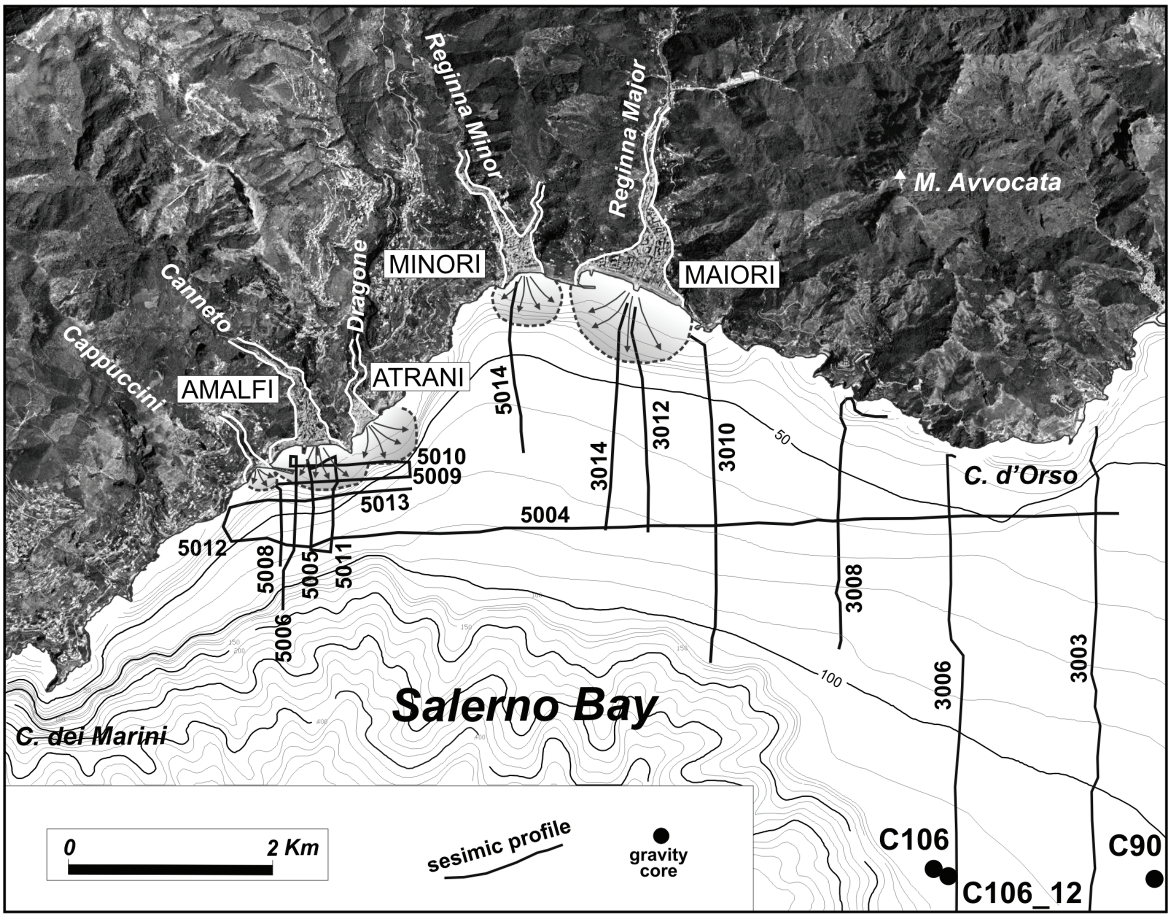

Fig. 6 Alluvial fan-deltas developing at the mouth of the main bedrock rivers of the Amalfi Coast between Conca dei Marini and Capo d'Orso. Location of seismic profiles and gravity cores discussed in this study are also shown.

Fig. 7 The alluvial fan at mouth of the stream Bonea (Vietri sul Mare) after the 24–25 October 1954 hydrological event.

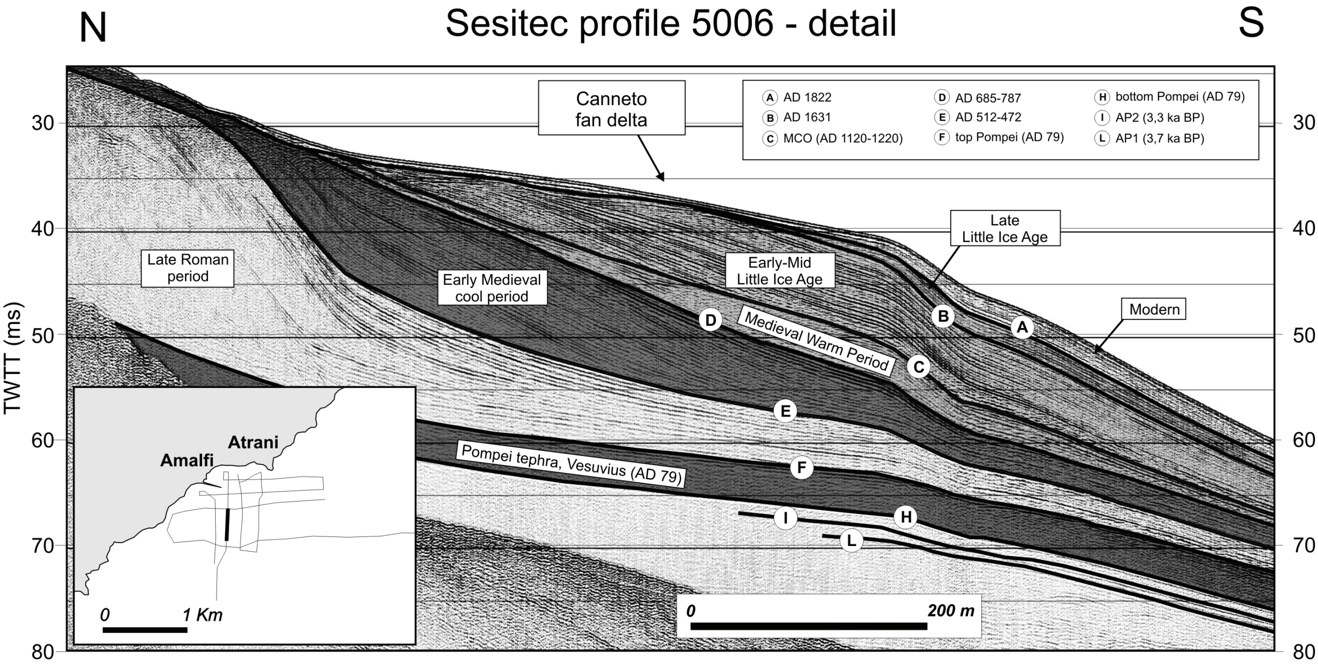

Fig. 8 The Canneto fan-delta found off the Amalfi village. Detail of a very high-resolution seismic profile showing seismic-stratigraphic units and their inferred association with major climatic changes of the last 2000 years. Letters A to L represent age-dated stratigraphic horizons. See inset map and Fig. 6 for location (from Sacchi *et al.*, 2009).

practically negligible in terms of influence on the overall stratigraphic architecture of the inner shelf system, and the main factor controlling stratal geometries and patterns, were likely the rates and modes of sediment supply.

The prominent gravity-driven instability and deformation of sediments detected at various stratigraphic levels within the delta slopes suggest that the stratal geometry of the fan deltas was dominantly dictated by the effective transfer of sediments by hyperpicnal (e.g. inertia, turbidity) flows directly fed by river floods. This implies a primary control by streamflow episodes that have provided conspicuous sediment yields to the coastal area, concomitant with the famous AD 79 Somma-Vesuvius eruption.

The detailed study of the internal stratigraphic architecture of the delta bodies indicates various depositional phases following the main AD 79 alluvial crisis, possibly modulated by the interplay between the availability of loose pyroclastic covers and the varying erosional rates due to the climatic oscillations occurring in the last millennia (Fig. 8; Sacchi *et al.*, 2009). In the last millennia, periods of cooler climate over the Mediterranean area were typically accompanied by increased rainy periods that may have resulted, in turn, in enhancing erosion over the slopes. Abrupt shifts between arid and humid phases are known to create temporary disequilibrium between climate, biotic and geomorphic processes, due to high rainfall erosivity and scarcity of protective vegetation covers (e.g. Dabrio, 1990; Mulder & Syvitski, 1995; Fernández-Salas *et al.*, 2006; Lobo *et al.*, 2006).

The major change detectable in the Amalfi fan deltas is represented by an unconformity surface occurring in the early medieval time, possibly associated with the onset of a period of climatic cooling, known as the Early Medieval Cool Period (*c.* AD 500–AD 800), that developed immediately after the Roman Warm Period. Further minor changes in the stratal patterns of the delta foresets indicative of high streamflow activity, are consistently imaged by the seismic record in all the individual fan deltas of the Amalfi coast. They may be correlated with the Medieval Warm Period (*c.* AD 900–AD 1100) and the Little Ice Age (*c.* AD 1400–AD 1850) (Fig. 8).

CONCLUSION

Hydrological events occurring on the Amalfi coast typically include a few days of steady rains with anomalous high levels of daily totals, followed by a few hours of heavy rain. The storm hydrograph for the 1954 catastrophic floods at Vietri sul Mare indicates a peak flow of more than 300 m^3/s, and discharges of about 200 m^3/s in the following hours. The spatial distribution of the rainfall for the same event shows a difference of more than 450 mm over a distance of only 15 km. These data, along with information coming from historical sources, strongly indicate that significant hydrological events with time recurrence of >100 years typically hit zones of limited areal extent, while a few kilometres away it may only rain at low intensity. Thus, even if the time recurrence of such events for a given locality can be very high, their confined character makes them highly erratic and does not prevent similar disasters occurring soon after in nearby localities.

Modelling of extreme hydrological events occurring on the steep coastal watersheds of the Amalfi coast has shown the importance of rainstorm-induced environmental effects resulting from sediment delivery from slope to streams. Slope debris mixed with rising floodwaters along the water paths can produce fast-moving streamflows of large proportion with significant hazardous implications. However, floods triggered by heavy rainfall owe their catastrophic character to destructive flood waves produced by abrupt draining of temporary debris dams where the flow backs up. Obstructions of the water paths by landslide deposits and abrupt draining of ephemeral lakes is a common observed phenomena able to induce exceptional temporary discharges with peak-flows as high as 8–10 m.

Sediment availability on the Amalfi coast strictly associates with volcanic watershed disturbance resulting from the famous AD 79 Somma-Vesuvius eruption. The pyroclastic fall-out event following the eruption deposited up to 2 m of erosion-prone volcaniclastic material on the steep coastal slopes causing conditions of increased geomorphic instability. The flood sequence is well documented in the fan-delta systems developed at the mouths of the main streams dissecting the Amalfi coast. The internal stratigraphic architecture of the delta bodies indicates various depositional phases following the main AD 79 alluvial crisis, possibly modulated by the interplay between sediment availability and climatic oscillations occurring in the last millennia. The major flood activity has been observed immediately after the Roman Warm Period with the onset of a period of climatic cooling, known as the Early Medieval Cool Period (*c*. AD 500–AD 800). Other alluvial crises may be correlated with the Medieval Warm Period (*c*. AD 900–AD 1100) and the Little Ice Age (*c*. AD 1400–AD 1850).

The study of historical sources allowed the identification and classification of 106 floods occurring during the last five centuries on the Amalfi coast, confirming the severe impact produced by streamflows throughout the centuries. The flood events were frequent and exceptionally destructive and have increased in number during the last two centuries, with a concentration in the autumn season. The systematic search for historic sources allowed estimation of the magnitude (Severity Class, SC) of floods on the base of their areal extent, the type of effects induced on the urban and physical environment and the recurrence intervals. The classification in severity classes can be used for risk assessment and time recurrence of extreme events in the study area.

The analysis of the Costa d'Amalfi landscape points to the preservation of the balanced interactions between human activity and natural environment. This can be obtained through the correct maintenance of cultivated terraces by the re-establishment and renewal of management of water and natural resources. In this context the knowledge coming from the intangible heritage (know-how, traditional knowledge, skills, feasts, etc.) plays a central role in defining the actions for hazard mitigation but, to stimulate the owners to maintain the water system, a new "suitability" based on assessment and modelling of land degradation and the associated hazard has to be established. This will support the development of town planning rules especially able to orient the involved stakeholders to save both the traditional and well tested water management system and the landscape stability.

REFERENCES

Budillon, F., Violante, C., Conforti, A., Esposito, E., Insinga, D., Iorio, M. & Porfido, S. (2005) Event beds in the recent prodelta stratigraphic record of the small flood-prone Bonea Stream (Amalfi Coast, Southern Italy). *Marine Geology* **222–223**, 419–441.

Casciello, E., Cesarano, M., Esposito, E., Pappone, G., Piaquiadio, G., Porfido, S. & Violante C. (2004) *Dissesti idrogeologici nel bacino del Bonea, Costiera Amalfitana (Salerno)*. Accademia dei Lincei, Rome, Italy.

Cinque, A. & Robustelli, C. (2009) Alluvial and coastal hazards due to far range effect of Plinian eruptions: the case of the Sorrento Peninsula (S. Italy) after the famous Vesuvius eruption in AD 79. In: *Geohazard in Rocky Coastal Areas* (ed. by C. Violante & M. Sacchi). *Geol. Soc. Spec. Pub.* (in press).

Cioni, R., Santacroce, R. & Sbrana, A. (1999) Pyroclastic deposits as a guide for reconstructing the multi-stage evolution of the Somma–Vesuvius caldera. *Bull. Volcanol*. **61**, 207–222.

Dabrio, A. (1990) Fan-delta facies associations in late Neogene and Quaternary basins of southern Spain. In: *Coarse-Grained Deltas* (ed. by A. Colella, & D. B. Prior). *Spec. Publ. Int. Assoc. Sedimentol*. **10**, 91–111.

Eliason, J., Kjaran, S. P., Holm, S. L., Gudmusson, M. T. & Larsen, G. (2007) Large hazardous floods as translatory waves. *Environmental Modelling & Software* **22**, 1392–1399.

Esposito, E., Porfido, S. & Violante, C. (2003a) Reconstruction and recurrence of flood-induced geological effects: the Vietri sul Mare case history (Amalfi coast, Southern Italy). In: *ICFSM2003, AGI, Fast Slope Movements Prediction and Prevention for Risk Mitigation* **1**, 169–172.

Esposito, E., Porfido, S., Violante, C. & Alaia, F. (2003b) Disaster induced by historical flood in a selected coastal area (Southern Italy). In: *PHEFRA (Palaeofloods, Historical Data & Climatic Variability: Application in Flood Risk Assessment*), Proc. Intern. Workshop, 143–148. ISBN-84-921958-2-7.

Esposito, E., Porfido, S. & Violante C. (eds) (2004a) Il nubifragio dell'Ottobre 1954 a Vietri sul mare-Costa di Amalfi, Salerno. Scenario ed effetti di una piena fluviale catastrofica in un'area di costa rocciosa. CNR-GNDCI n. 2870

Esposito, E., Porfido, S., Violante, C., Biscarini, C., Alaia, F. & Esposito, G. (2004b) Water events and historical flood recurrences in the Vietri sul Mare coastal area (Costiera Amalfitana, southern Italy). In: *The Basis of Civilization – Water Science?* (ed. by J. C. Rodda & L. Ubertini) (Proc. UNESCO/IAHS/IWHA Symp., Rome), 1–12. IAHS Publ. 286. IAHS Press, Wallingford, UK.

Fernández-Salas, L. M., Lobo, F. J., Hernández-Molina, F. J., Somoza, L., Rodero, J., Díaz del Río, V. & Maldonado, A. (2006) High-resolution architecture of Late Holocene highstand Prodeltaic deposits from southern Spain: the imprint of high-frequency climatic and relative sea-level changes. *Continental Shelf Res.* **23**, 1037–1054.

Frosini P. (1955) *Il nubifragio di Salerno del 25-26 ottobre 1954*. Giornale del Genio Civile, fasc. 3-4 marzo-aprile 1955, 179–188.

Fumanti, F., Rischia, I., Serva, L., Tranfaglia, G., Trigila, A. & Violante, C. (2001) *Effetti sul territorio dell'evento meteorico del 7-8 ottobre 1899 nel salernitano*. Accademia Nazionale dei Lincei, atti dei Convegni dei Lincei **181**, 395–410.

Larsen, M. C., Wieczorek, G. F., Eaton, L. S., Morgan, B. A. & Torres-Sierra, H. (2001) Natural hazards on alluvial fans; The Venezuela debris flow and flash flood disaster. US Geological Survey Fact Sheet 103–01.

Lazzari, A., (1954) *Aspetti geologici dei fenomeni verificatisi nel Salernitano in conseguenza del nubrifagio del 25-26 Ottobre 1954*. Bollettino Società dei Naturalisti, LXIII: 131–142.

Lirer, L., Munno, R., Petrosiono, P. & Vinci, A. (1993) Tephrostratigraphy of the AD 79 pyroclastic deposits in perivolcanic areas of Mt. Vesuvius. *J. Volcanol. Geotherm. Res*. **58**, 133–149.

Lobo, F. J., Fernandez-Salas, L. M., Moreno, I., Sanz, J. L. & Maldonado, A. (2006) The sea-floor morphology of a Mediterranean shelf fed by small rivers, northern Alboran Sea margin. *Continental Shelf Res.* **26**, 2607–2628.

Mulder, T. & Syvitski, J. P. M. (1995) Turbidity currents generated at river mouths during exceptional discharges to the world oceans. *J. Geol.* **103**, 285–299.

Passerini, G. (1924) *Intorno alle cause del disastro del marzo 1924 nella Penisola Sorrentina.* Bollettino "Ricerche ed Esperienze" dell'Istituto Agrario di Scandicci. Seconda Serie, VIII, 1–23. L'Industria Tipografica (Firenze).

Penta, F., Lupino, R., Camozza, F. & Esu, F. (1954) Effetti dell'alluvione del 26 ottobre 1954 nel Salernitano. *Rivista Italiana di Geotecnica* **6**, 245–257.

Perez, F. L. (2001) Matrix granulometry of catastrophic debris flows (December 1999) in central coastal Venezuela. *Catena* **45**, 163–183.

Porfido, S., Esposito, E., Molisso, F. & Sacchi, M. (2009) Flooding events in the Sorrento Peninsula coastal zone, South Italy, since the XVIII century. In: *Geohazard in Rocky Coastal Areas* (ed. by C. Violante). Geol. Soc. Spec. Pub. (in press).

Ruocco, D. (1957) *La distribuzione della piovosità nella Campania.* Rivista Geografica Italiana, Annata LXIV, Tip. Bruno Coppini e C., Firenze, 4.

Sacchi, M., Molisso, F., Violante, C., Esposito, E., Insinga, D., Lubritto, C., Porfido, S. & Tóth, T. (2009) Insight into flood dominated, mixed sliciclastic-volcanoclastic fan deltas: very high-resolution seismic examples off the Amalfi cliffed coast, Eastern Tyrrhenian Sea. In: *Geohazard in Rocky Coastal Areas* (ed. by C. Violante), Geol. Soc. Spec. Pub. (in press).

Servizio Idrografico (1958) *L'alluvione nel Salernitano*. Min. Lav. Pubblici, Annali Idrologici 1954, Ist. Poligrafico dello Stato, Roma, II, 65–78.

Sirgudsson, H., Carey, S., Cornell, W. & Pescatore T. (1985) The eruption of Vesuvius in AD 79. *National Geographic Res.* **1**(3), 332–387.

Tranfaglia, G. & Braca, G. (2004) Analisi idrologica e meteorologica dell'evento alluvionale del 25-26 ottobre 1954: confronto con le serie storiche e valutazione del tempo di ritorno di eventi analoghi. In: *Il nubifragio dell'Ottobre 1954 a Vietri sul mare-Costa di Amalfi, Salerno. Scenario ed effetti di una piena fluviale catastrofica in un'area di costa rocciosa* (ed. by E. Esposito, S. Porfido & C. Violante). CNR-GNDCI n. 2870

Violante, C. (2009) Rocky coasts: geological constrains for hazard assessment. In: *Geohazard in Rocky Coastal Areas* (ed. by C. Violante). Geol. Soc. Spec. Publ. (in press).