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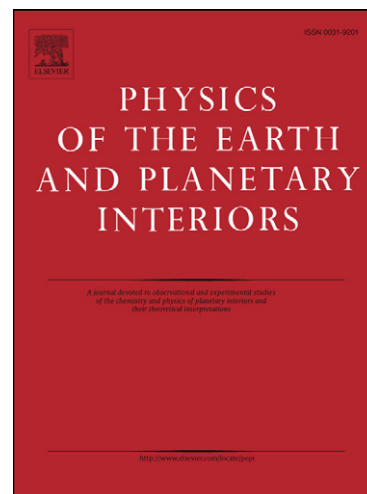
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2 **A multidisciplinary study of the volcanoclastic deposit named “Chiancone”,**
3 **inland and offshore, in the frame of the evolution of volcanism in the Etna area**

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6 **Abstract**

7 In this work a detailed study about the volcanoclastic deposit pyroclastic cone called Chiancone is carried out by 98
8 Vertical Electrical Soundings (VES) and by analysis of the surface morphology made by two Digital Elevation Model
9 (DEM) with high resolution. The results seem to confirm what has been suggested by other researchers and shed some
10 light on some dark aspects of this volcanoclastic deposit. In particular it was found that the Chiancone is quite a
11 complex geologic formation, whose deposition took place in several steps, filling in depressions of various conductive
12 substrate to depths of at least 300 m below the sea level. The conductive substrate generally shows a higher resistivity
13 than a clay one and is strongly tectonized and eroded. The multibeam surveys carried out offshore in the Ionian Sea,
14 allow us to identify the geolithological nature of the substrate, never before detected in the past. They show the existence
15 of an outcrop of a large cone-shaped submarine pyroclastic body, about 600 m deep, covered, near the coast, by
16 Chiancone deposits. The authors believe therefore that this pyroclastic body may form "inland" the conductive substrate
17 of the formations outcropping in the studied area (lava and Chiancone) and representing the product of the demolition
18 of one or more existing volcanic apparatuses prior to the Trifoglietto and Mongibello, which was given, in the past, the
19 name of Ancient Etna.

20 **Key words:** Mt. Etna; Chiancone; Morphology; Vertical Electrical Soundings.

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22
23 **1. Introduction**

24 In the past, Etna has been the subject of countless geophysical and geo-structural surveys and can be considered one of
25 the most studied volcanoes. It arose and grew along the eastern edge of Sicily, at the crossing point of two regional
26 tectonic structures (Fig. 1), which have aided magmatic migration within the crust and the formation of eruptive
27 apparatuses with a central rising axis, over a period of at least 150 ky B.P.. In this time interval several volcanic
28 edifices have developed, overlaying and juxtaposing on the ruins of previous ones. The deep geodynamic causes which
29 determined the successive periods of growth and demolition of the various eruptive apparatuses are still not clear, but
30 nonetheless the vast depressions called calderas represent the proof of a past dynamism, at times violent, in the Etna
31 area (Bousquet and Lanzafame, 2004; Branca et al., 2004). There were probably many types of phenomena which
32 caused the partial destruction of the various volcanoes and they developed over longer or shorter time frames. They
33 were followed by the removal in various different ways of the volcanoclastic deposit as well as its depositing in the

1 eastern sector of Etna. The volcanoclastics formed several fans of which the best known and most studied, in that they
2 still outcrop, are those called Chiancone (CH). This is a formation mostly constituted of an alluvial fan-shaped body
3 made up of debris flows and fluvial deposits, with differing degrees of compactedness, which occupy an area of about
4 25 km² according to Kieffer (1985) or about 40 km² according to Calvari and Groppelli (1996). The CH has a maximum
5 outcrop thickness of 30 m which can be seen along the Ionian coast (Olmo cliff) and a general slope of 3-4° eastwards.
6 The various calculations of its real volume and its extension are still under way and are based on data which are
7 sometimes unpublished hydrogeological surveys searching for water, and various types of onshore and offshore
8 geophysical surveys. The study of this geoformation is of notable scientific importance to explain the origin and
9 evolution of the Valle del Bove, an ancient collapse depression formed following the destruction of various alkaline
10 centres which existed before the Mongibello (AA VV, 1979).

11 According to Kieffer (1985) there are 4 opening phases of the Valle del Bove; the first two happened about 50 ky B.P.
12 and 35 ky B.P. and the lahars situated in the Macchia stream between Milo and Moscarello can be attributed to them.
13 According to Duncan et al. (1984), Guest et al., (1984), Chester et al., (1987), these lahars are probably associated with
14 the lower tephra (AA VV, 1979), dated around 26-20 ky B.P. and linked to the first event of the Valle del Bove
15 opening. The formation of the Chiancone in a strict sense, is instead associated to the last two phases which occurred in
16 the time frames 14-10 ky B.P. and 8-3 ky B.P.. Calvari and Groppelli (1996) hold that the Chiancone was deposited
17 during the life-span of the Ellittico volcano (40-15 ky B.P.) and so, the first event of the opening of the Valle del Bove
18 was much older than 5 ky B.P. as proposed by Romano (1982), Cortese et al. (1988). In this work the authors studied
19 the three-dimensional geostructural set-up of the pyroclastic body which crop out at medium-low altitudes of the eastern
20 sector of Etna by studying the interpretation of 98 Vertical Electrical Soundings. This sector has been analysed in the
21 past by other researchers using various other geological and geophysical methodologies. The analysis carried out with
22 geo-electrics shows the existence under the CH of a conductive body which, in the past, researchers attributed to
23 sedimentary rocks. The interpretation of the apparent resistivity curves and the geostructural surveys suggest that this
24 conductor emerges in the southern zone of the area under study and is dislocated by various faults and should instead be
25 associated to some pyroclastic formations mostly cropping out along the surface of fault between Acireale and S. Tecla.
26 The authors hold that this pyroclastic formation, older than the CH, might have been produced by the demolition of the
27 volcanic apparatuses which pre-existed the Ancient Alkaline Centres and the Trifoglietto, in agreement with Kieffer
28 (1985).

29

30 **2. Tectonic and geomorphological features.**

31 On the lower eastern side of Etna the largest volcanoclastic sequence in this sector of Sicily is exposed, whose geo-
32 lithological and structural evolution is directly linked to the dynamism of the volcanism and tectonics. This deposit,
33 mainly made up of volcanoclasts, which are called the Chiancone (CH), was deposited in a large depression generated at
34 the meeting point of two huge structures on a regional scale, oriented NNE-SSW (Messina-Giardini fault system) and
35 NNW-SSE (Ibleo-Maltese escarpment) (Fig. 1), (Cristofolini et al., 1979; Lentini, 1982; Monaco et al., 1995;
36 Lanzafame et al., 1996). It lies in an area bordered on the South by the S. Tecla fault oriented NW-SE (Fig. 2, faults a)
37 and to the North by the Macchia-Riposto fault (Fig. 2, fault i) oriented NE-SW, which are two seismically very active
38 volcanic-tectonic structures (Patanè and Imposà, 1995; Montalto et al., 1996; La Delfa et al., 2007). Moreover the CH is

1 cut across by various faults oriented NNW-SSE named the Timpe Fault System (TFS) (Fig. 2, faults c,d,e,f,l,m,n,p,q)
2 considered to be the inland extension of the Ibleo-Maltese escarpment; the TFS to the North shows mostly fragile type
3 deformations and also creep to the South (Stewart et al., 1993 a b; La Delfa et al., 2007). Along the southern edge of the
4 CH, a fault outcrops oriented NE-SW (Fig. 2, b) which has been historically active (Patanè and Imposa, 1995), but does
5 not appear on the geological map of Etna (AA.VV., 1979). On the Northern side two larger mesoseismic areas have
6 been found (Fig. 2, r,s) (Baratta, 1901), whose seismic-genetic axes are linked, respectively, to a non-outcropping
7 structure oriented roughly E-W (Fig. 2, g) and to the Macchia-Riposto fault (Fig. 2, i); this latter is shown by the
8 alignment of morphological escarpments, by the unusual orientation of a lava flow and by checking the flow direction,
9 roughly NE-SW, of the Macchia torrent (Fig. 2, i; Fig. 3). Finally, the NE extremity of the CH shows two
10 morphological lineaments oriented NNW-SSE and NNE-SSW (Fig. 2, h,o), formed by small escarpments and by
11 sudden changes in the streams aligned along the two above-mentioned directions. From a geological and genetic point
12 of view Rittmann (1973), McGuire (1982), and Romano (1982), considered the CH to have been formed by mud flows
13 associated with phreatomagmatic or phreatic explosive activity. According to Kieffer (1969, 1970, 1985), the CH is
14 mainly an alluvial deposit located on the top of mud flows; Di Grande and Di Maggio (1988) describe this formation as
15 an alluvial deposit more or less compacted and stratified. Guest et al. (1984) and Borgia et al. (1992), consider this
16 deposit as the product of erosion and landslides or dyke intrusion and lava overload which generate gravitational
17 instability, respectively. Along the Northern edge of the CH, the most ancient volcanics which outcrop are the lavas of
18 the Ancient Alkalic Centres (AAC) which lie under the lower tuffs correlated to the Trifoglietto (AA.VV., 1979), the
19 lavas of the Ancient Mongibello (Ellittico), the pyroclasts of the CH and the historical lavas (Fig. 3). To the West,
20 along the Northern edge of the Moscarello fault (Fig. 2, c; Fig 3), the Trifoglietto Unit lavas outcrop, which lie under
21 the pyroclasts of the Ancient and Recent Mongibello, the CH and historical lavas (Fig. 3). To the South between
22 S.Venerina and S.Tecla there are mostly outcrops of the Recent Mongibello and the historical lavas. Only along the S.
23 Tecla fault (Fig. 2, a) and along the escarpment East of Acireale, do the lavas associated with the AAC outcrop again.
24 On top of these latter lie the lavas, the lower tuffs and lahars of the Trifoglietto Unit (AA.VV., 1979), which are covered
25 on the top of the Recent and historical lavas of the Mongibello (Fig. 3). In the Digital Elevation Model (DEM) shown in
26 figure 4, two morphologically different zones can be distinguished which have been indicated as A and B. Zone A is
27 included in a triangular area whose corners are at the town of S. Venerina in the West and, in the East at two points
28 corresponding to the mouth of the Fago stream and at the southern-most tip of the town of Torre Archirafi, respectively.
29 This area is particularly disturbed by faults oriented NNW-SSE which outline Graben structures (Fig. 2: faults c and d, e
30 and f) and Horsts (Fig. 2: faults d and e) and is affected by various lava flows from the Recent Mongibello (Fig. 3). To
31 the East instead, there are some morphological structures, which have been described as a result of faulting, like the
32 sudden change in direction of the talweg of the Fago stream (Fig. 2, fault l; Fig. 4) and the escarpment at Praiola (Fig. 2,
33 fault m). Furthermore, Zone A has a hydrographic network made up of a few sub parallel streams oriented mostly
34 WNW-ESE. The talwegs show several interruptions in their stream probably caused by tectonic disturbances and the
35 various rectilinear stretches of drainage are often less than 2 km long. The water courses break off suddenly to the
36 WNW cut off by the TFS, or near a stream oriented about E-W, which crosses the whole CH and flows out north of
37 Priola Piccola (Fig. 4). Slightly further north, oriented almost E-W, a watershed separates the drainage lines of Zone A
38 from those of Zone B, which is also triangular in shape (Fig. 4). In this latter zone there are many more small water
39 courses which fan out and are generally oriented from WSW to ENE. In the eastern zone of Zone B, some stretches of
40 drainage are often rectilinear, short, oriented E-W, WNW-ESE and NE-SW and are probably associated to tectonic

1 structures oriented in the same directions. Along the coast, between Torre Archirafi and Riposto, the mouths of the
2 various water courses are at sea level. However, about 300 metres south of Praiola, the easternmost tip of the talweg of
3 a perched stream is at a height of 8 m a.s.l.. The largest value for this difference in height is about 20 m in a perched
4 stream located not far from Praiola Piccola, where the Olmo cliff (Fig. 3) is at its highest. Further north the difference
5 in height of another perched stream reduces and reaches a height of about 8 m. According to Del Negro and Napoli
6 (2002) the settling of the CH took place in two different events. In the first one the volcanoclastic deposit filled the
7 trough south of a morphologic sedimentary high. In the second period, the volcanoclastic deposit filled another trough
8 located north of this morphologic high where it reached its maximum thickness (Fig. 4, B Zone).

9 **3. Lithological features of the Chiancone**

10 Various detailed surveys have been carried out on the granulometry of the volcanoclasts, on the means of transportation
11 and on the ages of some volcanoclastic deposits of the CH, through radiocarbon analysis (Kieffer,1985; Chester et al.,
12 1987; Calvari and Gropelli,1996; Calvari et al., 2004).

13 Kieffer (1985) distinguishes between three main facies in the section of the Olmo cliff which runs along the Ionian Sea
14 coast (Fig. 3):

- 15 - a basal conglomerate (facies 1a) formed by little blunt lava blocks more than 1 m³ in size, immersed in an
16 abundant and compact reddish-brown matrix; this lithological facies which is considered as a layering of
17 different lahars, emerges for a few metres above sea level between Riposto and Torre Archirafi, and even
18 reaches a thickness of 3 metres to the south of this second town; 1 km south of Torre Archirafi it dips
19 progressively below the overlying layer and re-emerges north of Praiola afterwards;
- 20 - over this lies a conglomerate (facies 2a) made up of heterometrical lithological elements (from a few
21 centimetres to several metres in diameter), well blunt and immersed in an abundant matrix made up of
22 yellowish ash; this outcrops mainly south of Torre Archirafi as far as Praiola, and its thickness varies from 15
23 to 20 m and has a fluvial type of stratification;
- 24 - on the roof of this second facies lies a darker conglomerate (facies 3a) made up of black and grey but rarely
25 yellowish volcanic ashes, which contain mainly rounded pebbles of different sizes from a few centimetres to a
26 few decimetres and, sometimes, there are also some big blocks. This is formed by numerous stratified fluvial
27 deposits and is 10 m thick, 1 km north of Praiola; it is considered the result of the demolition and the
28 subsequent deposition of the underlying formation which, to the West, crop out at higher elevations.

29
30 Calvari and Gropelli (1996) have studied the CH sequence in detail from the stratigraphic, sedimentological and
31 petrographic points of view and have distinguished between 5 lithofacies: basal mud flow (lithofacies 1), debris flows
32 (lithofacies 2a), fluvial floods (lithofacies 2b), fluvial clast coarse grained (lithofacies 3), fluvial sand, silt, clay fine
33 grained and scattered lava clast (lithofacies 4), and pyroclastic fall and flow (lithofacies 5). The lithofacies 1 and 2a, the
34 lithofacies 2b and 3, the lithofacies 4 and 5, correspond respectively to the first, second and third facies proposed by
35 Kieffer (1985). Overall, if the thicknesses of the various layers are considered, the basal mud flow is only 5% of the
36 exposed lithologies. However this lithofacies, even though it outcrops discontinuously along the Olmo cliff, shows a
37 much greater thickness than the overlying ones, as the results of the geo-electric survey illustrated in paragraph 5 show.

38

1

2

3 4. Vertical Electrical Soundings

4 To obtain a detailed definition of the relationships between the various types of volcanic products and the sedimentary
5 basement, some geo-electric surveys and original sampling carried out in the Chiancone area by some geophysics
6 companies like the C.G.G., the C.M.P., the Universities of Catania, Milan and Palermo and Milan's Geolab,
7 respectively, were taken into consideration. Overall the apparent resistivity curves of 98 Vertical Electrical Soundings
8 (VES) were analysed, which cover almost uniformly the area under study (Fig. 5). The VES were carried out using the
9 classic type of electrode configuration as proposed by Schlumberger, with a maximum distance between current
10 electrodes of 4000 meters. These soundings were performed after considering the morphology, geology and structural
11 lineaments of the area to minimize the effects due to strong lateral variation of resistivity, as well as to respect the
12 theoretical geometry configuration of the assemblage. The apparent resistivity curves have been grouped according to
13 the classification criteria of Hummell (1929) into six types, referred to as K, HK, KQ, QQ, KQQ and KHAK (Fig. 6,a).
14 Their features are typically those found in the Etna area and correspond to layers of more or less high resistivity, i.e.
15 volcanic products, superimposed on a conductive layer generally identified as sedimentary basement. The apparent
16 resistivity data were processed to obtain single-dimensional models (1D) of the real resistivity distribution and thickness
17 of each VES using Marquardt's (1963) analytical technique. It consists of generating the best fit of experimental values
18 of apparent resistivity, thus giving a theoretical curve to which the best model of electric layers with various resistivity
19 and thickness are associated (Fig. 6,b). Equivalent models are calculated through the theorem of constant transversal
20 resistivity within the limits defined by the theoretical curve and that of the apparent resistivity. The resistivity anomalies
21 found in the experimental curve were then eliminated as they could mistakenly be interpreted as layers but which do not
22 actually exist. This was done through calculations of a matrix of coefficients, resulting from a combination of resistivity
23 and thickness. This procedure leads to a considerable reduction of error for the thickness, and makes possible a
24 comparison between the electrical and geological stratigraphy. In the area under study the lavas represent the least
25 common lithotype, while strong layers of both primary pyroclastic deposits and reworked volcanoclastics outcrop.

26 The resistivity of the lavas varies according to the degree of alteration, fracturing, porosity and the presence or absence
27 of water. The pyroclastic and volcanoclastic deposits show differing resistivities according to their granulometry (from
28 1 mm to a few metres or more), to their mineralogical make-up, to the degree of alteration and of humidity. The huge
29 variability both laterally and in depth of the physio-chemical conditions of the two lithotypes in the sites where the VES
30 were carried out, influenced the values of resistivity derived from the interpretation of the experimental electrical
31 curves. To correlate the various lithotypes to different classes of resistivity, a cumulative curve was preferred which
32 expresses as a percentage the number of times the resistivity values were measured (Fig. 7). Basically the curve shows 4
33 classes of values and the relative frequency percentage: $\rho \geq 1200$ ohm m, $1200 > \rho \geq 320$ ohm m, $320 > \rho \geq 140$
34 ohm m, $\rho < 140$ ohm m. The first one ($\rho \geq 1200$ ohm m), shows quite a low frequency percentage, and has higher
35 values for compact and/or fractured, porous lavas with low humidity; these are generally Recent Mongibello lavas. The
36 average and low resistivity values are associated instead with Recent or Ancient Mongibello lavas which are deeper,
37 altered and more humid. The second class of values ($1200 > \rho \geq 320$ ohm m), is found in the most superficial zone of
38 the CH. The highest values of resistivity are attributed to the presence of lava blocks bigger than 1 m^3 , very frequent,
39 immersed in a fine grain matrix. The lowest values are associated to a fine grain matrix, mostly on larger lithological

1 elements with a higher degree of humidity. This class of resistivity thus corresponds to the second facies proposed by
2 Kieffer (1985). The third class of resistivity ($320 > \rho \geq 140$ ohm m), is mostly associated to the deepest layer of the CH,
3 where there are abundant fine grain volcaniclasts with high humidity. This class corresponds to the first facies of
4 Kieffer (1985) and of Calvari and Groppelli (1996), less superficial, which discontinuously outcrops along the Olmo
5 cliff. However the interval of resistivity of the third class can also correspond to the more superficial layers of ash fall
6 and reshuffled volcaniclasts which correspond to Kieffer's third facies (1985). Finally, the fourth class of resistivity (ρ
7 < 140 ohm m), is associated to a deeper conductive formation (Table I) which, according to some researchers,
8 corresponds to sedimentary rocks like, for example, clay (Del Negro and Napoli, 2002). The correspondence between
9 the various classes of resistivity and the above-mentioned lithofacies was obtained by means of carrying out calibration
10 VES readings near boreholes up to 300 m deep, of which there are many in the area under study and of which the
11 detailed stratigraphy is well-known. VES readings taken near faults and deep incisions in the Chiancone and the
12 surrounding area were also taken into account. Here there is a clear stratigraphy of the Chiancone which was used to
13 calibrate and correlate correctly the resistivity parameter with the various lithofacies. Moreover, the optimal area
14 distribution of the VES, which take readings in numerous geologically significant points, makes the extrapolation of the
15 relationships between lithofacies and classes of resistivity to the whole area under study reliable. The methodology
16 used is the most common and the most appropriate one for exploring the geolithological features of an area, in this case
17 the Chiancone, using the results of the apparent resistivity soundings *in situ*. Obviously the transfer of the geo-electrical
18 information to the various lithological and structural aspects of the area under study was carried out also bearing in
19 mind the relationships of the overlapping and juxtaposition of the different outcropping geological formations, and that
20 the various classes of resistivity have been recognised in volcanic formations other than that of the Chiancone, as can
21 be seen from the geological map of Mount Etna (AA. VV. 1979) and other detailed scientific studies.

24 5. Analysis of the results

25 To further analyse the geometric relationships which exist between the various classes of resistivity and thus, the
26 relationships of overlaying and juxtaposition of the lithofacies associated to these classes, the spatial trend of resistivity
27 and thicknesses relative to the 73 VES was represented through five profiles. Four mostly cut the CH in a NNE-SSW
28 (A,B,C) and ENE-WSW direction (D), the fifth (E) in direction NNE-SSW cuts across the S.Tecla fault and only
29 marginally includes the CH (Fig. 5). Along profile A (Fig. 8), the CH is mostly represented by the 3rd class of
30 resistivity values which lies directly on the conductive substratum (4th class). Proceeding from the SSW to the NNE, in
31 the first half of the profile, the 1st class, attributed to the lavas, lies directly on the conductive substratum or on the 3rd
32 class of resistivity. It is on this latter, in the second half of the profile, that the CH terrains attributed to the 2nd class
33 mostly lie, but they are not very thick, generally less than 40 metres. The trend of the roof of the conductive substratum
34 (4th class) is very variable and shows a sharp downward dislocation towards the NNE of the profile. In profile B (Fig.
35 8), oriented like the previous one, the 3rd and 4th classes show the same overlapping observed in profile A. In the
36 second half of the profile, towards the NNE, the 4th class (conductive substratum) is noticeably dislocated downwards
37 and its roof reaches a depth of 160 m b.s.l.. The roof of the 3rd class however, stays above sea level and on it lie the
38 electrostrata belonging to the other three classes of resistivity. The 2nd class is more frequent and shows thicker

1 electrostata compared to those of profile A. The northernmost tip of profile C (VES 1-9; Fig. 8) includes the remains of
2 an ancient volcanic apparatus located north of Macchia (Cristofolini et al. 1982) made up of alternating lavas and
3 pyroclasts (1st, 2nd and 3rd classes of resistivity) which lie on the conductive (4th resistivity class) most probably formed
4 by sedimentary terrains. The roof of the conductive dips down towards the SSW to a depth of about 400 m b.s.l.. This
5 depth varies a lot and remains below sea level at the town of S. Venerina (Fig. 8), where the zone of lava invasion starts
6 (Fig. 3). To the South, the conductive rises above sea level. The 3rd class of resistivity, associated with the deepest
7 facies of the CH, shows a greater thickness along the tract of the profile between Macchia and S. Venerina (VES 10-
8 22), to the SSW of VES22, the thickness of the electrostratum relative to this class is notably reduced and in many VES
9 results does not appear. The CH terrains associated to the 2nd class are more frequent and, in many VES, are thicker than
10 those found in profiles A and B, when they lie directly on the conductive stratum. Profile D (Fig. 8), goes from WSW to
11 ENE and its conductive substratum has a very variable depth. Between the two classes of resistivity associated with the
12 CH, the most common is the 3rd, while the 2nd narrows noticeable from west to east. The lavas, 1st class, sporadically
13 appear at the WSW tip of the profile. Lastly, profile E cuts across the S. Tecla fault (Fig. 8). NE of this structural
14 discontinuity the 1st, 2nd, 3rd and 4th classes of resistivity become prevalent, the latter of these classes outcrops at the
15 base of the escarpment of the above mentioned fault. To the SW again the three above mentioned classes prevail
16 showing, however, much greater thicknesses. The 3rd class is less frequent and along with the 2nd class are probably
17 associable to different pyroclasts from those outcropping in the CH, ascribable to the Trifoglietto (AA. VV., 1979).

18 After having correlated the four classes of resistivity to the lithological facies along these profiles, the relationship
19 which exists between these latter in three-dimensional space was studied. For this the VES results not yet included,
20 because they were too far from the previously analysed five profiles, were taken into consideration. Later three 2D and
21 3D sketches were reconstructed (Fig. 9:1,2,3). In particular the figure 9:1 shows the surface morphology of the studied
22 area in which lavas and Kieffer's 2nd and 3rd facies outcrop (Kieffer, 1985); the deepest level of the CH (Kieffer's 1st
23 facies, 1985) and the basal conductive formation are respectively shown on figure 9:2,3. Moreover, on both the 2D and
24 the 3D sketches, the outcropping and two buried active faults linked to the 18-19 July 1865, 27 July 1979 (Baratta,
25 1901), earthquakes and the morphological alignments are shown (see also Fig. 2). The 3D sketch in figure 9 clearly
26 shows that the flow of the pyroclasts and lavas happened along two main directions indicated by the grey arrows (Fig.
27 9:1). The morphological trend of the surface of the deepest layer of the CH (Fig. 9:2), mirrors that of the surface
28 topography and so the flow of pyroclasts associated to this facies follows that of the lithofacies nearer the surface. This
29 movement seems to be conditioned by the unique morphology of the conductive substratum which shows some quite
30 deep depressions west of Torre Archirafi and of Pozzillo, separated by a watershed oriented roughly E-W located
31 slightly north of Pozzillo (Fig. 9:3,H). These depressions were filled by the deepest facies of the CH which climb over
32 the morpho-tectonic steps near and under the present day coastline (Fig 9:3) pouring out into the Ionian Sea. Overall,
33 there is a total inversion of the morphological relief and a complete masking of the morphology of the conductive
34 substratum. A detailed analysis of the relationship of the overlaying and juxtaposition between the four electrostrata was
35 carried out considering seven sections: four are oriented in a roughly N-S direction (Fig. 9:2,3; Fig.10,A,B,C,D) and
36 three in a roughly E-W direction (Fig. 9:2,3; Fig.10,E,F,G). The traces of these sections were also transferred to
37 geological maps (Fig.3) so as to correlate spatially the various electrostratigraphs and the corresponding outcropping
38 volcanological formations. The lavas (1st class of resistivity) are in the southern zone (Fig. 3; Fig. 10,B,C,D) and the
39 western one (Fig. 3; Fig. 10,E,F,G) of the area under study, lying mostly on the CH and at times on the conductive
40 substratum; these become thicker towards the W and generally fill the morphological lows. The stratigraphic sequences

1 revealed in the three wells located respectively at S.Venerina (350 m a.s.l.), 1 km to the SW and 2 Km SE of the same
2 location, are in accordance with the interpretation of the VES, clearly show that the lava covering is generally thin, little
3 more than 80 metres thick, and that below it the CH extends down for at least another 60 metres. The facies of the CH,
4 made up of fine grain, large volcaniclasts (2nd class of resistivity), becomes ever thicker (from a few tens to a hundred
5 or so metres) from East to West and mostly outcrops in the area under study and along the coast (Olmo cliff). It is often
6 dislocated by faults as shown in the various sections of figure 10. The deepest facies of the CH (3rd class of resistivity),
7 where there are abundant fine grain volcaniclasts, shows very variable thicknesses due to the very uneven morphology
8 of the conductive substratum. This facies reaches up to 400 metres thick west of Torre Archirafi (Fig. 10,B), and is full
9 of morphological lows and narrows from N to S. It is dislocated by most of the faults found on the surface (continuous
10 lines) and by others which do not crop out (dashed line) hypothesized on the basis of the rather complex trend of the
11 two surfaces which distinguish its top and bottom (Fig. 10). At the Olmo cliff it outcrops discontinuously with a
12 thickness of a few metres and (Kieffer, 1985; Calvari and Gropelli, 1996). Finally, the conductive substratum (4th class
13 of resistivity) shows a rather rough surface formed by horsts, with very steep walls and grabens that are at times deep
14 and narrow. This morphology, in our opinion, was determined by intense erosion, which has operated over a long time
15 period, modelling it together with the volcani-tectonic activity in this area. The conductive substratum rises up again
16 near the North of Torre Archirafi, Praiola North forming morpho-structural steps (Fig. 10,E,F) and outcrops near
17 S.Tecla dislocated by a fault (Fig. 9:3, fault b; Fig.10,B, fault b). Quite a deep excavation carried out in this latter
18 location showed the presence of a very fine grain, dark red pyroclastic formation, (dark red because it is very oxidized),
19 with a resistivity of less than 140 ohm m associable to the conductive substratum of an indefinite thickness, at least in
20 this area. In accordance with Del Negro and Napoli (2001), under the less thick CH, to the NW of Pozzillo and near
21 S.Venerina (Fig. 10,B,C,D), the substratum rises up again. This latter, according to the two researchers, should be
22 formed by clay. In our opinion, instead, it may be formed by the above-mentioned pyroclastic formation with low
23 resistivity, represented by the 4th class which extends towards the North.

24

25 6. Conclusions

26 The detailed geo-lithological and electrical study of the volcanic formations (lavas and pyroclasts) cropping out in the
27 triangle formed by the towns of S.Tecla, S.Venerina and Giarre-Riposto, was fundamental to improving our knowledge
28 of the evolution of volcanism in the Etna area. The geo-lithological, sedimentological and textural analyses of the CH's
29 uppermost layers which crop out, clearly show that it was formed during successive episodes with various modes of
30 genesis and transport of the volcaniclasts (Kieffer, 1985; Calvari and Gropelli, 1996) and its formation required overall
31 a period of 40-50 ky. Del Negro and Napoli (2002), during an onshore magnetic soundings found a morphological
32 high, oriented E-W, of the sedimentary substratum. This high borders two troughs: the southern shallower one was
33 filled by the CH mostly masked by the Mongibello lavas, while the northern one, which is deeper, seems to have been
34 filled in later. The geoelectric soundings carried out in this study confirms what Del Negro and Napoli (2002) state.
35 However, it highlights that the conductive substratum (which is sedimentary according to Del Negro and Napoli, 2002)
36 shows a rather complex morphology determined by strong erosive processes and by frequent faulting, which give it ever
37 deeper horsts and grabens going from South to North (Fig. 10,B,C,D). Moreover the CH's surface morphological
38 characteristics analysed with a DEM show the existence of two zones A and B which are substantially different. Zone
39 A is affected by relatively few sub parallel streams where the water run-off was interrupted or drastically reduced due to

1 lava invasions uphill of these watercourses. The notable dynamics of the faults oriented NNW-SSE and the pyroclasts
2 deposited later further North, in area B, where the flow lines are more numerous, must have also played a determining
3 role: the dynamics of the faults contributed to deviating the water drainage, both the pyroclasts and the lava flows
4 partially invaded the hydrographic network of the valleys in Zone A, filling it up. This succession of events suggests
5 the hypothesis that the surface pyroclastic facies of the CH were laid down at different times, first in the South and later
6 in the North. A similar conclusion can be reached by observing that the eastern side of the Etna Caldera shows a breach
7 to the SE (AA.VV. 1979). It is indeed possible that the various pyroclastic flows were channelled through this opening
8 towards the SSE and were deposited first in Zone A, in front of the opening itself and later in Zone B. Moreover the
9 conductive substratum morphology, affected by various grabens North and South of the watershed H oriented ESE-
10 WNW (Fig 9:3) in our opinion, contributed to the above-mentioned depositing of the pyroclastic flows. Lastly, the
11 overlapping found between the body of Zone B and that of Zone A is highlighted by the geometry of the offshore
12 border between the two bodies (Fig.11), which seems to be further confirmation of what has been previously asserted.
13 The slower water run-off towards the sea, moreover, determined a reduction in erosion in Zone A, which is slowly
14 uplifting. So along the coast, between the mouth of the Fago stream and Praiola Piccola (Fig. 4) where the Olmo cliff
15 has quite a high wall, there are several talwegs of watercourses, perched at different heights above sea level. The drastic
16 reduction in erosion must have begun about $13,000 \pm 2,600$ years BP, if we consider the maximum difference in height
17 of 20 metres of one of the watercourses and an average uplift (rise) of 1.5 mm/year (between 1.0 and 2.1 mm/year
18 according to Monaco et al., 1995). According to Kieffer (1985) between 14,180 years (age determined by C^{14}) and
19 12,000/10,000 years BP, the Ellittico Crater was formed, the penultimate phase in the opening of the Valle del Bove
20 occurred together with the subsequent deposition of the outcropping lowest CH levels. The above mentioned time span
21 overlays, surprisingly, the one found during the drastic decreasing in the erosive phenomena. It is plausible, therefore,
22 that the different hydrographies of Zones A, B and to the South of the Fago stream were determined by a strong
23 volcanic-tectonic dynamism of Etna in this period. North of Praiola Piccola the coast becomes quite low, probably due
24 to the fact that the volcanic-tectonic phenomena, and subsidence caused by the great thickness of the CH, work against
25 the general uplifting of the area. A crucial point in this study was that of determining the geo-lithological nature of the
26 conductive substratum which is often considered a non-volcanic sedimentary deposit (Bousquet et al., 1998; Del Negro
27 and Napoli, 2002), probably clay. In all the geognostic surveys deeper than 200 m whose results are known to the
28 authors, no clay has ever been found, only pyroclasts. Moreover, the interpretation of the experimental curves of
29 apparent resistivity rarely give values around 2 ohm m or, however, very low ones typical of clays. In any case,
30 resistivity values lower than 10 ohm m can also be attributed to levels of fine grain pyroclasts, which are much altered
31 and/or very humid. An unhoped for solution to this problem comes from the offshore multibeam surveys, carried out
32 near the Ionian coast of Etna, within the "Campagna Oceanografica 1908, Progetto V36 Etna", in which researchers
33 from the Universities of Rome, Calabria, Palermo and Catania (INGV) took part and whose results were partially
34 published in a degree thesis written for the Department of Geological Science of the University of Catania (Cavallaro,
35 2005-2006). Figure 11 clearly shows that offshore there is a geological fan-shaped body, indicated as C, underlying the
36 CH and with a main flow axis independent of those indicated as *a* and *b* onshore. In the same zone, Del Negro and
37 Napoli (2002) found a volcanoclast body which they considered still part of the CH (Fig. 12). In particular the pyroclasts
38 in Zone B, to the South lie on the geological body C as can be seen from the reciprocal contact between the two
39 offshore formations. Instead to the North, again offshore, they cover the sedimentary rocks, partially filling a morpho-
40 tectonic depression oriented NE-SW (Riposto Canyon). The CH in Zone A and the lavas further south cover most of the

1 body C onshore. In our opinion, the pyroclasts of the body C are genetically different from those of the CH, because
2 they lie from a stratigraphical point of view under this latter and show a sharply lower resistivity, less than 140 ohm m.
3 Such a low value can be associated to a much altered pyroclastic formation, rich in fluids and probably, very old. This
4 latter statement is supported by the consideration that, onshore, the surface morphology of the body C, identified in this
5 study as the conductive basement, is very rough due to erosion and tectonic phenomena which have been operating for a
6 long time. Finally, the top of the conductive substratum found under the southern edge of Zone A (Fig. 9,H) and
7 situated slightly further north of Pozzillo, corresponds, in our opinion, to the top of the pyroclastic body C (Fig. 11). It
8 was this latter that guided the flow of the CH's volcanoclasts towards Zones B and A. To the South it also controlled the
9 flow of the lava towards S.Tecla. Offshore, the pyroclastic body C reached a depth of 500 m b.s.l. banking up against
10 the ancient underwater volcanic apparatus (Patanè et al., 2009). This bank can be seen in the differences in the sea-floor
11 morphology around the edges of bodies C and D (Fig. 11,D).

12 On the basis of these considerations, various conclusions can be drawn.

- 13 - In the CH's pyroclasts there are various lithological facies which were generated 50-40 Ky B.P., in particular
14 violent geodynamic manifestations of the volcano (various opening episodes of the Valle del Bove, strong
15 hydromagmatic, strombolian explosions, etc.).
- 16 - In various phases, the CH's volcanoclasts have occupied some Grabens of the pyroclastic body C, which is in
17 southern zone of the area studied (La Delfa et al., 2007). In the northern zone, a tectonic depression as deep as
18 400 m and oriented WNW-ESE (Fig. 9:3), accommodated most of the pyroclastic flows. The North face of this
19 ditch, towards Giarre-Riposto seems to be made up of non-volcanic sedimentary rocks, while the South face is
20 formed by the pyroclasts from the geological body C, as the offshore multibeam surveys show (Fig. 11).
- 21 - The CH's pyroclasts poured into the sea reaching a maximum depth of 100 m b.s.l. (surveys by the "Istituto
22 Idrografico della Marina", 1993), near Torre Archirafi, overcoming two morpho-tectonic steps: the
23 sedimentary one North of Torre Archirafi (Fig. 9:3; Fig. 10,E) and the pyroclastic one (body C), South of
24 Torre Archirafi, near Praiola Piccola (Fig. 4). In accordance with our results, Loddo et al. (1989) using deep
25 dipole measurements found a rise in the non-eruptive substratum in the same area along the coast.
- 26 - Considering the presence of morpho-structural steps near the coast and the different depth of the base of the
27 CH to the west (about 300 m, below the sea level) and to the east, off the coast line (at about 100 m below the
28 sea level) of these steps, the possibility that the impact of the mass of the detritus, although quite modest,
29 falling into the Ionian Sea may have caused a tsunami wave (Pareschi et al., 2006) big enough to affect the
30 central-eastern Mediterranean about 8 000 years B.P. is excluded, in our opinion. Indeed, as is known, the
31 CH's pyroclasts were deposited in various successive episodes, over quite a long time frame (40-50 ky) and
32 considering the particular morphology of the conductive substratum in the area under study, they mostly filled
33 the various existing depressions to the west of these steps, interacting only a bit with the waters of the Ionian
34 Sea.

35 Instead, in our opinion, what is much more interesting is the existence of the pyroclastic body C which extends out into
36 the Ionian as far as 5 km from the coast and which forms, onshore, most of the conductive substratum under the CH.
37 This latter, on the basis of the morpho-structural and geo-electrical analyses carried out, is completely distinct from the

1 underlying fan-shaped geological body indicated as C. The authors of this study hold that it may have had a similar
2 origin to the CH and that it is the product of the demolition of one or more eruptive apparatuses which pre-existed the
3 Trifoglietto volcano. In fact, according to Kieffer (1985) between 150,000 and 70,000 ky B.P. there was an “Etna
4 ancient” which evolved in two phases. During the first phase which lasted about 50 ky, a vast, quite flat apparatus built
5 up followed by its partial destruction, as a system of calderas formed. During the second phase, which lasted about 30
6 ky, a large new apparatus built up with much more explosive activity and later it was partially destroyed. Following this
7 violent activity many lahars were deposited on the eastern side of the volcano, outcropping along the Acireale and S.
8 Tecla Timpas due to very frequent uprising and faulting phenomena in the area under study. The lithotype outcropping
9 around S.Tecla (Fig. 5) and found also in profile E of figure 8 to the South of Pozzillo, with resistivity lower than 140
10 ohmm (4th class), seems mostly to be made up of these lahars. These make up the conductive substratum of the CH,
11 corresponding to the 4th class of resistivity ($\rho < 140$ ohmm). It is therefore possible that the fan-shaped structure found in
12 the Ionian Sea was formed between 100,000 and 70,000 ky B.P. from the product of the demolition of the "Etna
13 ancient". This time span also ties in with the dating carried out by Corsaro et al. (2002), on various pyroclastic bodies
14 outcropping in the Acireale and S. Tecla Timpa, which are aged between 125 and 65 ky B.P. Finally, the underwater
15 volcanic apparatus in front of the Ionian coast of Etna (Patanè et al. 2009) acted as a impediment to the pyroclasts flux
16 of the body C (Fig. 10; Fig. 11), which partially overlaid the western flank of this apparatus. Thus it is held that it may
17 be the same age the “Etna ancient” or that it may, however, be older than 100 ky B.P.

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3 **Figure captions**

4 **Fig. 1** - Sketch map of Sicily: the main regional structures are shown of the eastern edge of the island and the area of
5 Etnean volcanism (A); the inset A shows the studied area (in grey) and the location of the Chiancone (CH).

6 **Fig. 2** – Structural framework of eastern sector of Etna: **a,b,c,d,e,f,m,n,p,q** are dip-slip normal faults with a little strike-
7 slip movements; **l** is a strike-slip fault; **g** is a buried fault, linked to mesoseismic area **r** of 18-19th July 1865 earthquake,
8 **i** is Macchia-Riposto fault linked to mesoseismic area **s** of 27th July 1879 earthquake (Baratta, 1901); **h,o** lineament with
9 structural meanings. The Digital Elevation Model (DEM) 3D, has been made using a topographic map with 1:2000
10 scale.

11 **Fig. 3** – Geological sketch of the outcropping volcanic products, according to AA.VV. (1979): (1) lavas, tephra and
12 tuffaceous sediments from the Ancient Alkalic Centres; (2) lower tuffs (Trifoglietto Unit); (3) products of the Ellittico
13 and Leone eruptive centres (Ancient Mongibello). (4) Chiancone; (5) a) historical lavas of the Recent Mongibello, b)
14 not dated Ancient and Recent Mongibello lavas; (6) recent alluvium; (f) fault; (l) structural lineaments; the electro-
15 stratigraphic sections A-G (see Fig 9 and 10) are drawn on the geological map to aid correlation between lithotypes and
16 electrostrata.

17 **Fig. 4** - Hydrography of the area where the Chiancone outcrops; a watershed separates zone A, where the watercourses
18 are oriented WNW-ESE, from zone B, where the watercourses flow more in an ENE-WSW direction.

19 **Fig. 5** – The map shows the location of the 98 Vertical Electrical Soundings (VES) and of the resistivity profiles
20 A,B,C,D,E.

21 **Fig. 6** – (a) Types of apparent resistivity curves; (b) best fit of experimental values of apparent resistivity (left) and best
22 model of electric layers associated (right) by using the technique of Marquard (1963).

23 **Fig. 7** – Cumulative curve of resistivity values obtained through the interpretation of experimental curves; it shows
24 basically four classes of values with different frequency percentages (see text).

25 **Fig. 8** – The letters A,B,C,D,E and the numbers from 1 to 98 indicate, respectively, the resistivity profiles and the VES
26 shown on the map in Fig. 5; 1st, 2nd, 3rd, 4th classes are the resistivity classes obtained using the cumulative curve in Fig.
27 7.

28 **Fig. 9** – (1) Morphology of the area under study, on the horizontal plane and in 3D: **a,b,c,d,e,f,i,l,m,n** traces of
29 outcropping faults; **g** buried fault; **h,o**, structural lineaments (see also Fig.2); A and B, main lines of run-off of the most
30 superficial lithofacies of the Chiancone indicated in the text as 2a and 3a (Kieffer, 1985); the white dashed line
31 separates the two zones with different run-off. (2) Morphology on the horizontal plane and in 3D of the surface of the
32 Chiancone's lithological facies 1a which is deeper and outcrops (Kieffer, 1985) correlated to the 3rd resistivity class
33 (Fig. 8): the lower case letters **a,b**, etc. have the same meaning as those shown in point (1); A,B,C,D,E,F,G, are the
34 traces of the sections shown in Fig.10. (3) Morphology on the horizontal plane and in 3D of the surface of the
35 conductive body which is considered the basal formation with 4th resistivity class (Fig.8): the lower case letters **a,b**, etc.
36 have the same meaning as those shown in point (1); the two horizontal surfaces (2 and 3) shows the traces of the
37 sections A,B,C,D,E,F,G; the horizontal surface (3a) show the traces of the various types of fault and structural
38 lineaments (in white).

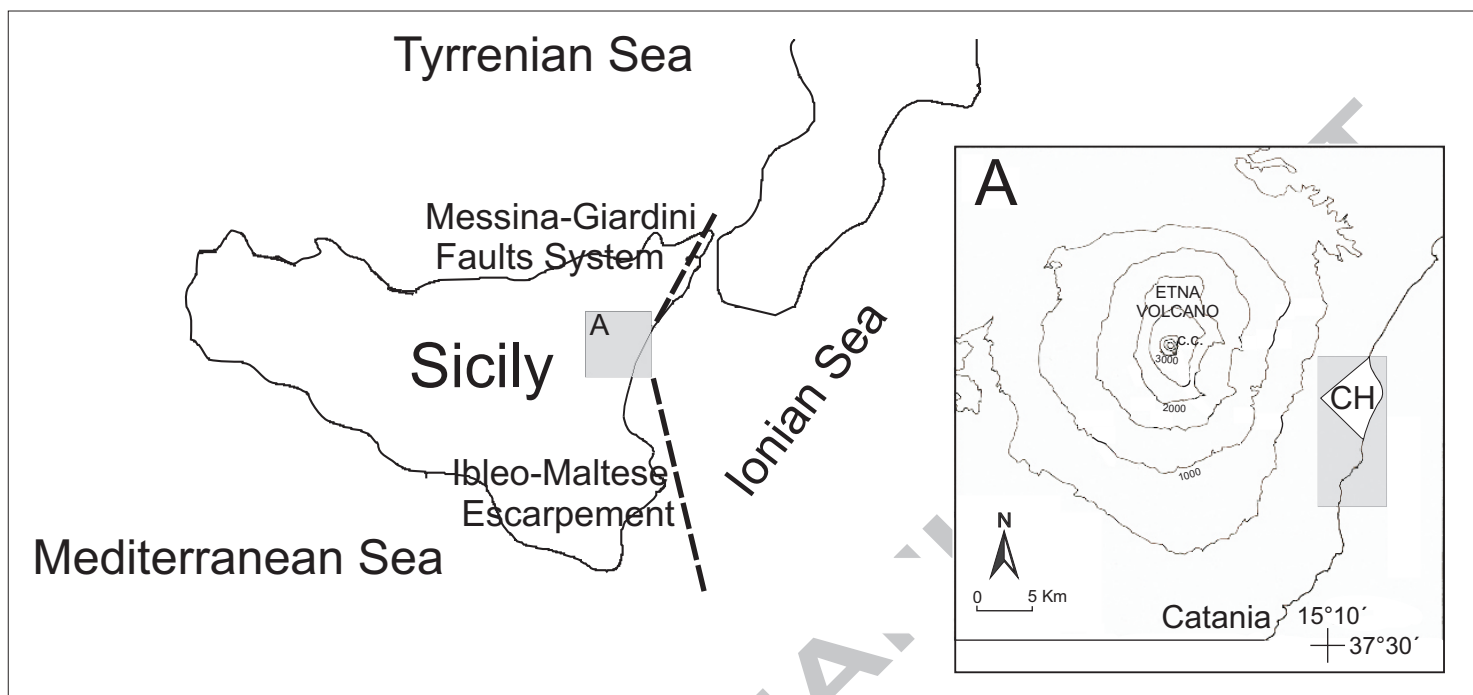
39 **Fig. 10** – The sections oriented roughly N-S (A,B,C,D) and E-W (E,F,G) show the trend at depth of the various
40 electrostrata and of the lithotypes correlated to these latter as follow: 1st class, electrostratum with $\rho \geq 1200$ ohm m
41 correlated to the lavas; 2nd class, electrostrata with $1200 > \rho \geq 320$ ohm m and $320 > \rho \geq 140$ ohm m, correlated to Kieffer's
42 (1985) lithofacies 2a and 3a, respectively deeper and more superficial; cl.3, electrostratum with $320 > \rho \geq 140$ ohm m
43 correlated to Kieffer's (1985) deepest lithofacies indicated with 1a; 4th class, electrostratum with $\rho < 140$ ohm m

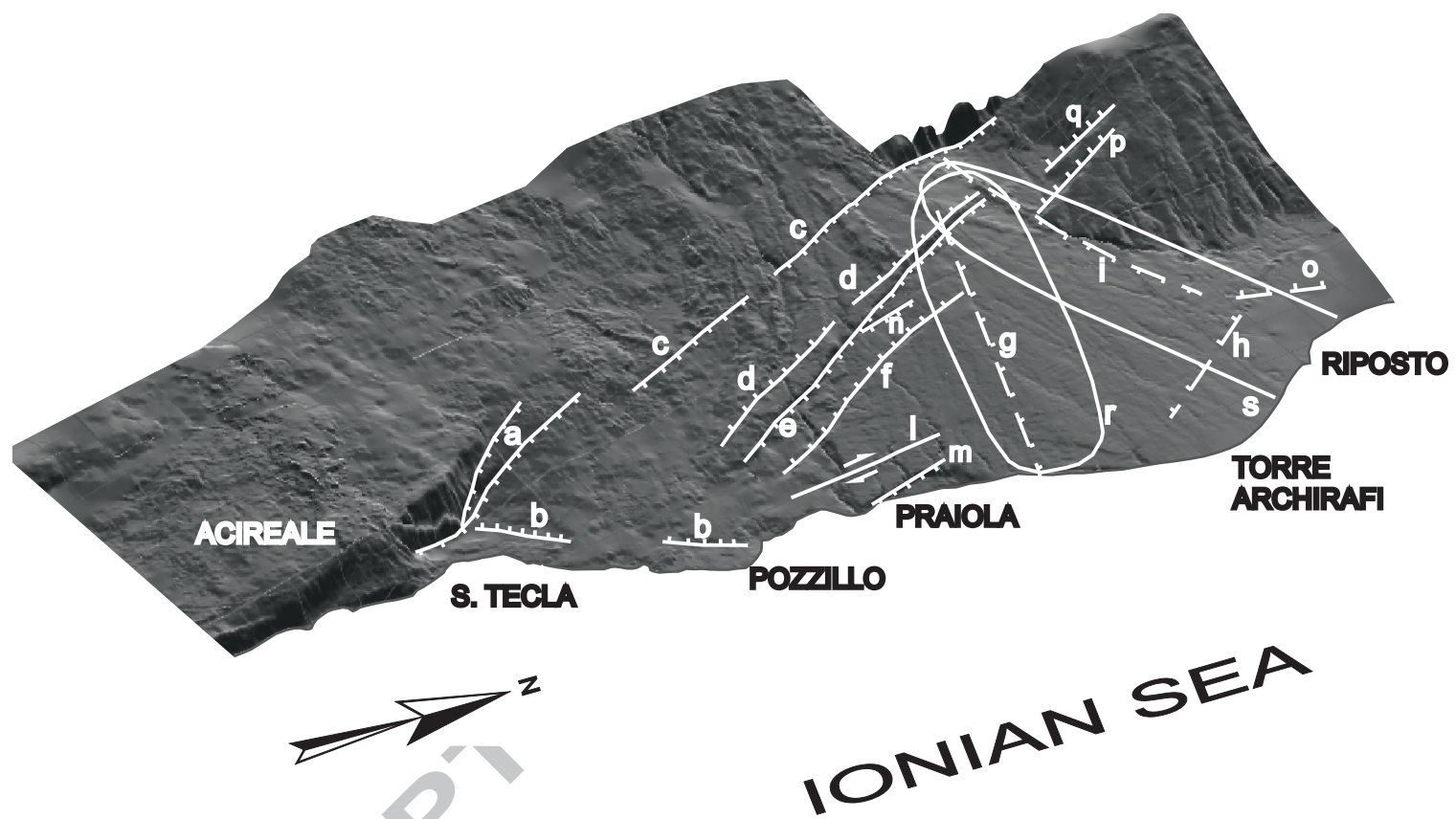
1 corresponding to the conductive substratum. 1) Remains of an eruptive apparatus located in the North-western sector of
2 the area under study; 2) SR, Sedimentary Rocks; SR?, Sedimentary Rocks or very altered and/or humid volcanoclasts; 3)
3 faults hypothesized on the basis of the morphology of the surfaces which border the electrostrata; a-m, outcropping
4 faults. The locations indicated in the sections are those located along the coast and easily allow correlation of the
5 variations of the geometry of the electrostrata in N-S and E-W directions.

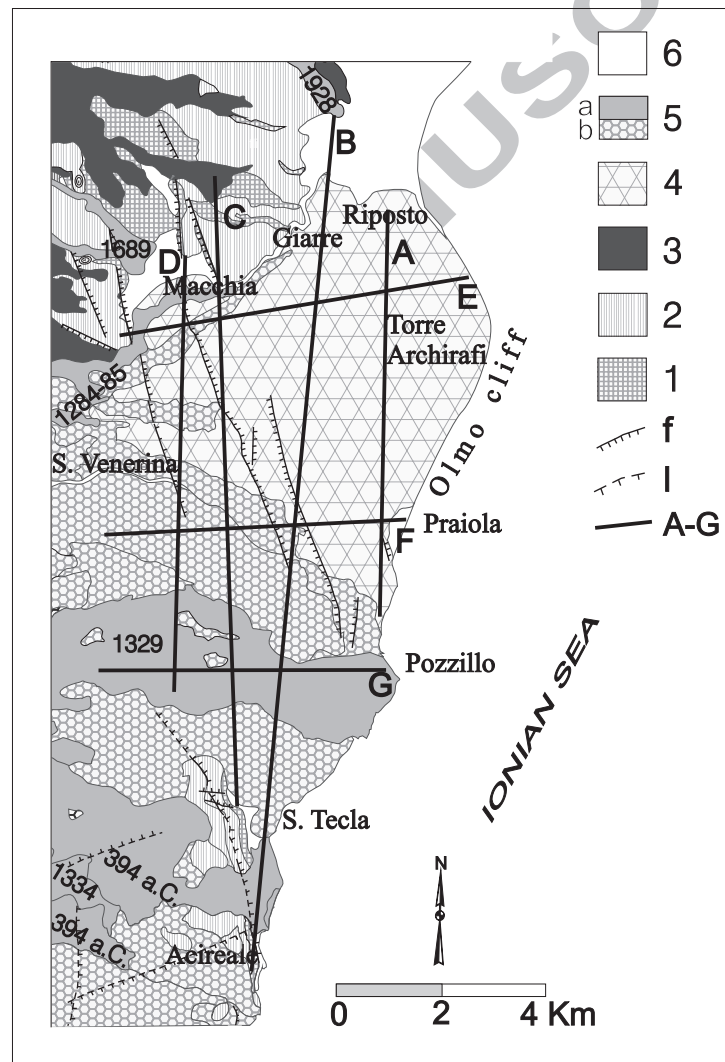
6 **Fig. 11** – A and B are the areas of outcropping of the Chiancone inland and offshore; a and b (white arrows) represent
7 the main lines of flow off of the Chiancone's volcanoclasts and of the overlaying lavas; C is the area of offshore
8 outcropping of the pyroclastic body underlying the Chiancone and the white arrow represents the corresponding main
9 line of off flow of the volcanoclastic body in the area C; this line, inland, is that of the underground watershed H shown
10 in Fig.9; D represents the NW flank of the underwater volcano (Patanè et al., 2009) which is 100,000 years B.P. older;
11 SR Sedimentary Rocks.

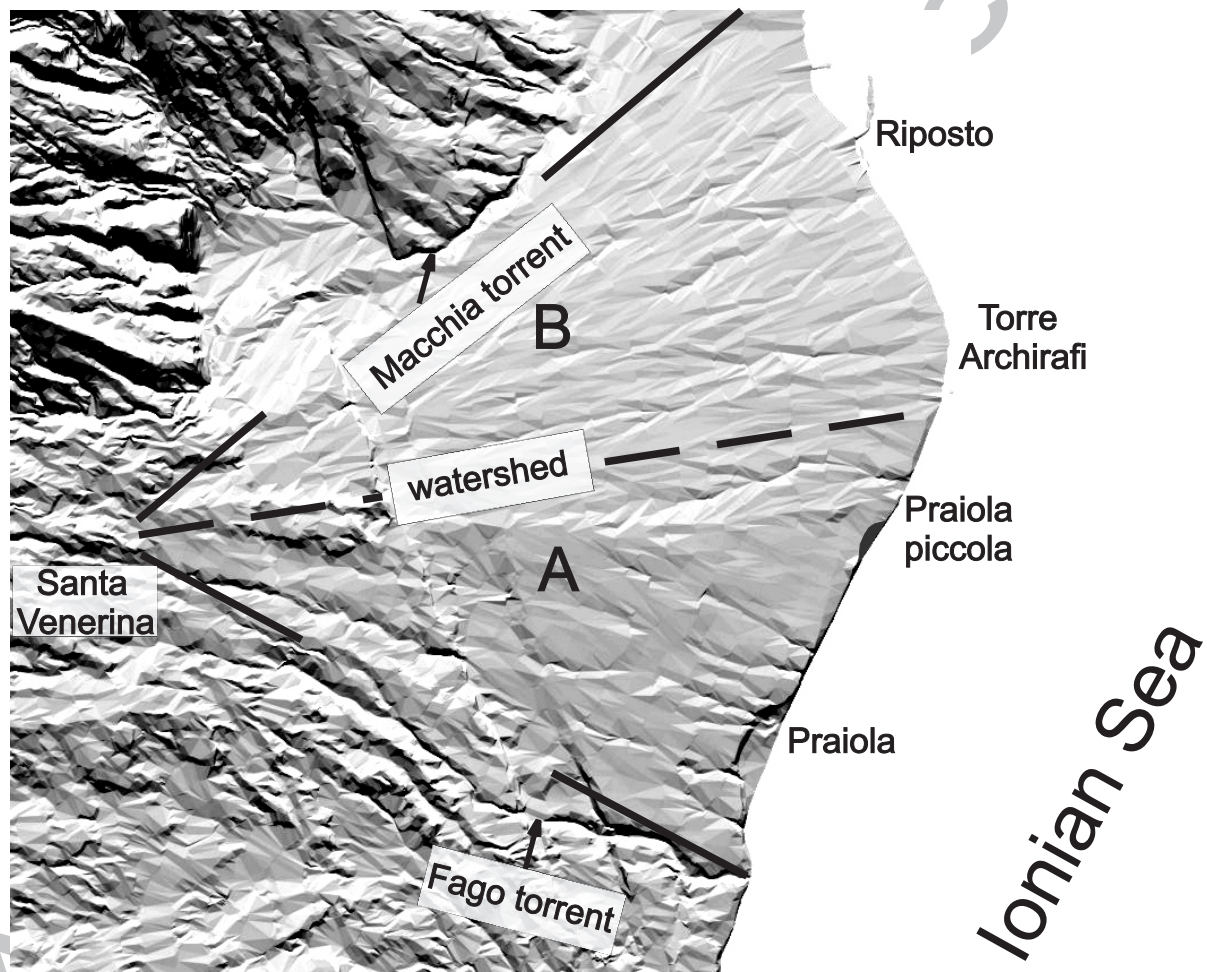
12 **Fig. 12** – Inland and offshore deposits of the Chiancone according to Calvari and Gropelli (1996), Bousquet et al.
13 (1998), Del Negro and Napoli (2002).

14 **Table I** - Correlation between resistivity classes and lithofacies.









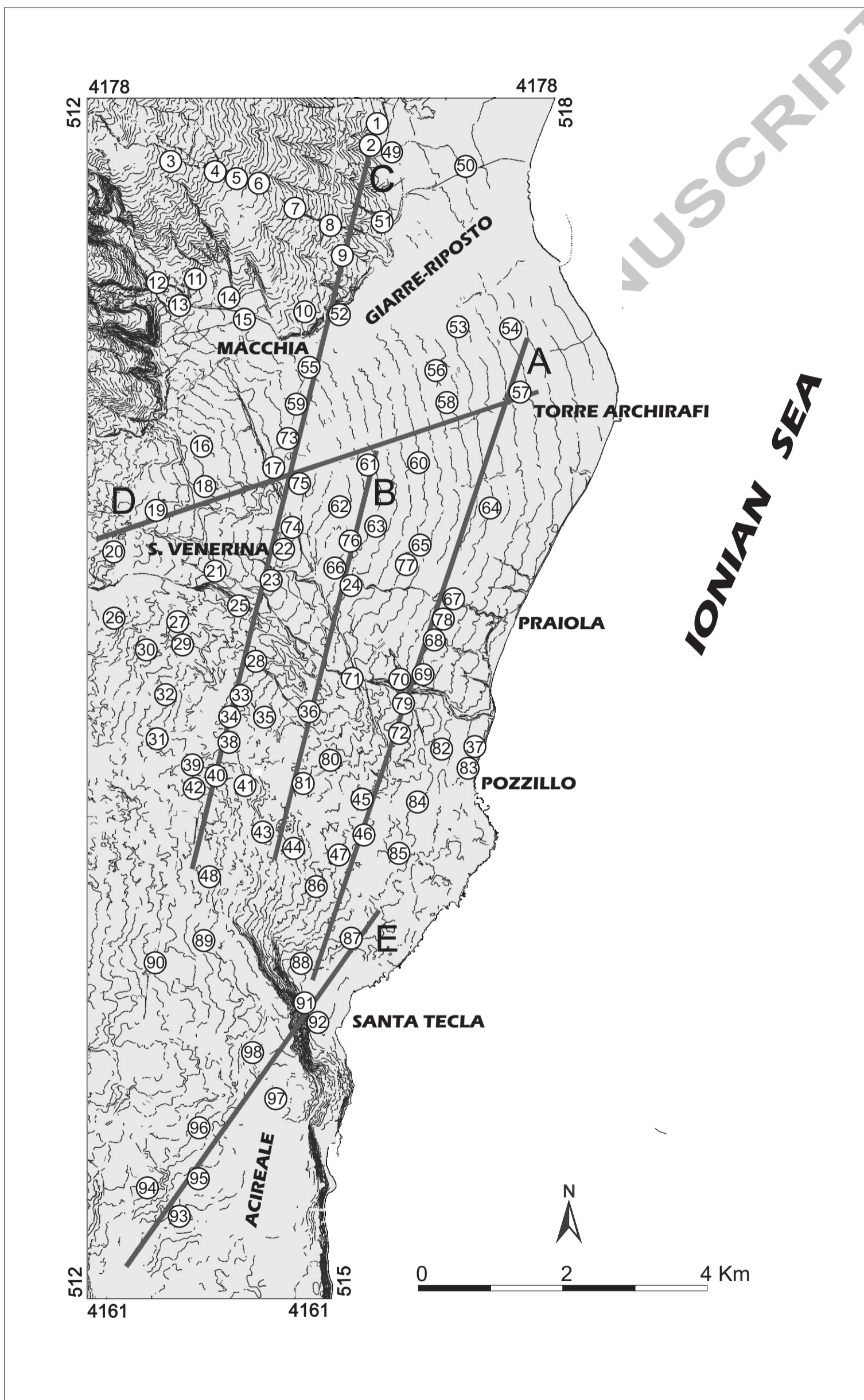
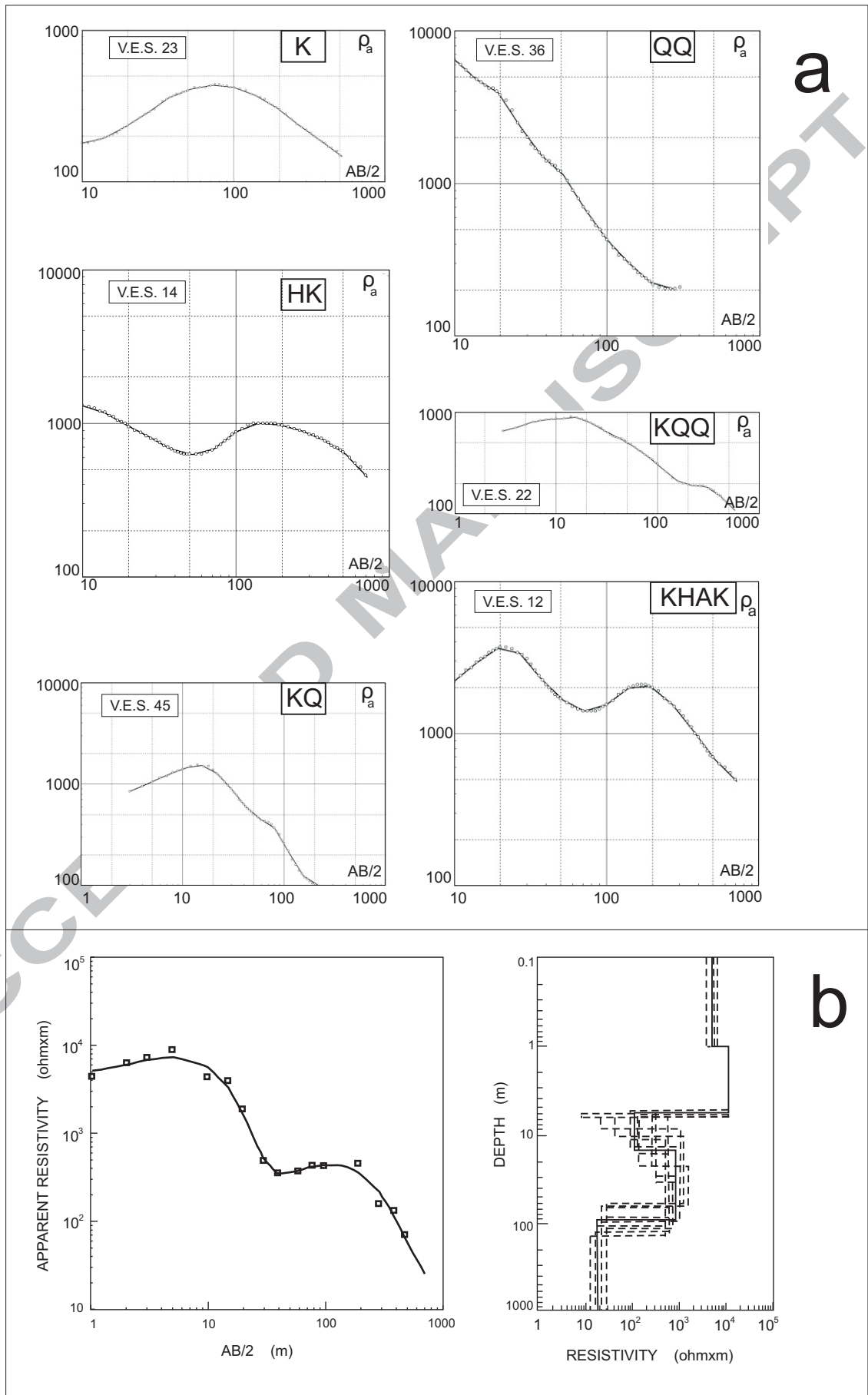


Figure 6



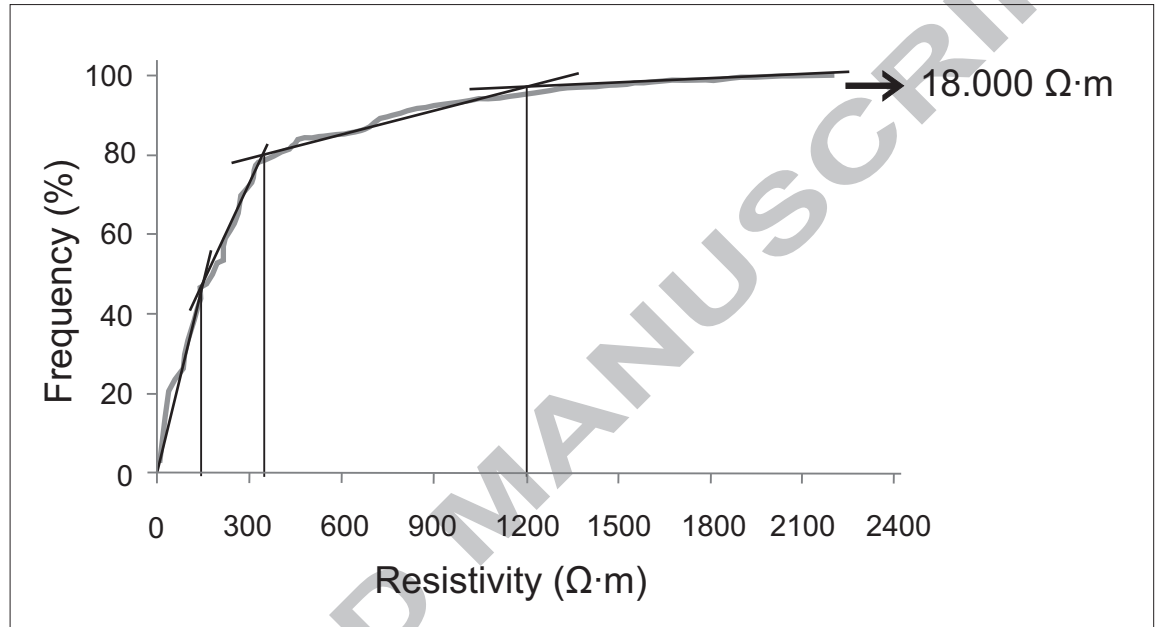
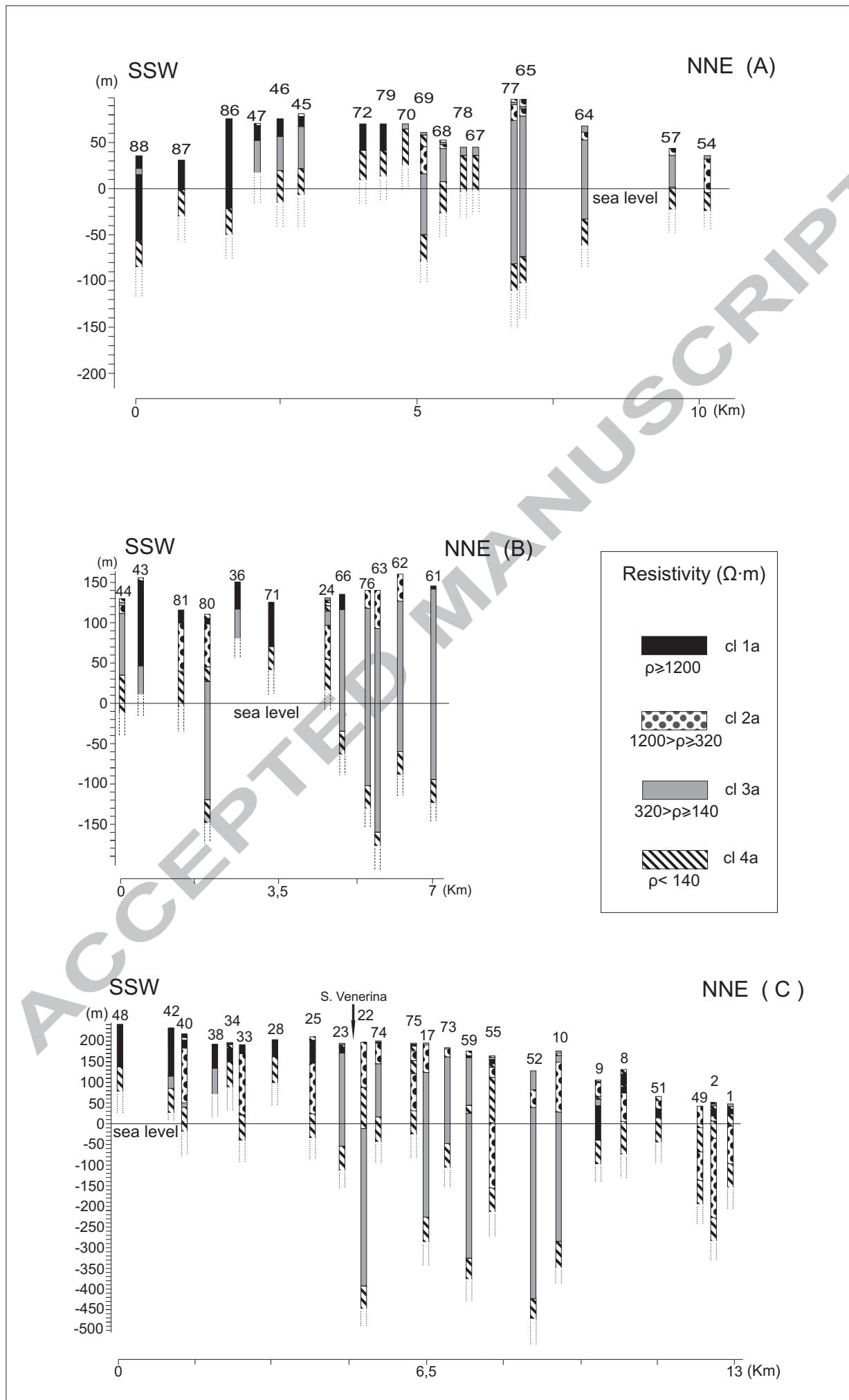


Figure 8



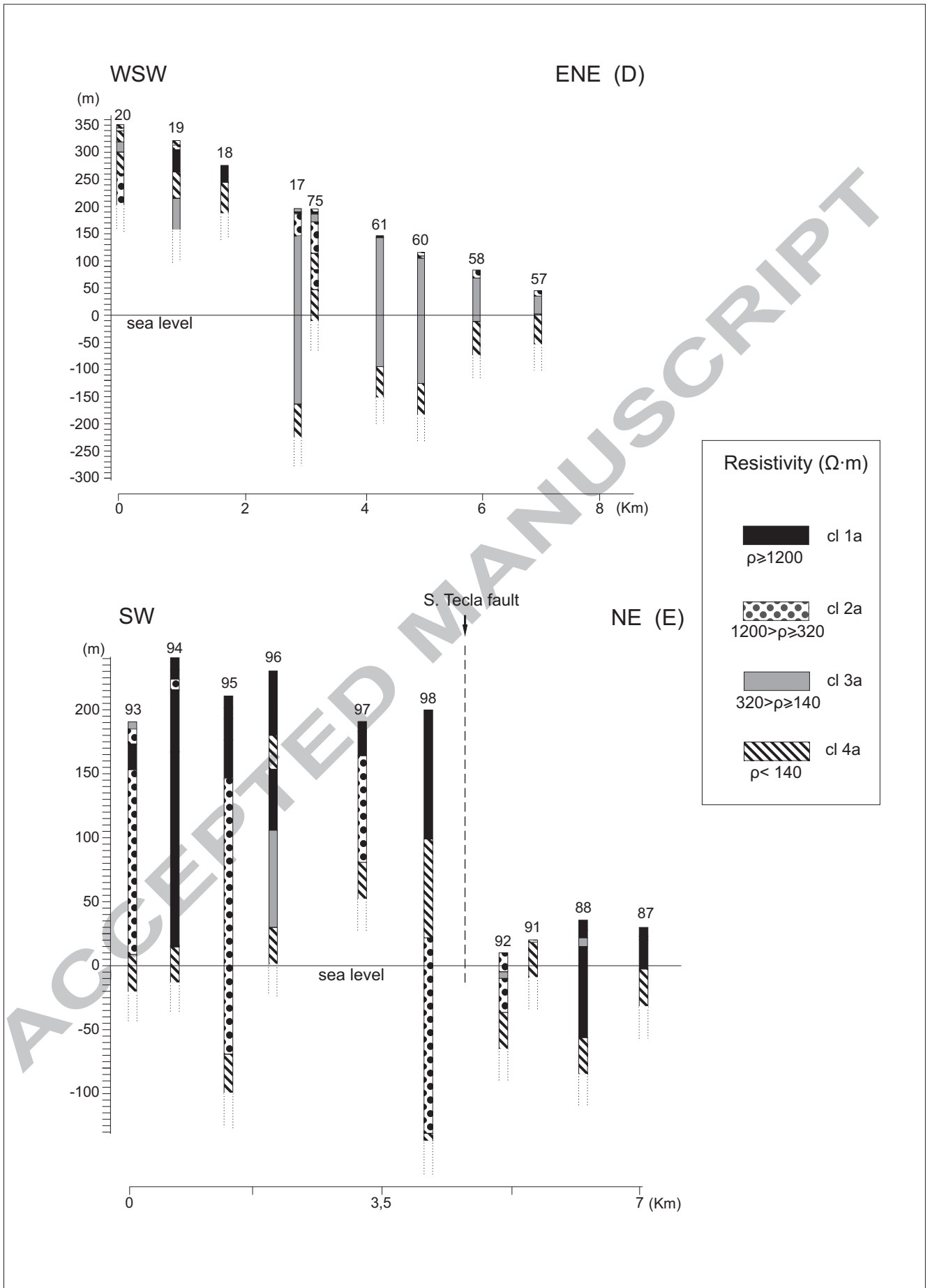


Figure 9

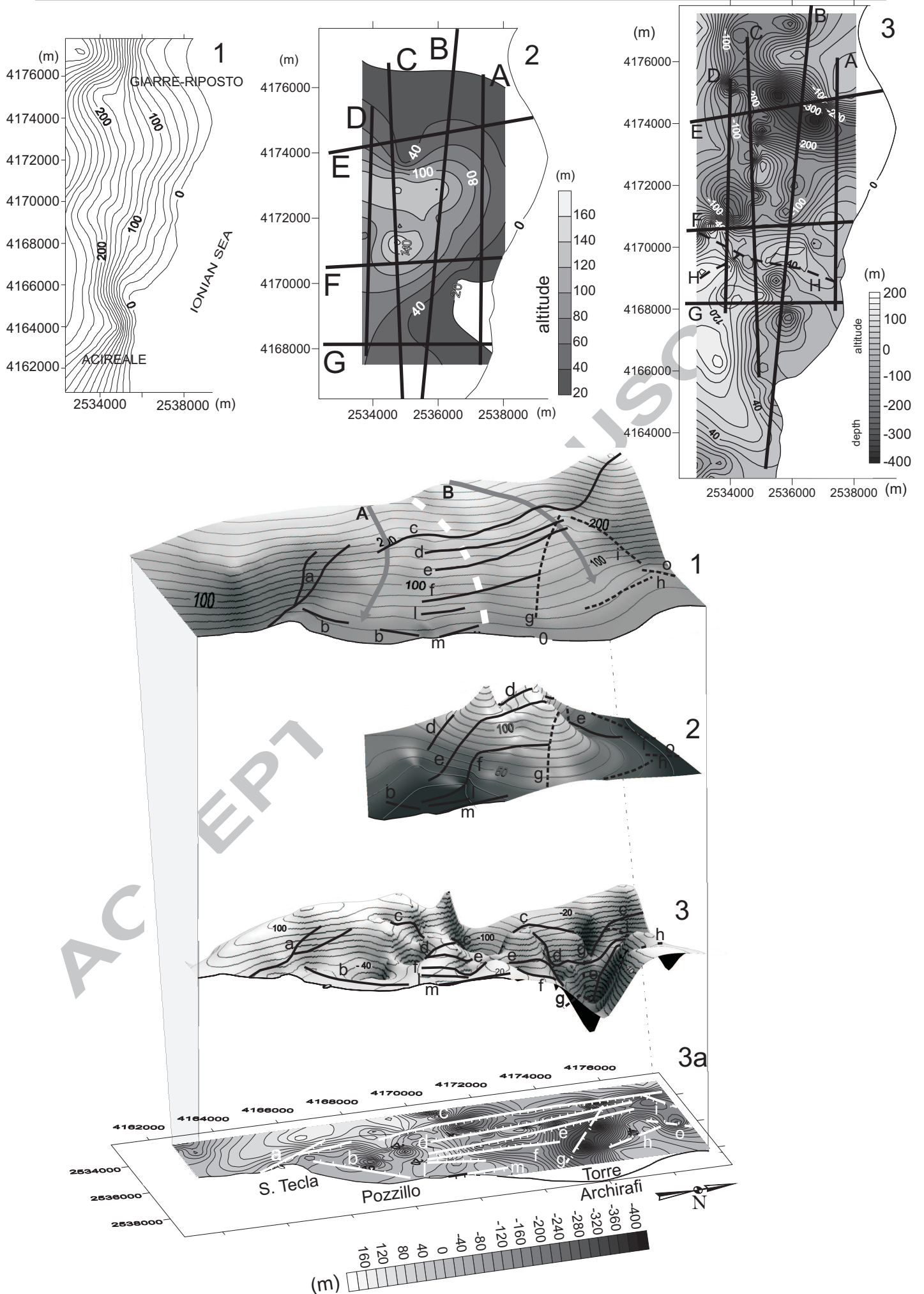
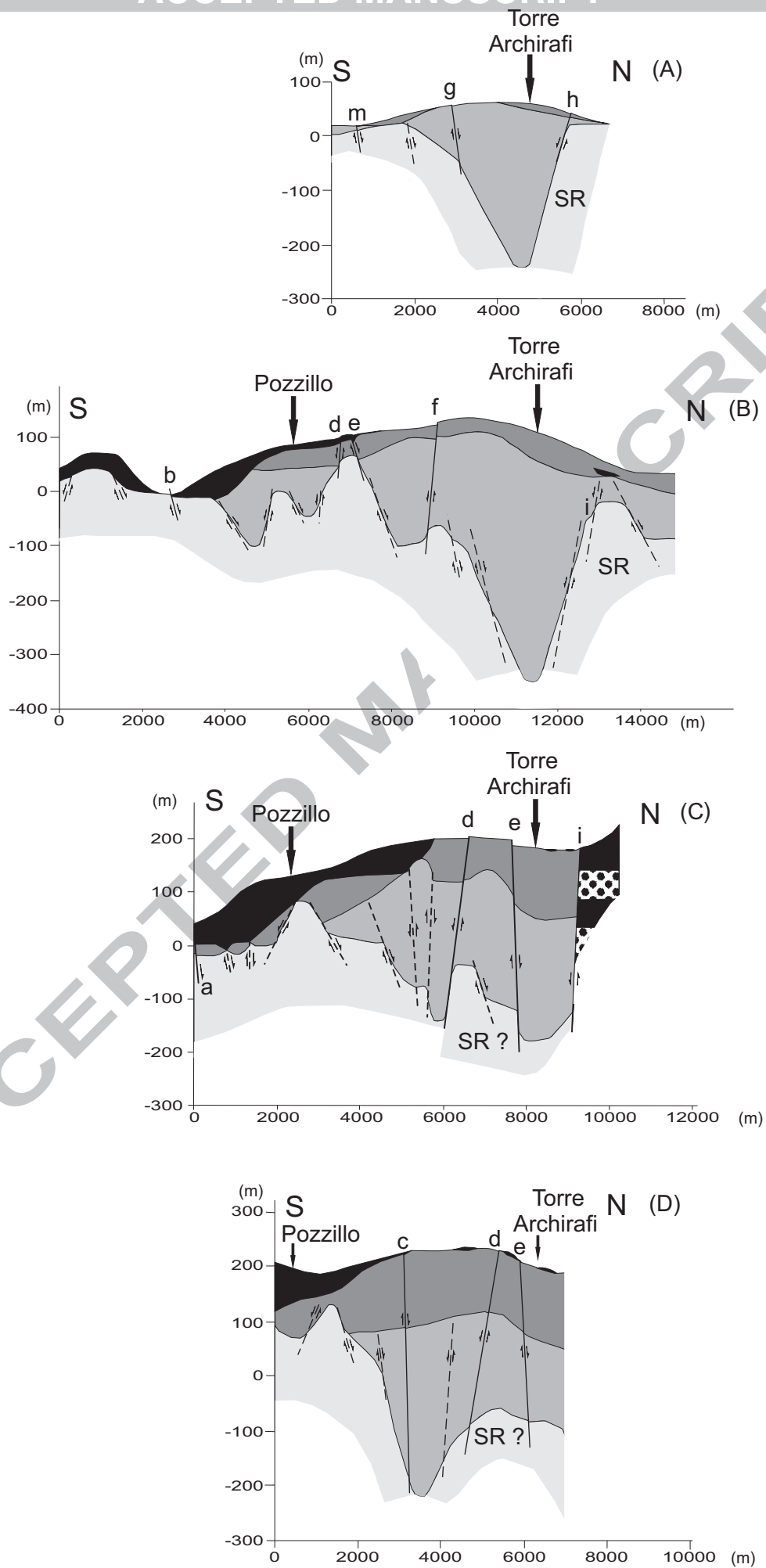
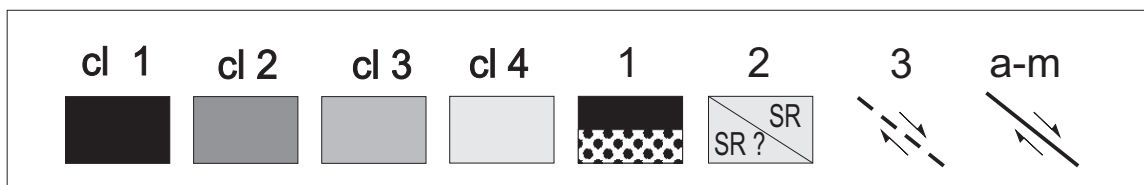
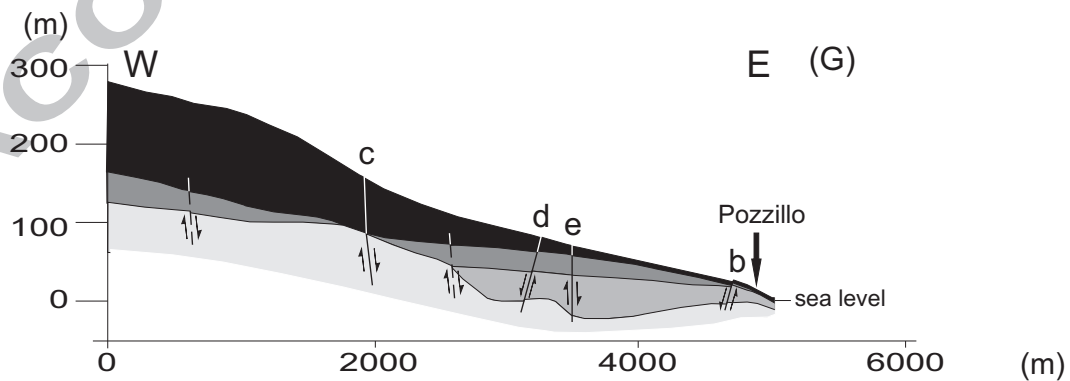
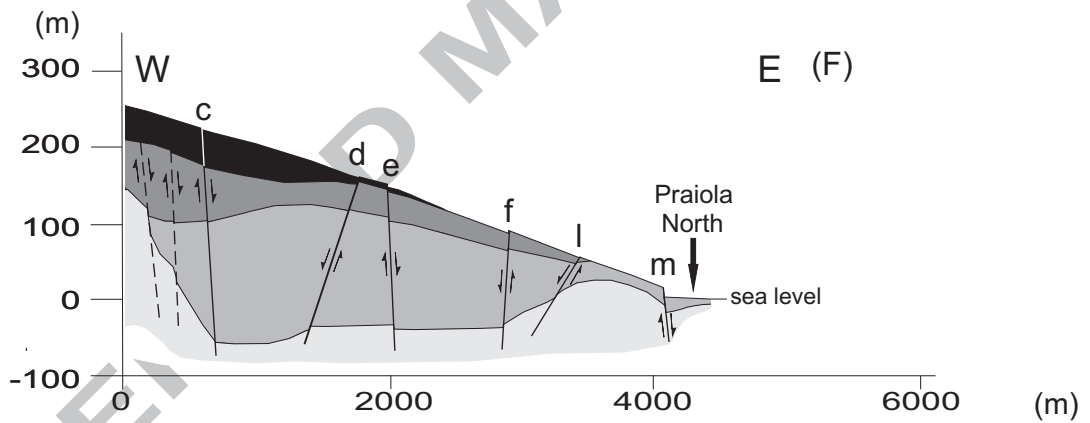
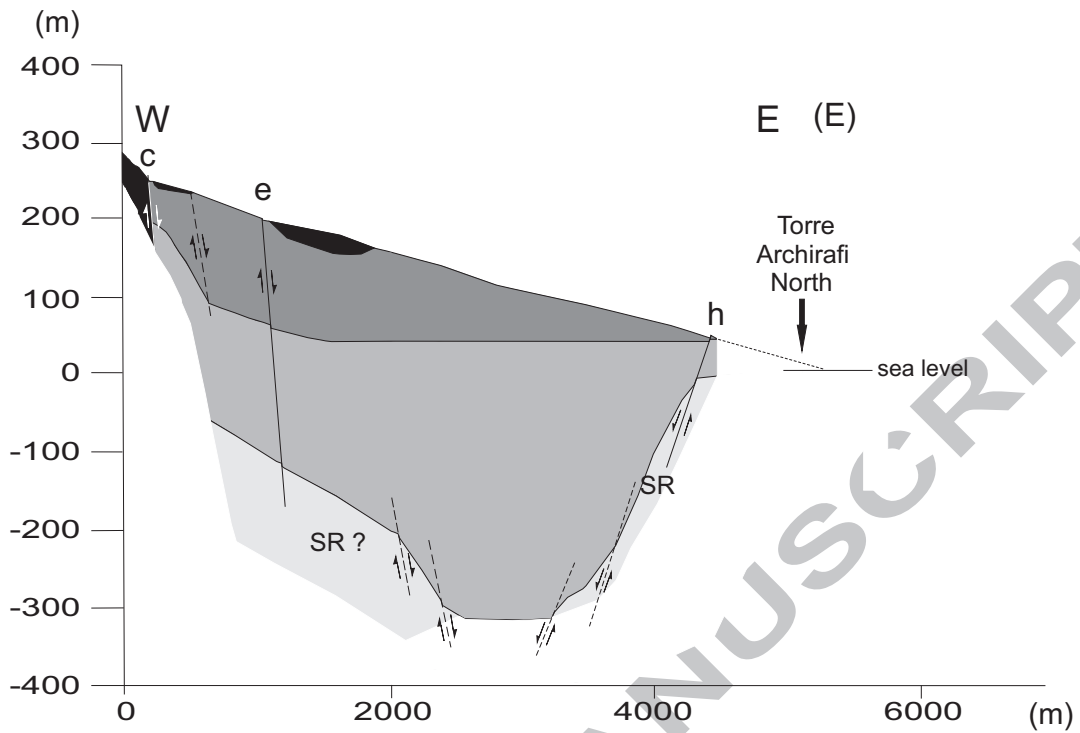
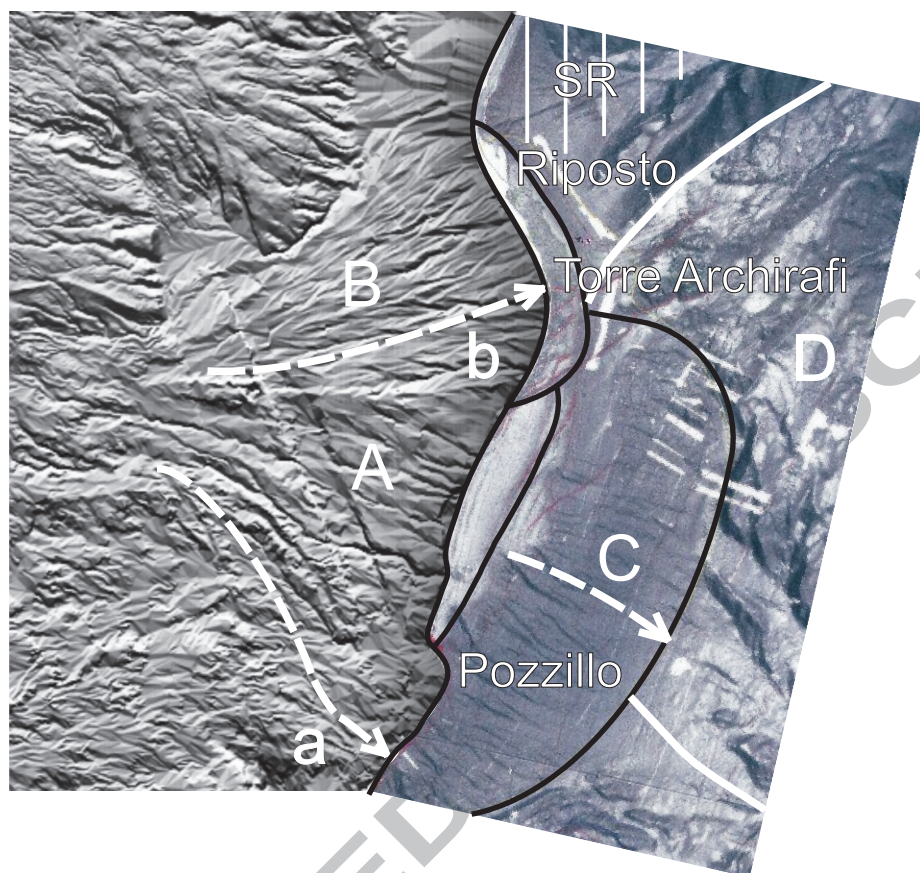
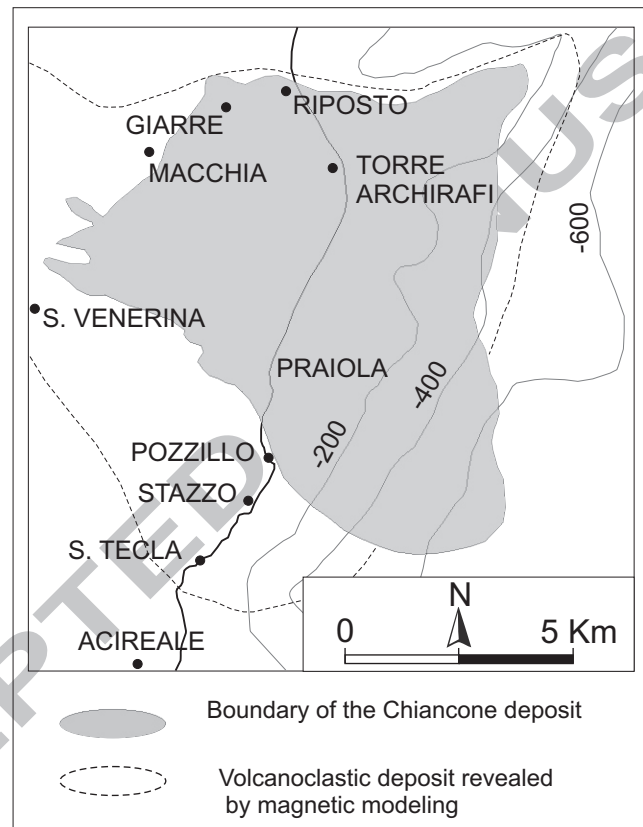


Figure 10









<i>Resistivity Classes</i>	<i>Resistivity Values ($\Omega \cdot m$)</i>	<i>Lithotype</i>	
cl 1a	$\rho \geq 1200$	Lava Flows	
cl 2a	$1200 > \rho \geq 320$	Second facies (Kieffer, 1985)	CHIANCONE
cl 3a	$320 > \rho \geq 140$	First facies (Kieffer, 1985; Calvari and Gropelli, 1996)	
		Third facies (Kieffer, 1985)	
cl 4a	$\rho < 140$	Deeper Conductive Formation	

1

2 On the basis of our considerations, various conclusions can be drawn.

3 - In the CH's pyroclasts there are various lithological facies which were generated 50-40 Ky B.P., in particular
4 violent geodynamic manifestations of the volcano (various opening episodes of the Valle del Bove, strong
5 hydromagmatic, strombolian explosions, etc.).6 - In various phases, the CH's volcanoclasts have occupied some Grabens of the pyroclastic body C, which is in
7 southern zone of the area studied (La Delfa et al., 2007). In the northern zone, a tectonic depression as deep as
8 400 m and oriented WNW-ESE (Fig. 9:3), accommodated most of the pyroclastic flows. The North face of this
9 ditch, towards Giarre-Riposto seems to be made up of non-volcanic sedimentary rocks, while the South face is
10 formed by the pyroclasts from the geological body C, as the offshore multibeam surveys show (Fig. 11).11 - The CH's pyroclasts poured into the sea reaching a maximum depth of 100 m b.s.l. (surveys by the "Istituto
12 Idrografico della Marina", 1993), near Torre Archirafi, overcoming two morpho-tectonic steps: the
13 sedimentary one North of Torre Archirafi (Fig. 9:3; Fig. 10,E) and the pyroclastic one (body C), South of
14 Torre Archirafi, near Praiola Piccola (Fig. 4). In accordance with our results, Loddo et al. (1989) using deep
15 dipole measurements found a rise in the non-eruptive substratum in the same area along the coast.16 - Considering the presence of morpho-structural steps near the coast and the different depth of the base of the
17 CH to the west (about 300 m, below the sea level) and to the east, off the coast line (at about 100 m below the
18 sea level) of these steps, the possibility that the impact of the mass of the detritus, although quite modest,
19 falling into the Ionian Sea may have caused a tsunami wave (Pareschi et al., 2006) big enough to affect the
20 central-eastern Mediterranean about 8 000 years B.P. is excluded, in our opinion. Indeed, as is known, the
21 CH's pyroclasts were deposited in various successive episodes, over quite a long time frame (40-50 ky) and
22 considering the particular morphology of the conductive substratum in the area under study, they mostly filled
23 the various existing depressions to the west of these steps, interacting only a bit with the waters of the Ionian
24 Sea.

25

26