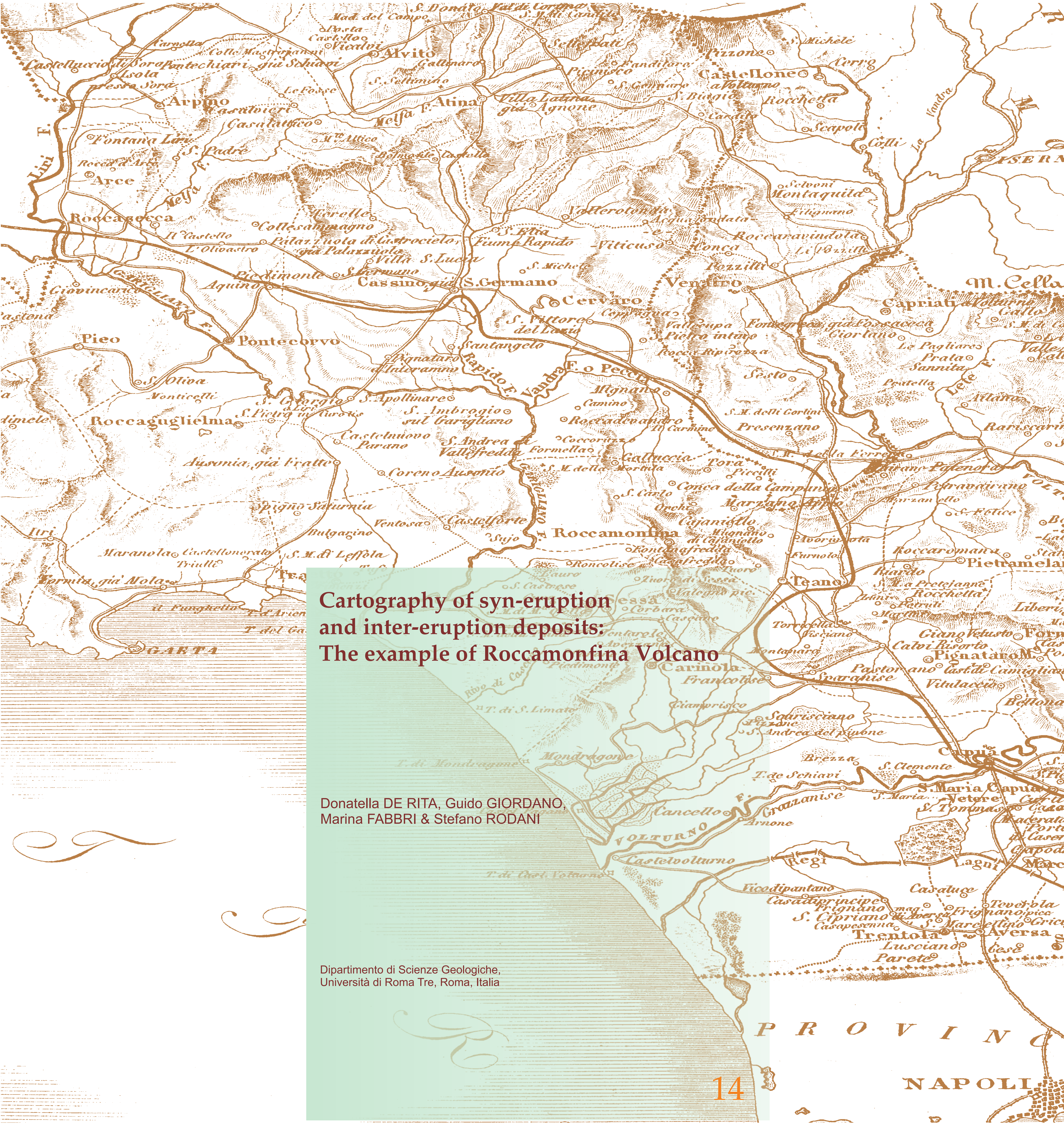

Cartography of syn-eruption and inter-eruption deposits: The example of Roccamonfina Volcano

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ABSTRACT

The geological map of the southwestern sector of Roccamonfina volcano suggests an example of how to represent the history of the volcano taking into account not only its eruptive phases but also its quiescent periods. In the southwestern sector of the volcano the pyroclastic deposits and lavas are laterally interfingered with resedimentated volcaniclastic deposits giving the oppurtunity to relate volcanic processes to resedimentation. Rarely volcaniclastic successions are found differentiated on geologic maps, even if their mapping would be useful for any application in volcanic areas, such as the evaluation of volcanic hazard associated with lahars, landslides, floodings etc. The lithostratigraphic units have been organized in UBSU, with a different nomenclature for sedimentary and volcanic units. Synthems have been defined through the presence of basal unconformities of regional significance that show high relief, are present at regional scale and can be referred, through geochronological data, to the isotopic stages of the Shackleton scale (1995). For volcanic units we have used the definition of Eruptive unit for units limited by unconformities, as paleosols or erosional surfaces, indicating a significative break in the eruptive history of the volcano. Syneruption resedimentated deposits are included in the Eruptive unit. Lithosome has been used to indicate the products of a number of eruptions separated by significant events as caldera collapses, abrupt changes in the chemical-petrographic compositions of the products or styles of eruption. The necessity to use different nomenclature for sedimentary and volcanic units arises by the evidence that unconformities of regional significance may not affect volcanic activity and, vice versa, important discontinuity in the volcanic activity may not occur in coincidence with regional erosive events. Unconformities of Synthems not entering in the Lithosoma sector mean that no significant changes in the volcanic activity occurred during sea level oscillations. Part of the Atlas is dedicated to the relationship between syneruption and intereraption deposits of the Piana del Riardo Synthem. The methodology is illustreated through the example of the Cupa White trachytic tuff (WTT) lahar deposits. The geometry and the lithological characteristics are evidenced through stratigraphic logs measured along the slope of the volcano. Finally a model is proposed to illustrate the generation and the emplacement of the lahar at Roccamonfina.

AIMS

1) To represnt syn- and inter-eruption depèosits related to the Roccamonfina Volcano;
2) To evaluate the relative importance on sedimentation of quiescence periods in comparison to eruptive phases;
3) To verify the use of Unconformity bounded stratigraphic units in volcanic areas;
4) To refer the volcanic activity to its regional framework.

KEYWORDS

Geological mapping, syn- and inter-eruptive deposits, Roccamonfina volcano, volcanic stratigraphy

RIASSUNTO

La carta geologica del settore sud-occidentale del vulcano di Roccamonfina è un esempio di come sia possibile cartografare la storia del vulcano non solo considerando i depositi relativi alla sua attività ma anche i processi accaduti durante le sue fasi di quiescenza. Nel settore sud-occidentale del vulcano i depositi piroclastici passano lateralmente a depositi risedimentati, offrendo così l'opportunità di collegare tra loro i processi vulcanici primari con quelli che ne determinano la risedimentazione. Raramente sulle carte geologiche i depositi risedimentati vengono ricollegati direttamente alle fasi erutive da cui derivano, anche se è ormai noto che la cartografia degli eventi di risedimentazione è estremamente utile per qualsiasi scopo applicativo, come ad esempio la valutazione della pericolosità in relazione ad eventi di lahars, frane, alluvionamenti, etc. Le unità litostratigrafiche presenti nell'area rilevata sono state organizzate in UBSU, utilizzando una nomenclatura diversa per le unità sedimenatrie e quelle vulcaniche. Il Sintema comprende unità sedimentarie limitate alla base e al tetto da superfici di discontinuità che abbiano evidente riscontro morfologico, siano riconoscibili a scala regionale e siano riconducibili sulla base di datazioni geocronologiche dei depositi agli stages isotopici di Shackleton (1985). Per le unità vulcaniche si è adottata come unità base l'Unità Eruttiva che comprende i depositi limitati da discontinuità indicanti una stasi significativa nell'attività del vulcano. I depositi sin-erutivi sono stati inclusi all'interno dellUnità eruttiva corrispondente. Il litosoma indica i depositi di un certo numero di eruzioni che possono essere raggruppate per unifoirmità di caratteri. Il litosoma è quindi limitato da superfici che indicano o collassi di caldera o cambiamenti drastici nella composizione chimico-petrografica dei prodotti del vulcano. La necessità di adottare una diversa numenclatura per unità sedimentarie e vulcaniche nasce dalla constatazione che dicontinuità determinate da eventi regionali, come ad esempio le oscillazioni del livello del mare, possono non avere un effetto significativo sull'attività del vulcano e viceversa drastici eventi di cambiamento nelle condizioni di attività del vulcano possono non avvenire in coincidenza con eventi regionali. Così superfic limiti dei Sintemi che non coincidono con le superfici limiti delle unità eruttive o dei litosomi indicano che in quel momento l'attività del vulcano era così parossistica da non essere minimamente influenzata dalle condizioni regionali. Una parte dell'atlante è dedicata ad evidenziare le relazioni geometriche e di facies delle unità sin e inter-eruttive nel Sintema della Piana di Riardo. La metodologia adottata è illustrata attraverso l'esempio dell'organizzazione lungo il pendio del vulcano dell'ignimbrite del WTT Cupa e dei depositi di lahar derivati. Per concludere viene proposto un modello per spiegare la generazione di depositi di lahar in condizioni climatiche simili all'attuale.

GEOLOGICAL MAP OF THE SOUTH-WESTERN FLANK OF ROCCAMONFINA VOLCANO

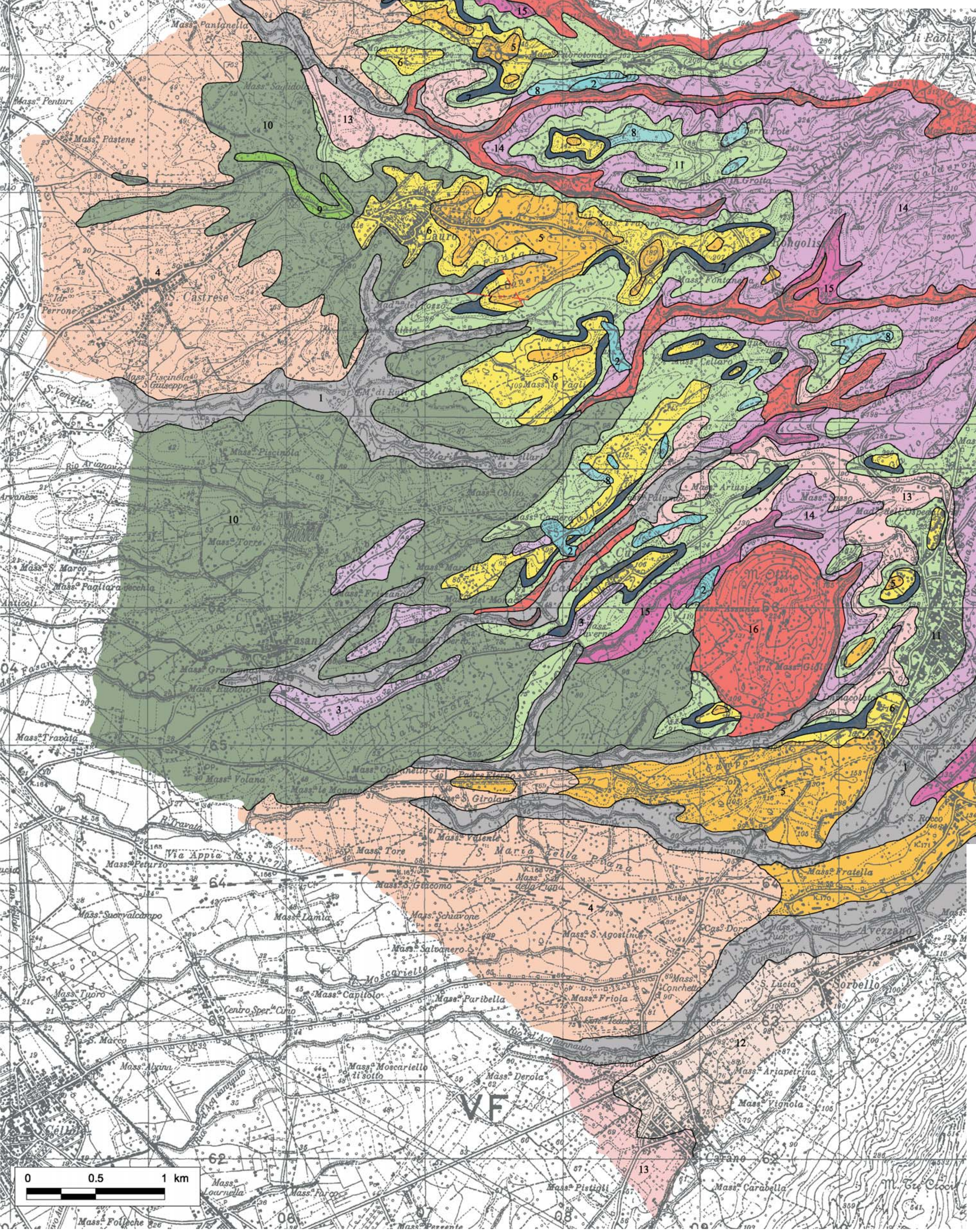


Fig. 1 - *Geological map of the south-western sector of Roccamonfina Volcano.*

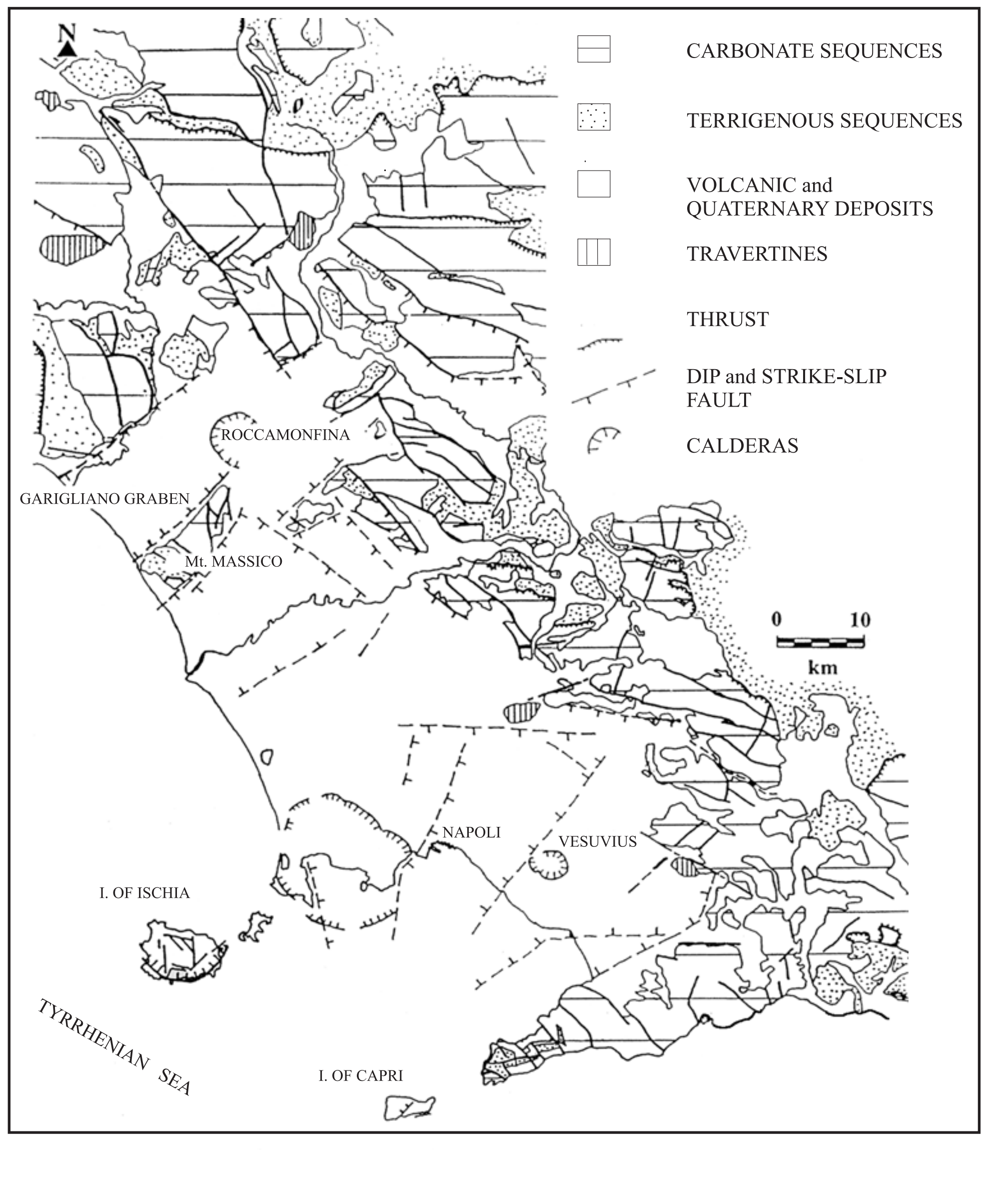


Fig. 2 - *Structural sketch showing the location of the Roccamonfina Volcano in Southern Italy.*

AIMS OF THE MAP

1) *To represent syn- and inter-eruption deposits related to the Roccamonfina Volcano.*

The first effort has been to identify for each eruption the relative syn-eruption and inter-eruption deposits. This has been done trough the analysis of many stratigraphical sections and trough the comparative analysis of the components of each deposit. Syn-eruption deposits are monogenetic in that they derive entirely from the components of the associated eruption. They are characterized by abundant fine-grained juvenile debris. Inter-eruption deposits are etherogenetic, containing conglomerate lenses indicating a progressive “clearing” of the flowing water during the post eruption processes of reintegration of the normal fluvial drainage condition. The inter-eruption deposits are limited at the base by erosive surfaces and are limited at the top by paleosols.

2) *To evaluate the relative importance on sedimentation of quiescence periods in comparison to the eruptive phases.*

The evolution of volcanoes includes, besides the eruptive phases, quiescent periods during which erosion and sedimentation prevail. Usually the extension and the thickness of the deposits emplaced during quiescent periods are comparable with those emplaced during eruptions. Their mapping and characterization help to understand the rate and style of dismantling of the volcano under morphodinamic and/or volcanotectonic agents. The inter-eruption deposits have been mapped in relationship with the primary deposits from which originated. They have been posed under the diction “continental units” to evidence their resedimentated volcaniclastic nature.

3) *To verify the use of the Unconformity Bounded Stratigraphic Units in volcanic areas.*

The lithostratigraphic units have been organized in Unconformity bounded stratigraphic units with a different nomenclature for sedimentary and volcanic rocks. This necessity arises by the evidence that regional and volcanic events occur at different scale and extension; volcanic events are local whereas regional events have regional extension. Synthem is used to indicate deposits limited at the top and at the base by unconformities related to oscillations of the sea level. Supersynthem is used when unconformities are caused by regional tectonic events. For the volcanic rocks, following the indication of Fisher & Schimincke (1984), eruptive units are deposits related to eruptions limited by significative breaks in the volcanic activity. Eruptive succession is used to indicate a succession of several eruptions whose thickness and extension do not allow to map them. The activity of a single volcano is named Lithosoma (see Fig. 3). Using this organization in the legend of the Roccamonfina map appears evident that when the volcanism is in progress, regional events as variations of the sea level may not be able to condition the style of the volcanic eruptions. When this happens, the volcano changes dramatically its style and usually a caldera collapse occur.

4) *To refer the volcanic activity to its regional geological framework.*

One of the most important aim the map would have been to offer a key to read the evolution of the volcano in the most general regional framework. To reach this topic we would have mapped the entire volcanic area with its surroundings that is outside the aims of the atlas. Nevertheless we hope that the map of the southwestern sector of the volcano is a good example of how to reach the aim.

UBSU	VULCANO DI ROCCAMONFINA	UNITA' LITOSTRATIGRAFICHE FORMALI ED INFORMALI				DESCRIZIONE	ETA'
Sintemi	Serie Eruttive	Transizionali/ Continentali	Vulcaniche di Roccamonfina		Vulcaniche flegree		
			Succ. eruttive	Unità eruttive	Unità eruttive		
					1	**UNITA' DELL'IGNIBRITE CAMPANA** Deposito piroclastico cineritico con lapilli pomicei neri a sanidino dispersi nella matrice, grigio, massivo, da zeolitizzato ad incoerente, a fessurazione colonnare. Può raggiungere i 15 m di spessore nelle valli.	33 ka (3)
Palumbo		2				**UNITA' DI MASSERIA PALUMBO** Depositi conglomeratico-sabbiosi poligenici generalmente stratificati e classati in facies fluviale, a riempimento di canali a V che reincidono la serie piroclastica della Piana di Riardo.	
Palumbo				3		**UNITA' DI FASANI** Depositi cineritico-lapillosi, di colore grigio, a stratificazione incrociata e pianoparallela, con impronte da impatto, di spessore massimo di 6 m. Il deposito è interpretabile come una successione da surge a ricaduta freatomagmatica.	
Fosso Maltempo	Piana di Riardo			C 4 B 5 A 6		**UNITA' DEL WTT GALLUCCIO** Unità piroclastica complessa a composizione trachitica (2). Dal basso è composta da: (A) depositi cineritico lapillosi a pomici bianche e a stratificazione incrociata, con impronte di tronchi d'albero, da surge sovrastati da depositi ignimbritici caotici e massivi a matrice cineritica con lapilli di pomici bianche e litici lavici passanti a (B) analoghi depositi ignimbritici a pomici grigie; livelli di breccia sono presenti verso l'alto dell'unità nelle zone prossimali. Spessore massimo 20 m. (C) Superiormente nelle zone mediali e distalmente sono presenti depositi aggradanti mediamente stratificati a granulometria limoso-sabbiosa costituiti per oltre il 60 % da ceneri e pomici derivanti da (A) e da (B), generalmente con gradazione diretta dei litici ed inversa delle pomici, con aumento della frazione litica verso l'alto organizzata in lenti conglomeratiche. L'unità, il cui spessore massimo è 5 m, è interpretabile come una sequenza deposizionale da lahar sin- e immediatamente post-eruttiva.	230 ka (5)
Fosso Maltempo	Piana di Riardo			7		**UNITA' DEL WTT S. CLEMENTE** Unità piroclastica a composizione trachitica (2). Alla base è presente un livello lapilloso a pomici bianche e litici lavici non gradate da ricadute spesso fino a 2 m, seguito da depositi cineritico-lapillosi a pomici bianche e stratificazione incrociata da surge. Spessore massimo 6 m.	
Fosso Maltempo	Piana di Riardo			8		**UNITA' DEL WTT AULPI** Unità piroclastica a composizione trachitica. Alla base è presente un livello lapilloso a pomici grigie e litici lavici a gradazione prima inversa e poi diretta da ricaduta, seguito da depositi ignimbritici caotici e massivi a matrice cineritica grigia con lapilli pomicei e lavici. Spessore massimo 5 m.	
Fosso Maltempo	Piana di Riardo	9				**UNITA' DI LAURO** Depositi conglomeratico-sabbiosi composti prevalentemente di clasti lavici poligenici, da arrotondati a subarrotondati, generalmente stratificati e classati, in facies fluviale a riempimento di canali che reincidono profondamente la successione sottostante.	
	Piana di Riardo			B 10 A 11		**UNITA' DEL WTT CUPA** Unità piroclastica a composizione trachitica (***) Dal basso è composta da (A) depositi cineritici e cineritico-lapillosi biancastri, a stratificazione incrociata, con impronte di tronchi d'albero, con lenti classate di pomici bianche subarrotondate, da surge passanti verso l'alto a depositi ignimbritici caotici e massivi a matrice cineritica con lapilli di pomici bianche e litici lavici, nelle zone prossimali organizzati in livelli di breccia; (B) nelle zone mediali e distalmente sono presenti depositi aggradanti mediamente stratificati a granulometria limoso-sabbiosa costituiti per oltre il 60 % da ceneri e pomici derivanti da (A), generalmente con gradazione diretta dei litici ed inversa delle pomici, strutture convolute da "de-watering" e da densità, che verso l'alto si intercalano a lenti conglomeratiche di litici lavici. L'unità, il cui spessore massimo è 13 m, è interpretabile come una sequenza deposizionale da lahar sin- e immediatamente post-eruttiva.	300 ka (8)
	Piana di Riardo	12				**UNITA' DI CARANO** Depositi fluviali conglomeratici e conglomeratico-sabbiosi costituiti in prevalenza da litici lavici poligenici e subordinatamente da pomici arrotondate, generalmente stratificati e classati.	
	Piana di Riardo			B 13 A 14		**UNITA' DEL BROWN LEUCITIC TUFF** Unità piroclastica complessa a composizione da fonolitica a leucititica (9). L'unità è composta dal basso da: A) depositi ignimbritici litoidi per zeolitizzazione, giallo-marroni, vacuolari a scorie nere e livelli di breccia presenti verso l'alto nelle zone prossimali; (B) depositi incoerenti, caotici e massivi, poveri in juvenile e ricchi in litici in facies da debris flow sono presenti verso l'alto nel settore di Sessa Aurunca; lateralmente passano a depositi a geometria aggradante, sabbioso-limosi, mediamente stratificati con intercalazioni conglomeratiche, costituiti per oltre il 50% da materiale juvenile derivante da (A) e relazionabili a sequenze di lahar sin- e immediatamente post-deposizionali. Spessori massimi 25 m.	385 ka (9)
	La Frascara		B 15 A 16			**SUCCESSIONE DI MONTE OFELIO** A) Lave prevalentemente tefritico-leucitiche (4). B) piroclastiti lapillose a scorie relative ad eruzioni centrali dello stratocono e di apparati eccentrici e loro rimaneggiati sabbioso-conglomeratici.	630 - 400 ka (1,10)

I) Ballini *et alii* (1989a); II) Ballini *et alii* (1989b); III) Barberi *et alii* (1978); IV) Bergomi *et alii* (1969); V) Chiesa *et alii* (1985); VI) De Rita & Giordano (1996); VII) Ghiara *et alii* (1973); VIII) Giannetti & Luhr (1983); IX) Luhr & Giannetti (1987); X) Radicati Di Brozolo *et alii* (1988).
The WTT symbol stays for "White Trachytic Tuff." It has been retained because it is an old term, very used in the international letterature concerning Roccamonfina Volcano.

GEOLOGICAL SETTING

Roccamonfina Volcano is located 120 km southeast of Rome and belongs to the alkali-potassic volcanic province of central Italy, which developed since Middle Pleistocene as a consequence of the extension at the margin of the Tyrrhenian sea. The volcano developed in a topographic depression, surrounded by the Mesozoic-Cenozoic calcareous basament blocks of the Monti Aurunci to the NW, Mount Massico to the SW, Mount Maggiore to the SE and Mount Cesima and Camino to the N (Fig. 3). The blocks expose mostly Triassic to Cretaceous shelf carbonates overlain by Miocene flysch shortened by the Apennine orogenesis. Starting in the Late Miocene, crustal extension associated with rifting of the Tyrrhenian basin caused the development of the Horst and Graben structural character of the area. Roccamonfina lies at the intersection of a main NW-trending tectonic depression and the transverse, NE-trending, Garigliano Graben (Fig. 2).

Volcanic activity at Roccamonfina has been subdivided into three main Epochs (De Rita & Giordano, 1996): the first Epoch (630-400 ka) includes the time span between the oneset of volcanism until the main summit caldera collapse. During this Epoch 100-120 km^3 of mainly high-potassic lava and strombolian deposits were erupted. The second Epoch (385-250 ka) comprises highly explosive eruptions from vents located inside the caldera, along a NE-trending fracture system. These eruptions emplaced small-to intermediate volume, phonolitic to trachytic ignimbrites, which produced

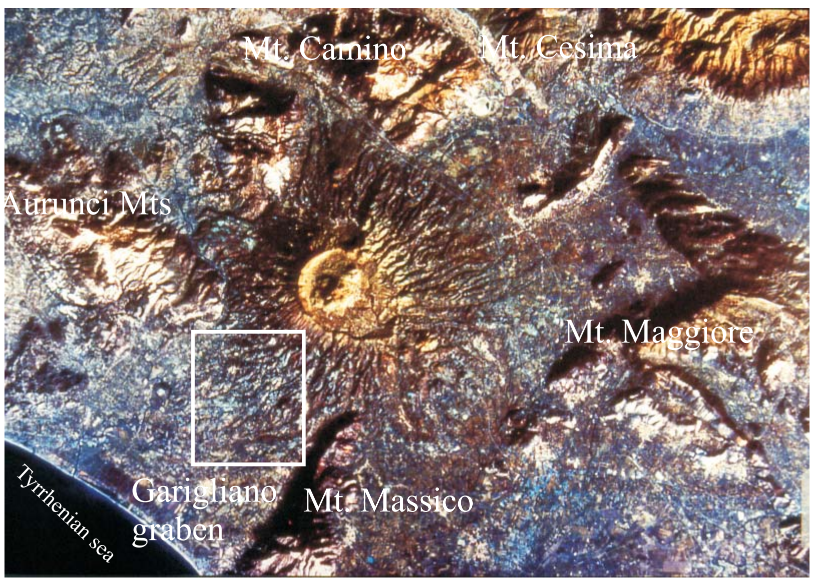


Fig. 3 - *Satellite image of the studied area. Roccamonfina Volcano is a Pleistocene composite volcano, about 10 km in radius, belonging to the Roman magmatic Province, along the Tyrrhenian margin of the Italian peninsula. It is located south of Rome and north of the Vesuvio and Campi Flegrei volcanoes. It developed in a depressed area at the intersection of the main NW-trending tectonic depression and the transverse NE-trending Garigliano graben. The volcano is sourronded by the Mesozoic-Cenozoic calcareous structural highs of the Mts. Aurunci to the NW, Mt. Massico to the SW, Mt Maggiore to the SE and Mt. Cesima and Mt. Camino to the N.*

Fig. 4 - *Panoramic view of Roccamonfina Volcano from the south-west. The western slopes of the Roccamonfina ancient strato-volcano are still well preserved and show high slope gradients gently lowering to meet the flat area of the ring plain. This ancient morphological shape of the strato-vulcano strongly affected the empalcement of the ignimbrites of the Piana di Riardo Lithosome.*

the largest contribution to volcaniclastic sedimentation in the area. The third Epoch (250-50 ka) is the last eruptive epoch and involved the emplacement of two latitic lava domes inside the caldera along the NE-trending fracture system. Effusive and explosive activity occurred from many parasitic centers aligned along N-trending lineaments. The total volume erupted during this Epoch is about 1 km^3.

The southwestern sector of Roccamonfina Volcano records the emplacement of volcanic and volcaniclastic products across the entire time span of the life of the volcano.

The older pre-caldera products have been included in the Monte Ofelio succession, which is part of the La Frascara Lithosome. The succession is mostly constituted by tephritic-phonolitic lava flows and by pomiceous lapilli fallout beds.

The overlying five small to intermediate volume compound ignimbrite units have been included in the Piana del Riardo Synthem and are found along the middle and lower slopes of the volcano (LUHR & GIANNETTI, 1987; COLE *et alii*, 1993; GIORDANO, 1998).

The post caldera activity includes almost five major median volume ignimbrites (1-4 km^3; D.R.E.), characterized by fall surge deposits, ignimbrite flow units and by syn-eruption deposits related to the immediate reworking of the unit during and inmediately after each eruption.

LITHOLOGICAL CHARACTERISTICS AND GEOMETRY OF THE SYN-ERUPTION AND INTER-ERUPTION DEPOSITS

Each syn-eruption lahar deposit associated with the five ignimbrite units of the Piana del Riardo Synthem is monogenetic in that derive entirely from the ignimbrite's components (ash, pumice, crystals and lithics) and shows significant lateral facies variation according to the paleotopography. The ignimbrites are made of several cubic kilometres of loose pumice and lava lithic debris emplaced along the hyperbolic slope of the volcano.

The lahar deposits are organized in a coarsening-upward, aggradational, and back-stepping succession of medium- to thickly bedded, progressively juvenile-poorer, non-cohesive debris-flow to fluvial deposits.

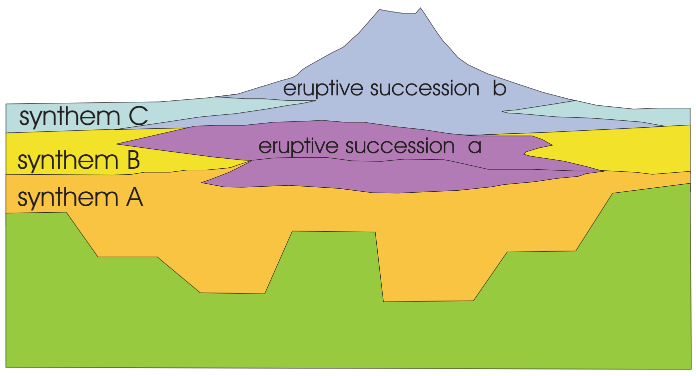
The WTT-Cupa-related lahar deposits offer a good example of how volcaniclastic deposits relate to their primary volcanic deposit along the slope of the volcano.

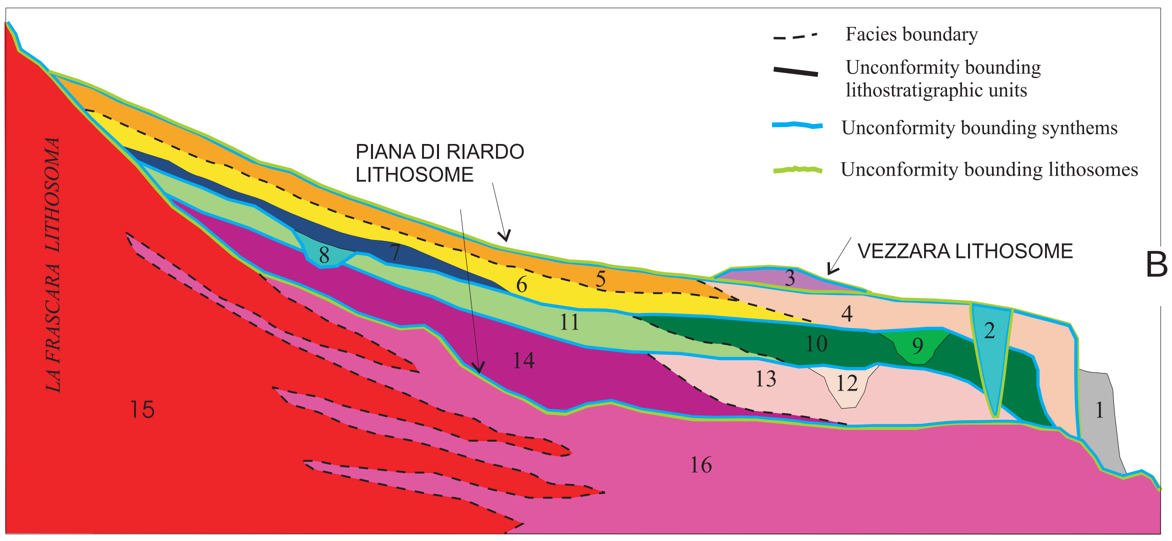
In proximal facies, along the steep upper slopes of the volcano (logs A and B in Fig. 6), several cross-cutting, box-shaped channels cut the ignimbrites (Fig. 7). Channels are filled with sand to cobble-size, lava lithic-rich well sorted deposits which can be interpreted as fluvial and hyperconcentrated-flow sand and conglomerate. They represent lag deposits related to processes of bulking due to the removal of light pumice and ash debris from the upper slope.

Along the middle slopes, where the average inclination decreases to few degrees (logs C and D in Fig. 6) the ignimbrites are cut by low relief erosion surfaces. The volcaniclastic deposits that onlap this erosion surface form a coarsening upward succession whose lower part is made of tabular, purely aggradational medium bedded ash and pumice-rich sand and silt deposits (Fig. 8). Density and water-escape structures are common (Figs. 9 and 10). Upward, the succession becomes progressively coarser, with increasing presence of well-sorted conglomerate lenses and sheets, interbedded with and cut with-in aggradational ash rich deposits of the underlying facies (Figs. 11 and 12). The juvenile component decreases to less than 50% of the deposit. The deposits of the lower part of the medial facies succession are mainly emplaced by hyperconcentrated flows to non-cohesive debris flows, whereas the deposit of the upper part of the succession suggests the occurrence through time of highly energetic flood events.

VOLCANIC ACTIVITY	PRODUCTS AND LANDFORMS	UNCONFORMITY BOUNDARIES	UNCONFORMITY BOUNDED STRATIGRAPHIC UNITS
Eruptive pulse (seconds to minutes). Times interval Q between phases geologically insignificant; Q; Q; Eruptive phase (minutes,hours, days); ERUPTION (days,month, years)	Association of : Airfall, Pyroclastic flows, Lahars, Lava flows	Unconformity surfaces, amalgamation surfaces, by-pass or non depositional surfaces. Soils, erosional surfaces corresponding laterally to deposits	ERUPTIVE UNIT
Time interval Q between eruptions of significant duration for soils or erosional breaks to occur; Q; Q; Eruption; ERUPTIVE EPOCH (tens, hundreds or thousands of years)	Association of products. Volcanoes or parts of a volcano	Base and top of a volcanic sequence, soils, caldera collapse, sector collapse or surfaces that can be traced laterally into significant unconformities of the sorrounding sedimentary environment	ERUPTIVE SUCCESSION. LITHOSOMA
Time interval Q sufficient for tectonic events to occur; Q; Eruptive epoch; ERUPTIVE PERIOD (thousands to millions of years)	Volcanoes, volcanic complexes		VOLCANO, VOLCANIC DISTRICT

A





B

Fig. 5 - A) *Stratigraphical relationship between UBSU and volcanic units and organization of the volcanic products. Following the indication of* FISHER & SCHMINCKE *(1984; first and second columns to the left) we propose to name eruptive units those deposits limited by unconformity surfaces, such as soils, erosional surfaces corresponding laterally to deposits ecc., indicating significative breaks during the activity of a volcano a generally limiting an eruption. Lithosoma corresponds to the Eruptive succession of* FISHER & SCHMINCKE *(1984) and includes units deposited during longer periods of the volcano history usually closed by caldera collapses or modification of the chemical-petrographic composition of the products. The small scheme shows that regional unconformities limiting Synthem may not influence the evolution of the volcano, whereas significative discontinuity in the history of the volcano may not coincide with regional unconformities. For these reasons we suggest to use a different nomenclature for the sytratigraphic organization of volcanic rocks. This has the advantage to evidence the evolution of the volcano in its regional contest.*

B) *Stratigraphic scheme of the southwestern area of Roccamonfina Volcano. The scheme evidences the geometrical and stratigraphical relationship between regional synthems, volcanic lithosomes and eruptive units. Numbers refer to the map legend. Lithosomes are bounded by two different in color lines when the basal unconformity has both regional and volcanic significance. In each eruption unit syneruption and inter-eruption deposits have been included.*

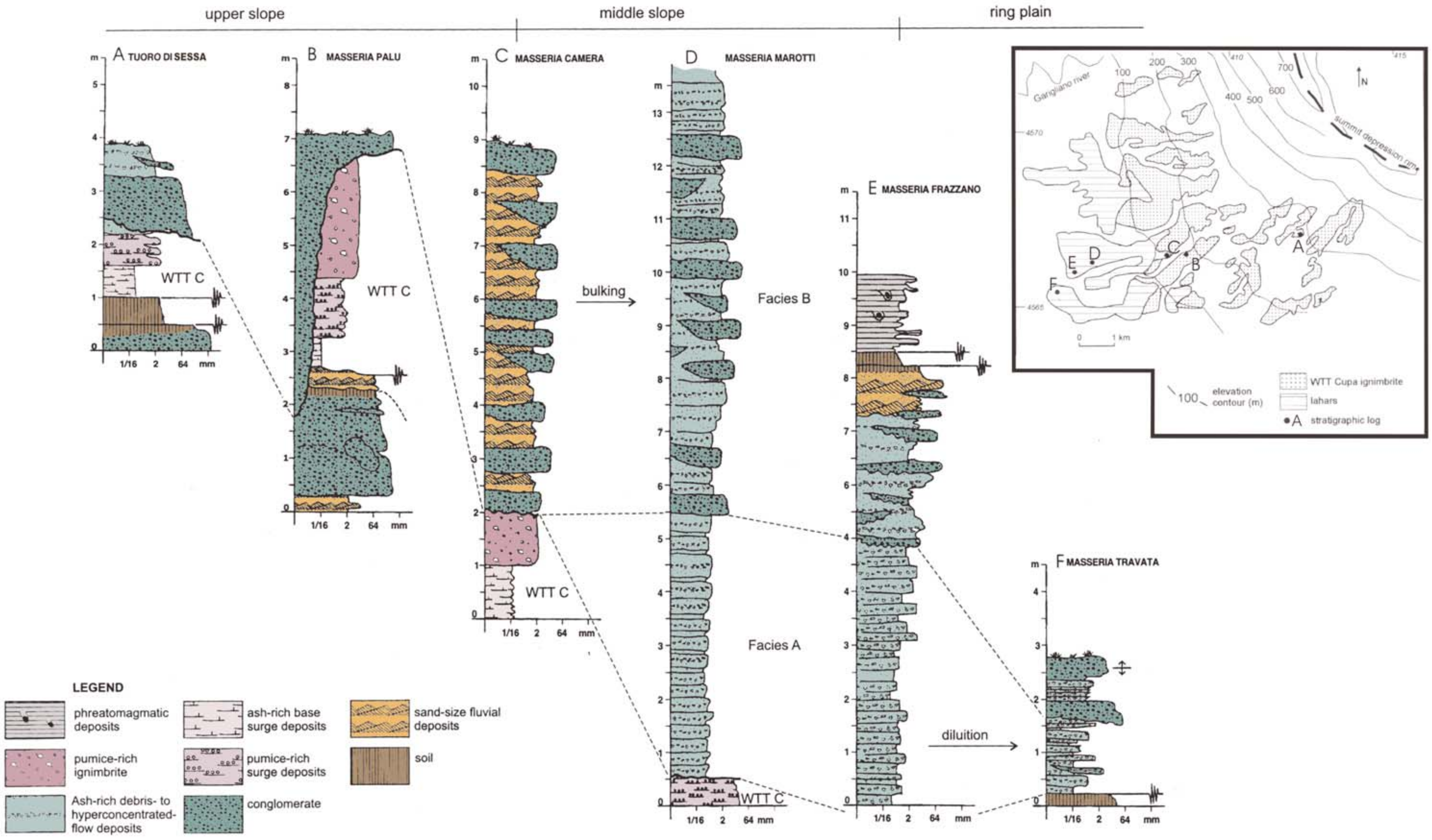


Fig. 6 - *Stratigraphic logs measured through the WTT-Cupa-related lahar deposits along the slope of Roccamonfina volcano. To show how syneruption and intereruption deposits relate to the ignimbrite deposit we use the example of the WTT-Cupa ignimbrite and its related lahar deposits. The stratigraphical logs have been measured at different locations along the slope of the volcano. Number refer to locations indicated in the small square (upper right). Syn-eruption and intereruption deposits have been distinguished on the base of their lothological characteristics and on their geometry. Along the upper slopes of the volcano volcaniclastic deposits mainly consist of fluvial and hyperconcentrated-flow conglomerate and sand deposits related to processes of bulking of still dilute lahars. Along the middle slopes, the volcaniclastic deposits form a coarsening-upward succession emplaced from hyperconcentrated flows to non-cohesive debris flows. Toward the top of the succession lithic-rich conglomerate lenses and ash and pumice-rich sand and silt beds suggest the occurrence through time of highly energetic flood events. In the open ring plain lahar deposits form a tabular aggradational roughly reverse graded beds deposited by a sequence of hyperconcentrated flow to fluvial events in a braided river flood plain environment (from* Giordano et alii, *2002).*

Fig. 7 - *Box shaped channels filled with lava-rich conglomerate and sand cutting the WTT-Cupa ignimbrite at proximal location (Tuoro di Sessa, log A of Fig. 6). The box shape of the channels suggests erosion by sediment-loaded, braided-stream flows (*Allen*, 1982).*

Along the lower slopes of the volcano in distal facies (Logs E and F of Fig. 6) and in the surrounding ring plains, where the morphology is almost flat, lahars emplaced an aggradational succession of bedded, ash-rich, hyperconcentrated-flow deposits entirely derived from the ignimbrite's components.

The succession coarsens upward with increasing presence of lava-rich conglomerate lenses, fluvial in origin, interpreted to record the progressive restoration through time of the drainage network. The vertical transition from the finer to the coarsen facies has been called the Facies A

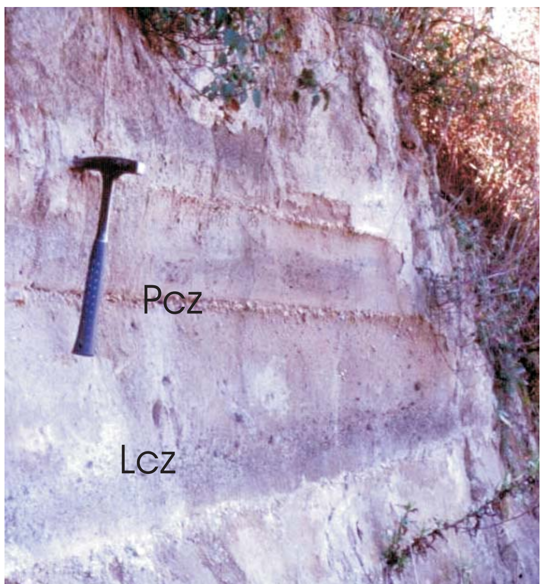


Fig. 8 - *Tabular aggradational succession of medium-bedded, juvenile rich deposits (Masseria Frazzano, log E of Fig. 6). Individual beds are coarse-tail graded with pumice concentration zones (pcz) developed at the top and lithic concentration zones (lcz) developed toward the base, above few centimeters of reversely graded beds.*

Fig. 9 - *Density structures developed between a lower ash-rich bed and the upper lithic-rich bed (Masseria Frazzano, log E of fig. 6). These type of structure generally characterize medial facies, along the middle slope of the volcano.*

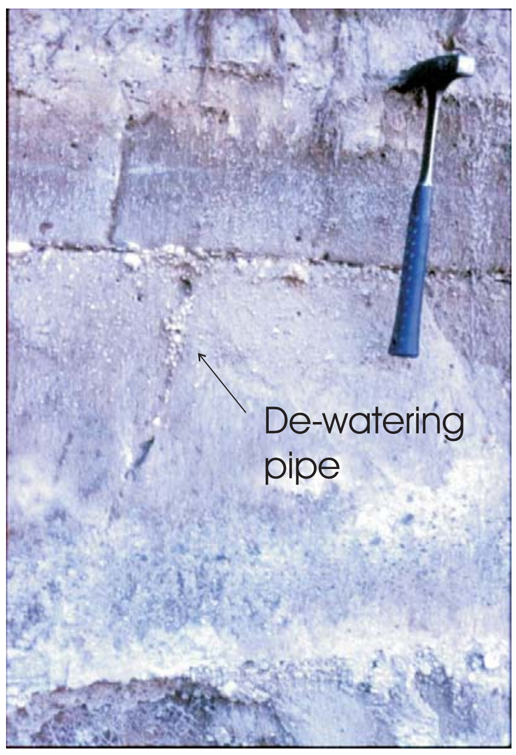


Fig. 10 - *Pipe-like de-watering structure filled with pumice lapilli (Masseria Frazzano, log E of Fig. 6).*

Fig. 11 - *Lithic rich conglomerate lenses inter-bedded with deposits of the facies A (Masseria Marotti, log D of Fig. 6).*

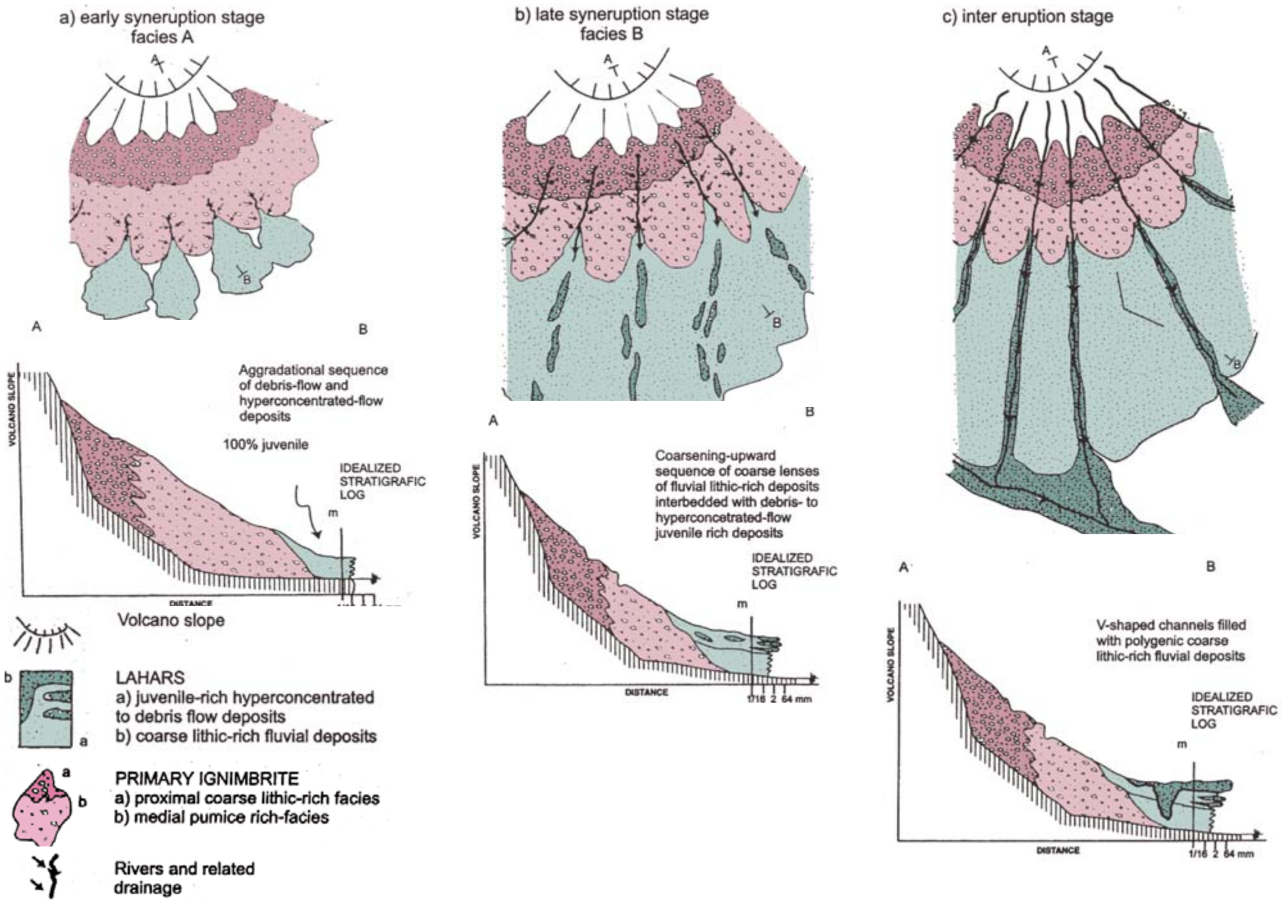


Fig. 13 - *Model for the generation and emplacement of rain-generated lahar at Roccamonfina. The model shows the evolution through time of the drainage system after the emplacment of the WTT-Cupa ignimbrite (300 ka). Climate during interglacial stage 9 (*SHACKLETON *et alii 1990) would be expected similar to the one experienced today in Central Italy, i.e. temperate, with seasonal abundant rains. During the early syn-eruption stage erosion starts at the distal end of the ignimbrite deposit producing fine-grained and juvenile rich, hyperconcentrated and debris flows. During the late syn-eruption stage the drainage network is progressively restored upslope and lahar deposits are interbedded with fluvial conglomerates. During the inter-eruption stage the restoration of the drainage network and the removal and redistribution of most of the pyroclastic debris allows the flowage of clean streams that re-incide the lahar deposits (from* GIORDANO *et alii, 2002).*

Fig. 12 - *Conglomerate lenses of facies B (Masseria Marotti, Log D of Fig. 6). Along the middle slope of the volcano, the succession becomes upward progressively coarser, with increasing presence of well-sorted conglomerate lenses. The conglomerate lenses are made of subangular to subrounded lava cobbles and pebbles. The juvenile component decreases to less than 50% of the deposit.*

/Facies B transition. The succession is cut by incised gullies filled with polygenetic fluvial deposits which indicate the restoration of inter-eruption condition.

The facies association shown by the WTT-Cupa-associated lahars allows to reconstruct an ideal evolution through time of the drainage system after eruptions similar to that of the WTT-Cupa (Fig. 13). Climate conditions would be similar to the one experienced today in Central Italy.

At the final phases of the eruption, erosion starts from the distal deposits of the ignimbrite and proceeds progressively more upslope. Early lahars are loaded of abundant fine-grained juvenile debris. The inferred mechanism of transport is through debris to hyperconcentrated flows. The ash-rich related deposits form a tabular and aggradational geometry. Several tens of lahar events may be possible.

Progressive reintegration of the drainage system are indicated by the occurrence of fluvial conglomerate and sands in the volcaniclastic suyuccession. The geometry is still aggradational.

The transition from syn-eruption to inter-eruption stage is marked by the abandon of the depositional surface which therefore became exposed to weatering to produce paleosol at the top of the succession.

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