Per. Mineral. (2002), *71*, 2, 159-189 http://go.to/permin

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment, Archaeometry* and *Cultural Heritage*

Subaerial Plio-Pleistocene volcanism in the geo-petrographic and structural context of the north/central Iblean region (Sicily)

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Submitted, March 2002 - Accepted, July 2002

ABSTRACT. — This paper deals with the petrographic, geological, stratigraphic and structural aspects of subaerial mid-Pliocene to Pleistocene volcanic rocks outcropping in the northern sector of the Iblean Plateau.

In the examined area, almost the entire Iblean sedimentary and eruptive sequence, from Late Cretaceous to Holocene, outcrops. Three main sedimentary cycles are identified.

A detailed field survey has revealed the link between magmatism and extensional-transtensional tectonics the latter principally connected to the structural NE-SW direction and characterised by both strike-slip and vertical movements. In particular, the late Miocene volcanic products (*Lower Volcaniclastic Deposits*) are connected with the mid-Miocene tectonic phase and represent a revival of basic eruptive activity after the late Cretaceous-early Tortonian hiatus. Similarly, the mid-late Pliocene/early Pleistocene volcanic activity is linked to the mid-Pliocene tectonic phase.

On the whole, the composition of the volcanic products ranges from nephelinite - ankaratrite to tholeiite, without any correlation with spatial distribution or age.

Subaerial Plio–Pleistocene volcanism emitted 10–15 km^3 of products. Subalkaline products prevail over alkaline ones (tholeiite 62%; basanite 22%; alkali-basalt 8%; hawaiite 4%; transitional basalt 3%; nephelinite and ankaratrite 1%).

These products are the result of partial melting of different metasomatised spinel peridotite lithospheric sources. The partial melting fraction progressively increases and source depth decreases from strongly alkaline to tholeiitic magmas.

The alignment of eruptive centres with the tectonic features, together with the petrographic and geochemical features of the volcanites, indicate that the magma rose directly from the mantle along fault planes.

RIASSUNTO. — L'Altopiano Ibleo è stato interessato dal Mesozoico al Quaternario da numerosi e discontinui eventi magmatici. Nel suo settore settentrionale, in particolare, affiorano livelli vulcanici del Tortoniano (*Vulcanoclastiti Inferiori*) e del Pliocene inferiore e medio (*Vulcanoclastiti Superiori*) ed estesamente vulcaniti subaeree di età Pliocene medio–superiore/Pleistocene inferiore. Queste ultime sono state oggetto di analisi petrografiche, geochimiche, stratigrafiche e strutturali al fine di mettere in relazione l'attività magmatica con gli eventi tettonici.

Nell'area in esame è esposta l'intera sequenza sedimentaria iblea (Cretaceo superiore–Olocene) all'interno della quale è possibile riconoscere tre principali cicli sedimentari.

La dettagliata analisi di campagna ha permesso di osservare il legame esistente tra i fenomeni

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magmatici e la tettonica estensionale e/o transtensionale che si sviluppa principalmente con direzione NE-SW ed è caratterizzata da movimenti sia verticali che trascorrenti. In particolare risulta chiaro il legame tra le *Vulcanoclastiti Inferiori* e la fase tettonica del Serravalliano superiore-Tortoniano inferiore e quello tra le *Vulcaniti Subaeree* del Pliocene medio-superiore/Pleistocene inferiore con la fase tettonica del Pliocene medio.

Nel complesso, la composizione dei prodotti del magmatismo ibleo (da nefeliniti-ankaratriti a tholeiiti) non mostra alcuna relazione con la distribuzione spaziale e con l'età degli stessi.

Le *Vulcaniti Subaeree* Plio-Pleistoceniche affiorano per un volume complessivo di 10-15 km^3 con prodotti subalcalini largamente prevalenti rispetto a quelli alcalini (tholeiiti 62%; basaniti 22%; alkalibasalti 8%; hawaiiti 4%; basalti transizionali 3%; nefeliniti and ankaratriti 1%). Tali magmatiti sono il risultato della fusione parziale di una sorgente mantellica litosferica a spinello variamente metasomatizzata. Secondo tale modello, inoltre, i magmi subalcalini si sono formati per maggiori gradi di fusione e a profondità minori rispetto a quelli alcalini.

La coincidenza tra gli allineamenti dei centri eruttivi riconosciuti e le direttrici tettoniche ed il carattere primitivo dei magmi indicano che questi ultimi sono risaliti direttamente dal mantello lungo zone di faglia.

Key Words: *Plio-Pleistocene Iblean volcanism, petrography, structural geology, Sicily.*

Introduction

Late Miocene-Quaternary volcanic products outcroping in the northern part of the Iblean Plateau, is part of the discontinuous magmatic activity which occurred from Mesozoic to Holocene in eastern Sicily. Trua *et al.* (1998) consider Mt. Etna as the most recent episode of this magmatism, notwithstanding the differences in both tectonic regime and geochemical character between iblean and etnean volcanic rocks.

This paper deals with the petrographic, geological, stratigraphic and structural aspects of subaerial mid-Pliocene-Pleistocene volcanism. In particular, we studied the northern-central Iblean area, excluding the extreme north and north-west tips, characterised by marine to subaerial volcaniclastic products and lavas.

The lithospheric geodynamic regime and the reconstruction of volcanic activity is improved by lithostratigraphic and structural study of sedimentary sequences.

Processing of recently acquired field data has led to the production of some petrological and volcanological works (Beccaluva *et al.*, 1993, 1998) and a geo-petrographic map (Beccaluva *et al.*, 1991; 1993), for which the present study may be considered the explanatory note.

To attempt the chronological reconstruction of the Plio-Pleistocene tectonics and related volcanic activity, in geological mapping particular attention was paid to the litho stratigraphy of the sedimentary sequence following the first outcropping eruptive products (*Lower Volcaniclastic Deposits*). In addition, the oldest faults are also mapped in detail because they were probably the conduits for rising magma.

The study area lies north of Licodia Eubea, Giarratana, Palazzolo and Melilli, extending to the Plain of Scordia and Lentini; to the west it is bounded by the Licodia Eubea meridian and to the east by that of Melilli. Although recent geological maps of this area do exist (Lentini *et al.*, 1984, 1986; Grasso, 1997), there is no detailed geopetrographic map with volcanic bodies identified on it.

All the Neogene iblean products, with the exception of the most recent marine and continental Quaternary volcanic deposits (occurring only towards the Catania Plain, on the extreme northern outskirts), outcrop in the study area. The late Cretaceous volcanites were included in the pre-Tortonian basement. Borehole data also show the volcanic products intercalated in the sedimentary sequence as far as the Mesozoic (Patacca *et al.*, 1979; Bianchi *et al.*, 1987; Longaretti and Rocchi, 1990; Rocchi *et al.*, 1995).

Outcropping sediments consist of neritic and local bathyal Mio-Pliocene limestone. During the Quaternary, the environment evolved principally to littoral tending locally to neritic.

The pre-Miocene carbonatic sediments testify to a cliff environment to the east and a platform evolving to a basinal environment to the west.

All mapping was carried out to scales of 1:10.000 and 1:25.000 scale[1].

APPROACH TO THE SURVEY

The extensive occurrence in the study area of subaerial Plio-Pleistocene volcanites had already been reported in the literature of the late 19th century and summarised in Baldacci's monograph (1886). More recently, attention has been paid particularly to morphology, genesis of eruptive products and characteristics distinguishing submarine and subaerial lithologies. SCHMINCKE *et al.* (1997) correlated the chemistry of volcanites younger than 5 Ma to eruptive types and emphasized the contribution of eustatism, isostasy and exogenous gravitative phenomena to rapid changes in the eruptive and environmental conditions in the Militello-Palagonia area.

With reference to Plio-Pleistocene subaerial volcanism, the occurrence in south-eastern Sicily of a fault network and the lack of recognisable central volcanic morphologies has led numerous authors to hypothesise fissural volcanic activity. On more careful examination, these subaerial volcanites are not affected by Pliocene faults. On the contrary, the latter are almost always sutured by volcanic products and must therefore have been formed immediately before or during the volcanic eruptions. The occurrence of morphologies indicating volcanic centres has also frequently been noted, although their context is often unclear.

The search for presumed eruptive centres was carried out on the basis of the following evidence:

– lava flow structure (columnar lavas, flow unity, blistering, reddening, etc.);

– presence of scoriae;

– present-day morphology.

The last piece of evidence appears to be reliable on the basis of the following assumptions:

– subaerial flows obviously move downwards;

– observed morphological changes are not connected with the subsequent tectonics, which only involved the peripheral Iblean area;

– post-effusive erosional activity, probably considerable as it was protracted over several million years, did not cause any substantial modifications in morphology.

Probable boundaries between various lava flows were hypothetically drawn to correspond with morphological elements (predominantly valleys), assuming that they correspond to morpho-structural discontinuities.

Although we are well aware that some of the centres identified are only presumed, we believe that the results obtained may be considered valid. The suggested existence of various lava flows and effusive centres is substantiated by petrographic and geochemical analyses, which have frequently highlighted differences between contiguous flows.

The Plio-Pleistocene lava flow sequence was considered as a single lithostratigraphic unit, and both its age and relationships with the other formations were identified; the same *modus operandi* was adopted with reference to other volcanites.

Detailed lithostratigraphic study of the Quaternary sediments determined both the relative age of eruptive activity and fault chronology. Faults were mapped and referred to the late Miocene-Pliocene and to Quaternary.

GEOLOGICAL AND STRUCTURAL SETTING

The Iblean region rests on an about 30 km thick crust (CAPUANO *et al.*, 1993), gradually decreasing northwards (Mount Etna) to 10 km (BARBERI *et al.*, 1982; CRISTOFOLINI *et al.*, 1985; BECCALUVA *et al.*, 1998). On the whole, the south-eastern Sicilian lithosphere is over 90 km thick (PANZA and SUHADOLC, 1990). It

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[1] For all mentioned localities, see attached map.

represents the northern sector of the Pelagian block (Burollet *et al.*, 1978; Boccaletti *et al.*, 1989), a paleogeographic - structural unit between the north African and Sicilian regions. Its evolution during the Neogene was determined by the collision, still active, between the African, represented by the Iblean sector, and the European plate, corresponding to the Maghrebian and Kabilo-Calabride Chains on the southern front (Monaco and Tortorici, 1995; Finetti *et al.*, 1996).

To the east, the Pelagian-Iblean sector is structurally separated from the Ionian basin by an important system of prevalently NNW-SSE normal faults with strong vertical displacement (Iblean-Maltese escarpment) (Fig. 1). Symmetrically, to the west, it is bounded by a fault network running prevalently NE-SW, active in several periods from late Miocene to Quaternary. They gradually lowered the Iblean sector westwards by several thousand metres of total displacement. As a consequence, sedimentary basins, linked also to transtensional tectonics, were formed in the westernmost structurally depressed areas during the Pliocene and Quaternary. The «Gela Foredeep» is one of these basins, which was filled during the early Pleistocene by

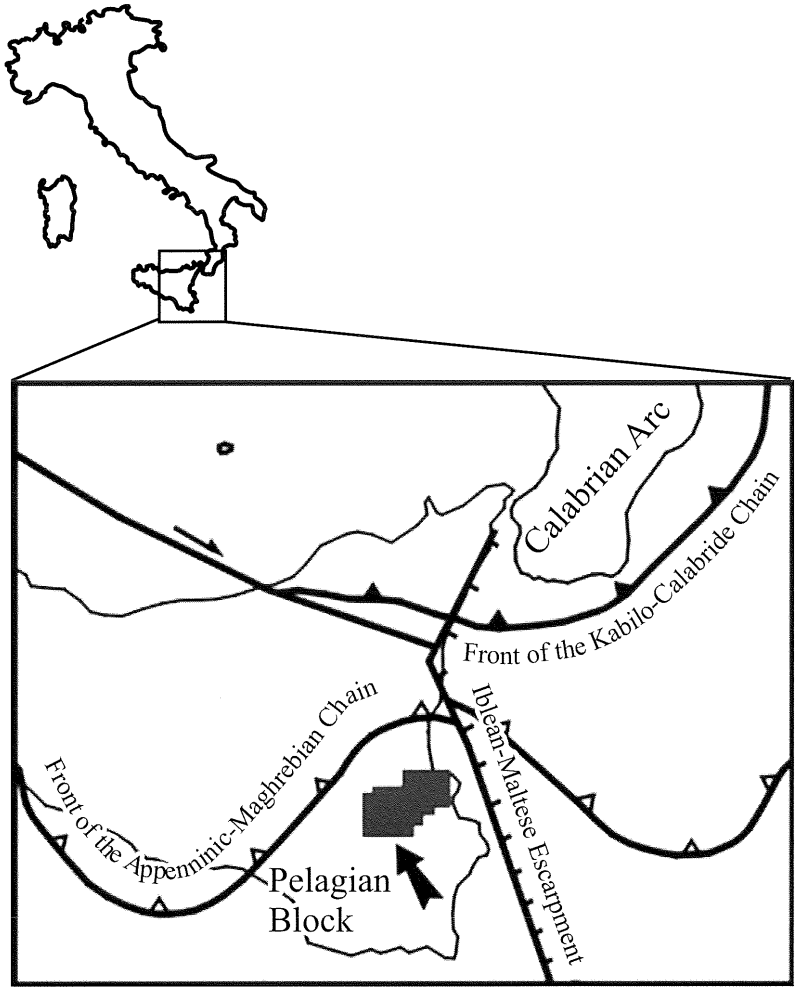

Fig. 1 – Location of study area (dark).

allochthonous Mio-Pleistocene sediments (Gela Nappe) (BENEO, 1958; ROCCO, 1959; OGNIBEN, 1960, 1969; RODA, 1965) and later filled in by Quaternary marine sediments. The Gela Nappe front lies partially on the above-mentioned composite tectonic escarpment.

Similarly, to the north the Iblean sector is affected by numerous NE-SW collapse structures, which cause it to subduct under the Apennine-Maghrebian Chain, represented at the front by the Gela Nappe. The boundary between these structural elements is prevalently covered by Etna volcanic products. The intense collisional tectonics caused by convergence of the African and European plates has led to numerous diachronous eruptive manifestations and to segmentation of the Iblean structure. Although the Iblean Plateau seems to be a single horst, it is in fact segmented into several minor blocks, owing to the extensional and transtensional faults which lead to a continuous succession in space of horsts and grabens of varying dimensions. Northwards, outside the study area, the principal structures are the Scordia-Lentini graben, the Primosole-Serravalle horst and the Catania plain structural depression. The coast is characterised by a regular alternation of horsts (Agnone, Gisira, Mt. Tauro, Magnisi, La Maddalena, Portopalo) and grabens (Augusta, F. Marcellino, Floridia, Rosolini-Pachino), related to the transtensional component of the Iblean-Maltese escarpment (GRASSO, 1993).

The main tectonic lines (Scicli, Comiso, Ispica, etc.) mark the structural Miocene-Quaternary evolution of both the Iblean and Maltese sectors (GRASSO *et al.*, 1986).

LITHOSTRATIGRAPHIC SUCCESSION

Almost the entire Iblean sedimentary and eruptive sequence, from Late Cretaceous to Holocene, outcrops in the study area. There are not represented only the Eocene-Oligocene terms of the eastern facies outcropping south-east of Melilli and near Pachino, immediately outside the study area.

The oldest (Cretaceous) sediments are eastward of carbonate platform facies and westward of deep basin facies (limestone and marl). This lithological and environmental differentiation continues up to the middle Miocene, whereas during the Tortonian the whole area was characterised by almost uniform platform environmental conditions. During the Messinian, a paralic-evaporitic environment characterised the outskirts of the already emerged central Iblean portion. The study area lies between the eastern and western sectors.

During the early Pliocene, after the peculiar paleogeographic and sedimentological conditions of the late Miocene and the successive uplift of a further portion of the Iblean Plateau, marly clay (*Trubi* Fm.) sedimented around the emerging area. Successively, especially to the north and north-east, submarine effusive activity prevailed, up to the lower-middle Pliocene. During the early-middle Pleistocene, mainly at the extreme edge of the area, littoral and neritic deposits were laid down.

During the late Cretaceous and Tortonian, prevalently submarine eruptive activity occurred. From the middle Pliocene up to the Quaternary, subaerial volcanic products were emitted in the already uplifted central Iblean region, whereas to the north subaerial and submarine volcanic sequences are found alternating.

The pre-Cretaceous succession is known above all through boreholes, sometimes reaching 5000 metres in depth (KAFKA and KIRBRIDE, 1959; RIGO and BARBIERI, 1959; RIGO and CORTESINI, 1961; SCHMIDT DI FRIEDBERG, 1964). They reveal a limestone sequence extending to the early Trias which, like the outcropping facies, indicates a platform environment to the east and basin conditions to the west (PATACCA *et al.*, 1979). In the middle Lias, basin conditions were established throughout the area, whereas, during the late Cretaceous, Triassic conditions were re-established.

The whole outcropping lithostratigraphic succession is described below, starting from the oldest terms.

PRE-LATE MIOCENE BASEMENT UNITS *(Hybla, Amerillo, M. Climiti, Ragusa, Tellaro and Palazzolo formations: 1[2])*

The Cretaceous volcanites and sedimentary formations (Hybla, Amerillo, Ragusa, Tellaro, Palazzolo) underlying the Tortonian eruptive level (*Lower Volcaniclastic Deposits*), are grouped under this heading. In particular, from bottom to top, the following sequence may be found:

Late Mesozoic sequence

Marly limestone and subordinate grey-green marl, with ammonites, aptics and belemnites, prevalently early Cretaceous in age (*Hybla* Fm.), outcropping some kilometres south of Licodia Eubea, up to 100 metres thick and passing to the west during the late Cretaceous to cherty limestone (Amerillo Fm.).

In the eastern part (Costa Saracena): calcirudite and rudist limestone (10-20 m) on late Cretaceous volcaniclastic arenite, pillow breccias and submarine lavas (130-400 m).

Eo-Oligocene sequence

In the western sector, calcirudite with slumping, passing topwards in stratigraphic continuity first to whitish layered calcarenite and then to whitish calcilutite and calcisiltite (10-80 cm layers) interbedded with marl and marly limestone (layers: 5-30 cm) (Ragusa Fm.-Leonardo Member), 100 metres thick.

In the eastern sector and outside the study area, these sediments are represented by calcirudite and calcarenite with macroforaminifera (50 m).

Early Miocene sequence

In the western sector: mostly calcarenite, subordinate whitish calcirudite (layers up to 5 m), passing upwards to greyish calcarenite and yellowish marly-sandy alternations; topwards marl becomes prevalent passing gradually to the overlying marly Tellaro Formation. The whole sequence (150 m) corresponds to the Irminio Member of the Ragusa Formation.

In the eastern sector: whitish-yellowish calcarenite, passing upwards to calcarenite and calcirudite with algae and bryozoa (Mt. Climiti Fm.).

Midle Miocene marl and limestone.

To the west: grey-blue and yellowish marl, sometimes with lens-shaped layers of a more competent calcarenitic-marly alternation, in stratigraphic continuity over the preceding terms (200-300 m; Tellaro Fm.).

To the east: calcarenite and calcirudite (apical Mt. Climiti Fm).

Tortonian limestone and marl.

To the west: apical Tellaro Formation, passing eastwards to the Palazzolo Formation limestone; the latter shows a lower "nodular" calcarenitic-marly alternation (Gaetanì Member) and an upper greyish calcarenitic and calciruditic level (Buscemi Member). The lower part (100 m) tends to disappear eastwards near Sortino; instead, the upper part increases up to 200 m in the same direction.

To the east: top levels of calcarenite and calcirudite, constituting the top of the Mt. Climiti Formation.

LOWER VOLCANICLASTIC DEPOSITS *(Carlentini formation: 2)*

These correspond to the late Miocene Volcanites reported in the literature by DI GRANDE (1972) and later defined by GRASSO *et al.* (1982) as the Carlentini Formation. In the northern Iblean Plateau, they constitute a fairly continuous east-west body from Mt. Lauro to the Ionian sea and represent the renewal of Cretaceous volcanism. This formation includes the slightly older Guffari valley volcanites (DI GRANDE *et al.*, 1999). They are prevalently explosion breccias, sometimes associated with pillows, hyaloclastite and subordinate lavas, of shallow submarine environment (maars, according to TRUA *et al.*, 1998) and, more rarely, subaerial. In the eastern sector, the *Lower Volcaniclastic Deposits* unconformably overlie the sedimentary basement (Mt. Climiti Fm). The breached facies bears mantle and deep crustal xenolites (POMPILIO and SCRIBANO, 1992; SCRIBANO, 1995; PUNTURO and SCRIBANO, 1997).

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[2] The number is every time referred to the numeration on the attached geological map.

In the western sector, the *Lower Volcaniclastic Deposits* overlie Late Tortonian sediments; in the eastern sector, the basal level is slightly older, fitting the age of the Mt. Climiti Formation over which they lie.

Lentini *et al.* (1986) describe some diatremes with associated volcaniclastic products, characterised in their core structure by explosive breccias with both volcanic and limestone clasts up to decametric size in a volcaniclastic and carbonatic matrix. The marginal part of the diatreme contains phreatomagmatic and arenitic deposits with volcanic and carbonatic elements, showing crossed stratification and minor parallel lamination. Load and impact structures are also present, as well as layers with «accretionary lapilli» and reverse grading.

All the observed diatreme stuctures are related to faults and are often located at their intersection. Of such areas near Melilli, the northern one (Perecontate) is the most evident, due to its size and structure. Its diatreme limits also contain sliding structures, as well as a mélange of volcanic elements and basement sedimentary rocks.

These volcaniclastic products mainly go back to two large-scale eruptive episodes (Lentini *et al.*, 1986). The first gave volcaniclastic products and lavas in the areas immediately surrounding numerous, perhaps diachronic, volcanic edifices. The second one covered a large area, with more distal products.

However, effusive activity may have been more complex, as suggested both by the diachronism of the basal levels and by the local intercalation of some marine, biohermal or calcarenitic lenses or, rarely, continental silts.

The thickness of the *Lower Volcaniclastic Deposits* varies from a few metres to over 100 m. On the basis of facies distribution, the main emission areas were located near Sortino, Carlentini, and west of Mt. Tauro. The volcaniclastic products outcropping in the latter locality are over 100 m thick and constitute a fairly isolated body with uncertain stratigraphic position.

To the east (Mt.Tauro), the *Lower Volcaniclastic Deposits* tend to disappear and may be represented (Lentini *et al.*, 1986) by a decimetric level within the carbonatic series. Outside the study area, this volcanic complex outcrops west as far as the Margi river and south as far as Solarino.

MESSINIAN LIMESTONE *(M. Carruba Formation: 3)*

The Messinian limestone, due to its notable paleogeographic significance, constitutes an important key-layer for dating the volcanism and tectonic-structural evolution of the Iblean region. Already known as «calcarenitic-ruditic-marly alternation» (Di Grande, 1972), this limestone was later called the Monte Carrubba Formation by Grasso *et al.* (1982), who locally identified a lower infralittoral and an upper tidal-lagoonal layer.

For the entire area, these sedimentary rocks testify to paralic environmental stability over a short, well-documented chronological interval. To the east, they are friable fossiliferous or oolitic calcarenite, sometimes laminated, calcirudite and fossiliferous marl up to 50 m thick. In the western sector (near Vizzini and Licodia Eubea), the Mt. Carrubba Formation is up to 150 m thick and consists of tripolaceous marl, evolving upwards, first to detritic or evaporitic limestone and then to primary or secondary gypsum. The latter is referred prevalently to the Early Messinian, as it represents the lower level of the central Sicilian evaporitic sequence. Its distribution testifies to the emergence of part of the Iblean Plateau already in the Early Messinian (Di Grande and Romeo, 1981).

PLIOCENE SEDIMENTARY SEQUENCE *(4, 6)* AND UPPER VOLCANICLASTIC DEPOSITS *(5)*

Carbonatic rocks ranging in age from early to mid-late Pliocene outcrop in the western part of the study area and outside it to the north-west. On the whole, they reveal a complete sedimentary cycle, similar to that identified in Central Sicily. At the same time, considerable eruptive activity occurred, in both continental and shallow submarine environments with, in the latter case, the development of volcanic-sedimentary alternations.

The complete sequence and structural relationships with the Miocene sedimentary units are clearly visible in the Licodia Eubea area.

The terms are described below, according to the stratigraphic sequence and spatial distribution shown on the attached map.

Marly limestone and calcareous marl (Trubi:4)

These are typically white in colour, sometimes ferruginous, mostly deeply fractured, poorly layered, passing in the upper part (Licodia Eubea) first to an alternation of marly limestone and white marl intercalated with some layers (20-70 cm) of yellowish-brown volcanic arenite, and then to whitish-blue marl. The map clearly shows their time-space relationships with the Pliocene volcanites, which close rapidly to the south and south-west, while the Trubi and marl tend to disappear to the north-east and south. On the north-western slope of the hill of Licodia, the top levels, with volcanic arenite, are involved in intraformational slumping. The thickness of this formation, usually small, reaches about 100 m near Eubea. Locally, there are monogenic calcareous breccias (Roccadia: south of Carlentini), coarse fossiliferous sand, bluish marl and silt (Mt. Lauro). Age ranges from lower to mid-Pliocene.

Upper Volcaniclastic Deposits (5)

These products are related to mainly submarine basic volcanism (tholeiitic-ankaratritic). Rare continental episodes have been identified, mainly consisting of phreatomagmatic hyaloclastite and breccias, pillow lavas and pillow breccias and, subordinately, massive lavas. Breccias *s.l.* prevail between Buccheri, Vizzini and Militello; they are yellowish in colour due to their altered hyaloclastitic matrix. They are often coarse-grained, with sharp lava elements, pillows or pillow fragments. At Licodia Eubea, they are set in a well-defined stratigraphic position, confined to the upper part of the *Trubi Fm.*, between the calcareous-marly-volcano-arenitic alternation and bluish-white marl. Northward (as far as Stazione di Mineo) they have the same lithostratigraphic position and contain numerous sedimentary lenses (0-15 m); the oldest of these sedimentary layers (near Vizzini) have *Trubi* facies, whereas the most recent (Poggio Maravola) consist of calcarenite or sandy marl.

Age is Lower-Mid-Pliocene. The maximum thickness of the *Upper Volcaniclastic Deposits* outcrops near Militello V. C. and in the Vizzini-Licodia-Mt. Tallarita area, where it reaches several hundred metres.

West of Vizzini, these volcaniclastic products show a considerable thickness reduction, due to rapid lateral heteropy with Pliocene sediments, disappearing near Licodia Eubea. South of Mt. Altore, they are mainly volcaniclastic arenite and rudite and, subordinately, both pillow lavas and columnar lavas. They are organised in numerous lens-shaped banks (0-50 m) separated by sedimentary levels (0-30 m). The latter are calcareous marl near the base and typical white marl upwards.

Between Stazioni di Vizzini-Licodia and Vizzini, sedimentary intercalations are infrequent and thin out disappearing eastwards. In this area, the *Upper Volcaniclastic Products* are arenitic-ruditic containing rare pillows, sometimes with pillow lava levels or, locally upwards, subaerial lavas with columns and onion-like exfoliation. The latter consist of spheroidal bodies (40-60 cm) of altered reddish and vesicular lavas, with coarse concentric exfoliation. Dykes oriented NW-SE, E-W, N-S and NE-SW also occur.

Brownish-yellow hyaloclastite, coarse or subordinately fine arenitic in dimension, is abundant between Licodia Eubea and Mt. Timpasecca. SCHMINCKE et al. (1997) distinguish a lower interval (Poggio Inzerillo Fm) and an upper one (Poggio Pizzuto Fm).

White Calcarenites (6)

These mid-upper Pliocene products outcrop at Licodia Eubea and NE of Mt. Tallarita. They normally overlie Pliocene volcaniclastic products, Pliocene bluish-white marl (Licodia Eubea) or Pliocene subaerial lavas (east of Stazione di Mineo). They are white-yellowish calcarenite, stratified, locally in lens-like banks, alternating with marly or yellowish marly-sandy layers. East of Timpasecca and Tallarita, they begin with thin intercalations inside the *Upper Volcaniclastic Products.*

SUBAERIAL VOLCANITES (MID-UPPER PLIOCENE / LOWER PLEISTOCENE) *(7-13)*

These products outcrop east of Licodia Eubea-Giarratana as far as the Jonian sea, covering an area of more than 50 km^2. They are massive, dark, basic lavas with both alkaline and subalkaline affinity (ROMANO and VILLARI, 1973; CRISTOFOLINI and BATTAGLIA, 1975; BATTAGLIA *et al.*, 1976). On the whole, they constitute large, usually quite thin lava flows piles, only reaching thicknesses of up to 150 m when they fill paleo-valleys. In some cases, they also consist of somewhat discontinuous subaerial volcaniclastic products.

The sequences are sometimes represented by piles of flow-units characterised by vesicular and scoriaceous lavas at the top. At the crossroads of the SS 194 road with that to Passeneto, at least two flow-units overlie submarine volcaniclastic products. Contacts are marked by reddened soil and vesicular structure in the lavas. At Mt. Altore, where the prevailing flow direction is eastwards, at least four lava flows are clearly apparent. The thickness of each flow is variable and connected to the morphology existing at the time of effusion, filling in depressions and leaving out structural highs.

The southernmost outcrops of this area are rarely affected by the tectonic activity which followed this subaerial magmatism. On the other hand, northwards, the lavas and overlying early Pleistocene sediments are involved in the Scordia-Lentini Graben development of Pleistocene age. On the whole, lava flows suture the fault lines of the mid-Pliocene tectonic phase, to which they are genetically linked.

Frequently (near Porrazzito, C. Contado, between Mass. Manchitta and C. Salafia, Mass. Badia, Cava Mulinelli near Lentini, west of Petraro, etc.), these volcanites fill pre-existing tectonic depressions and lie against previous fault planes. The latter structural condition is also made clear by the absence, certainly not attributable to erosion, of volcanites on the hanging wall of the fault. The overlying contacts are marked by an irregular surface, due to the mid-Pliocene erosive phase, which appears to have been brief and quite intense.

The lava base often shows a thin layer of onion-like exfoliation lavas, presumably linked to infiltration of steam along contraction fissures as the lava flowed on «damp» surfaces (RITTMANN, 1973).

Radiometric K/Ar determinations give absolute ages of 2.8 Ma at Mt. Cassara and 2.2 Ma at Mt. Altore (GILLOT, pers. comm.), 2.16 Ma south-west of Montagnola and 3.05 Ma at Mt. Sughereta (BARBERI *et al.*, 1974). These data are partially confirmed by the mid-Pliocene/lower Quaternary stratigraphic position. According to SCHMINCKE *et al.* (1997) and GRASSO and BENCKE (1998), the chronological interval of these volcanic products northwards is occupied by submarine deposits (Mt. Caliella Formation) passing to subaerial tholeiite (Militello Formation) and by the lower portion of the Poggio Vina Formation. The upper chronological limit is supplied by the age of the overlying early Pleistocene calcarenite and clay.

EARLY PLEISTOCENE SEQUENCE *(15, 14)*

During the lower Pleistocene, a new transgression affected the marginal sector of the Iblean region, with consequent sedimentation first in a littoral and later in a deeper environment. This sedimentary episode was interrupted by rapid uplift of the area. The distribution, thickness and facies sediments are also linked to the local morphology and to synsedimentary tectonics. They constitute a sequence of two locally heteropic lithostratigraphic units.

Yellowish-white calcarenite (15)

This formation, unconformably overlying various older lithostratigraphic terms, outcrop along the northern Iblean margin, between Francofonte and the Jonian sea, and along the eastern strip between Melilli and Agnone, where they do not reach 150 m. a.s.l.. As a consequence of their outcrop altitude, it appears that along the northern Iblean escarpment there was greater uplift than to the south, more accentuated westwards. This formation marks the beginning of the early Pleistocene transgression. Inland, the relative marine invasion produced prevalently erosive paleoforms, sometimes with thin deposits (BORDONARO *et al.*, 1984). The formation is mainly composed of soft, yellowish-white, organogenic calcarenite, locally passing to an alternation of friable calcarenite and sand or sandy marl. The fairly evident stratification (2-30 cm) is generally parallel, sometimes crossed or with slumping structures. The base sometimes contains conglomeratic lenses with numerous lava clasts (10-100 cm).

Thickness ranges from a few metres to 70 m, although borehole data indicate thicknesses of up to 150 m. Moving away from the paleocoast, thickness may be zero, passing from calcarenite to clay. Locally (near Lentini and Carlentini), variations in thickness are connected with synsedimentary tectonics, as testified by vertical layers and slumping structures (DI GRANDE and NERI, 1987; DI GRANDE, 1997, GRASSO and BENCKE 1998).

The thicknesses observed in the Agnone promontory are smaller than those of the Lentini-Augusta graben, denoting that local uplift was already beginning in the early Pleistocene. The layers dip on average north along the northern strip and east along the eastern one. These sediments also outcrop extensively outside the study area. To the west (Mineo-Grammichele-Vittoria), they pass laterally to sand and clay.

Yellow-blue clay (14)

This formation is constituted by clay or sandy clay, blue or yellowish in colour, of a deep marine environment characterised by stratigraphic continuity or local heteropy with the early Pleistocene *Yellowish-white calcarenite*. The outcropping thickness is less than 50 m, whereas borehole data show over 300 m in the Augusta graben and 250 m in the Scordia-Lentini graben.

Outside the study area, to the east and south-east, the *Yellow-blue clay* locally unconformably overlies various older formations by means of a thin (50-100 cm) sandy layer which replaces the early Pleistocene calcarenite. Westwards and northwards, the sedimentary basin was connected to the Gela Foredeep, into which the Gela Nappe took place during the lower Pleistocene (OGNIBEN, 1969; BUTLER *et al.*, 1992; GRASSO *et al.*, 1995; LICKORISH *et al.*, 1999).

MIDDLE PLEISTOCENE CALCARENITE *(16)*

This is associated with various orders of marine terraces outcropping in the north-eastern area, between 30-200 m in altitude. Most of it consists of sand, calcarenite, gravel and conglomerates, which may be related to several transgressive episodes, mainly during the Middle Pleistocene.

Locally, especially outside the study area, it is correlated with erosive marine platforms of various orders, sometimes with thin deposits, associated with marine morphosculptures (CARBONE *et al.*, 1982a, 1982b; DI GRANDE *and* RAIMONDO 1982; BORDONARO *et al.*, 1984).

OLD TERRACED CONTINENTAL SEDIMENTS *(17)*

These consist of sand, gravel, silt and black soil, and are always connected with flat morphology 50-700 m in altitude. These terraced spaces, in various orders, may be attributed to the old hydrography. In agreement with BORDONARO *et al.* (1984), the oldest and highest orders are related to late Pleistocene morphosculptures and marine deposits. The more recent terraced levels are linked to the early Holocene coastline evolution.

Some outcrops north of the Sortino area are associated with depressed volcanic morphology and genetically connected to several eruptive centres.

RECENT TERRACES AND PRESENT-DAY DEPOSITS *(18)*

These include the most recent terraced and present-day deposits connected with Holocene hydrography and evolution of coastal morphology.

LANDSLIDES *(19)* AND DEBRIS *(20)*

These are composed of old or present-day detritic bodies, alluvional fans and slumps. The most evident ones outcrop west of Mt. Lauro and are linked to original lava-flow fronts overlying clayey sediments and sliding with the substrate, perhaps connected with Quaternary tectonics.

TECTONIC OUTLINES

Tectonic phases

The relationships between outcropping lithostratigraphic units and faults define several tectonic phases. The oldest, middle Miocene in age, may be observed, with prevalently NW-SE and subordinately NE-SW faults, in the eastern part of the study area and, outside it, between Augusta and Siracusa. This tectonic fase is extensional in type and immediately followed the emplacement of the *Lower Volcaniclastic Deposits*. The shallow, relatively constant marine depth of effusion and the paralic environment of the overlying Messinian sediments testify to a period of tectonic quiescence following this phase (CARBONE *et al.*, 1982b).

During the late Miocene, immediately after or partly contemporary with the deposition of the Mt. Carrubba Fm., a further tectonic phase reveals structural lines prevalently oriented like the previous ones in the eastern area and NE-SW to the west. This phase, which in the west may extend as far as the early Pliocene, is responsible for the discordance between the early Pliocene and the older formations.

The most evident structures belong to the successive middle-Pliocene tectonic phase, which led to the definitive emergence of most of the study area. In this area, GHISETTI and VEZZANI (1980, 1981) stressed the transcurrent style of some of the tectonic structures. Examples are right transcurrent Scicli-Ragusa-Mt. Lauro and the left trascurrent Vizzini-Sortino-Siracusa lines.

The emergence of the areas still submerged in the mid-late Pliocene (Licodia Eubea, Piano Gulfieri) occurred between the mid-late Pliocene and the early Pleistocene. The structures of this tectonic phase overlap the previous ones, particularly along NE-SW, NNE-SSW and ENE-WSW directions and accentuate the horst, graben and semigraben structures already defined in previous phases. Both middle Pliocene and mid-late Pliocene-early Pleistocene tectonic phase determined the morphology governing the Pleistocene paleogeographic evolution.

Another important phase, especially due to its young age and numerous NE-SW faults, mainly developed during the middle Pleistocene and uplifted the early Pleistocene sediments. It ended before the development of the older terraced marine deposits (mid-late Pleistocene) which sometimes suture its faults.

This last tectonic phase had already been announced, during sedimentation of the basal levels of the *Yellowish-white calcarenite*, by the first uplift of the Agnone promontory and by early Pleistocene syntectonic structures present along the Iblean escarpments (Lentini, Scordia, Palagonia, Mineo, etc.) and, partly, on the western edge, by the first lower Pleistocene movements of the Gela Nappe.

The present morpho-structural configuration was reached with a further series of less important tectonic events occurring along the same faults directions as the previous ones.

According to SCHMINCKE *et al.* (1997) this tectonic evolution was enhanced by combined eustacy and subsidence.

Regarding the early Pliocene-Present age, in the eastern part of the area and near Siracusa, various uplifts and downlifts due to either tectonics or eustacy may be observed (DI GRANDE and RAIMONDO, 1982; BORDONARO *et al.*, 1984; BIANCA *et al.*, 1999). These movements gave rise to less important marine ingressions and regressions which are not represented in the described lithostratigraphic sequence. At the present time, the coast near Siracusa appears to be involved in a transgressive marine phase, as revealed by submerged Greek and Roman settlements.

Principal folds

In the study area, folds are well represented although the prevalent tectonic elements are faults. According to the formations involved, these folds may be divided into two groups: folds involving older terrains, extending as far back as the mid-late Pliocene; and folds also involving Quaternary formations. The folded areas are sometimes characterised by inverted relief.

The most evident older folds are the following:

– *Licodia Eubèa Synclinorium* and minor correlated synclines and anticlines, all inverted in relief, ranging in age from early Miocene to mid-late Pliocene. The principal fold axis runs NE-SW; secondary fold axis, linked to the Messinian-early Pliocene tectonic phase, run NW-SE.

– *Boschitello Brachyanticline,* with inverted relief, involving outcropping early Cretaceous-middle Miocene units. It is cut by many small faults and interrupted to the NE by a large fault connecting it with the *Licodia Eubea Synclinorium.*

– *Monterosso Almo Anticline,* involving the same outcropping terms as the previous structure. A fault with large displacement puts it in contact with the *Boschitello Brachyanticline.*

– *Palazzolo-Sortino Monocline*, which includes other minor structures, consisting of outcropping Miocene terms.

The Quaternary group is essentially formed of monocline structures and subordinate bland anticlines and synclines. The most important are the *Francofonte Monocline,* dipping east, and the *Lentini Monocline,* dipping north.

Faults and related structures

The faults examined, mostly with subvertical planes and extensional in character, are more evident in the limestone outcrops. On the basis of terrains involved, the mapped faults were divided into two groups in the geo-petrographic map. The first group contains faults connected with the older tectonic phases and later partly renewed and are generally older than the middle Pliocene, although they were still active occasionally and locally during the late Pliocene. The second group contains mainly Quaternary faults. At times, the group 2 faults are the prolongations of group 1, giving rise to the hypothesis of a later revival.

Fault displacements range from a few to a hundred metres in group 1 and from a few to 50 m in group 2. In both cases, the sum of single displacements leads to structures with several hundred metres of total displacement.

The group 1 faults occurring in the southern area involve formations ranging from Cretaceous to mid-late Pliocene and are linked to the older tectonic phases. To the east, as already stated, the prevailing direction is NW-SE but NE-SW to the west; in the intermediate area, both directions are present. There is also a variety of minor directions throughout the region.

Group 2 also involves the early Pleistocene units. Their Holocene revival is possible, although at the moment it cannot be demonstrated. These Quaternary tectonic faults, oriented mainly NE-SW, occur in the northern area.

The distribution of the two fault groups suggests that the uplift of the Iblean Plateau occurred first to the south of the Licodia Eubea-Lentini-Agnone line.

The fault association gave rise to more or less uplifted or downlifted structures, generically called horsts and grabens. According to the age of the faults two structural groups are distinguished, although they appear geometrically interconnected and are sometimes overlain.

According to the age of the faults, figure 2 shows the areas which were prevalently uplifted and those which were downlifted. For the older group and in the context of the uplifted areas, two categories are distinguished, according to intensity of uplift.

The main structures of the group 1, often covered by more recent formations, are:

– *Contrada La Caduta Horst,* immediately south of Licodia Eubea, bounded to the north by a fault with a large displacement involving early Cretaceous-Pliocene units and active during and immediately after the sedimentation of all the Pliocene deposits. To the south, it is bounded by faults with smaller displacements. It partially delimits the *Boschitello Anticline.*

– *Vizzini-Mt. Pancali-Agnone Horst,* stretching E-W and partially connected with the previous structure. In the early Pleistocene, it constituted the structural element of connection between the emerging Iblean area and the northern submerged area.

– *Monterosso-Villasmundo Horst:* this defines an uplifted area, stretching NE-SW, interrupted near Giarratana by the Roccaro graben. It forks between Mt. S. Venere and

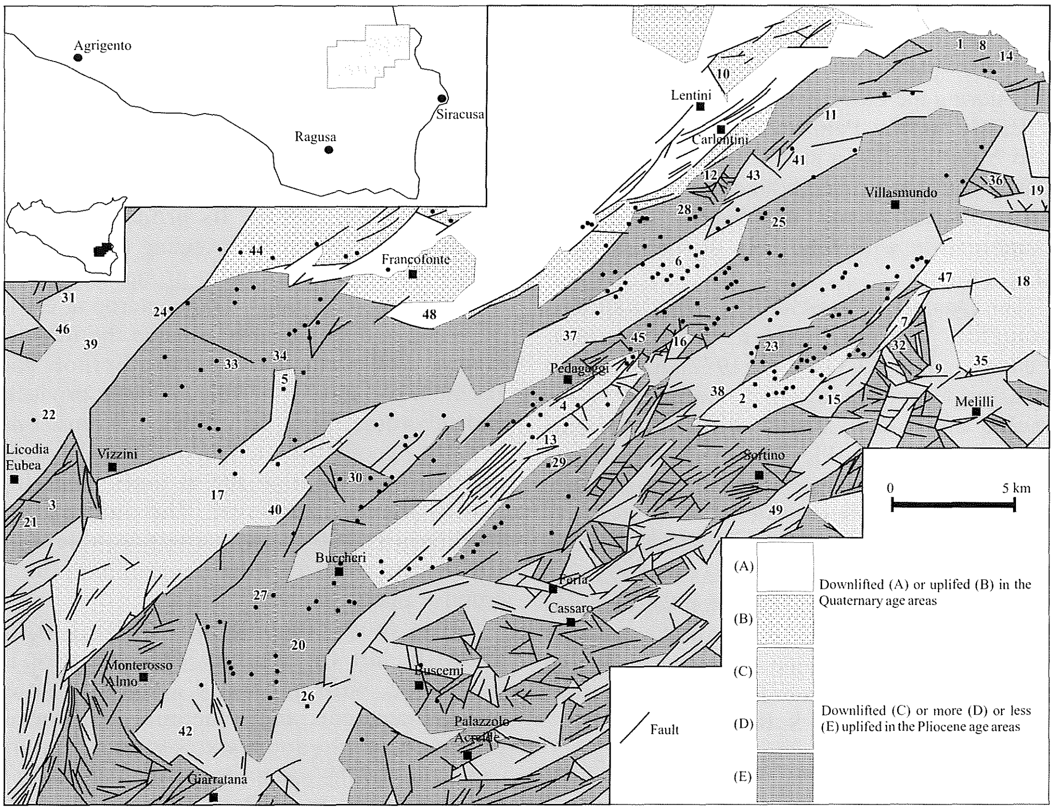

Fig. 2 – Structural scheme of study area. 1-49 Location of the more important localities mentioned in the text: 1) Agnone; 2) Badia; 3) Boschitello; 4) C. Abbadia; 5) C. Bordonali; 6) Casazza; 7) C. Salafia; 8) Castelluccio; 9) Cava dei Molini; 10) Cava Mulinelli; 11) Contado; 12) Contrada Bosco; 13) Costa Castagna; 14) Costa Saracena; 15) Cucuzzedda; 16) Cuppodia; 17) Fiume Grande; 18) Fiume Marcellino; 19) Fiume Mulinello; 20) Guffari; 21) La Caduta; 22) M. Altore; 23) M. Carrubba; 24) M. Casenuove; 25) M. Cassara; 26) M. Erbesso; 27) M. Lauro; 28) M. Pancali; 29) M. S. Venere; 30) M. Sughereta; 31) M. Tallarita; 32) Manchitta; 33) Montagnola; 34) Passanetello; 35) Perecontate; 36) Petraro; 37) Pezzagrande; 38) Pianette; 39) Poggio Maravola; 40) Poggio Morbano; 41) Porrazzito; 42) Roccaro di Margi; 43) Roccadia; 44) S. Biagio; 45) Serra Paradiso; 46) Timpasecca; 47) Torrente Belluzza; 48) Torrente Risicone; 49) Valle Giardini.

Pedagaggi, owing to the insertion of the Costa Castagna Graben (a highly asymmetrical structure with its south flank formed of numerous faults with small displacements and its north flank consisting of a single fault with a large displacement). To the west, it is bounded by the Licodia Eubea-Passaneto depressed area.

– *Costa Saracena Horst*: this constitutes the emerging connection with the Iblean-Maltese Escarpment.

– *Fiume Grande Graben*, immediately south of Vizzini: stretching NE-SW, to the north it presents two splits and its boundary appears quite unclear; to the south, between Vizzini and Monterosso, it is bounded by a fault with a large displacement.

– *Pezzagrande-Casazza Graben*, south of Mt. Pancali, very clearly bounded by faults with large displacements.

– *Badia Graben*: a small, well-defined structure south of Mt. Carrubba.

– *Marcellino Graben and Augusta Graben*: only their western tips are *visible*. These structures played an important paleogeographic role during the Early Pleistocene transgression.

Lastly, in the Palazzolo-Buscemi, Sortino and Melilli areas, a series of horst structures developed, sometimes bounded by faults with large displacements, in irregular geometric combination with relatively depressed areas (Fig. 2).

The Quaternary structures (group 2) are less complex. The most evident is the Scordia-Lentini graben (Di Grande, 1972), a important structural depression which, due to previous faults, was re-activated at different moments until the mid-early Pleistocene. Together with other grabens (Simeto, Augusta, Marcellino, Floridia, etc.), it is considered a «pull-apart» structure with respect to the tectonic line of the Iblean-Maltese escarpment (Grasso, 1993). To the south and west, the connection between this Scordia-Lentini structure and the already uplifted part of Pliocene age occurs through weakly uplifted areas (Francofonte horst, Carlentini semigraben, S. Biagio horst, etc.).

VOLCANOLOGICAL AND PETROGRAPHIC OUTLINES

The study of the Plio-Quaternary subaerial lavas cannot neglect an examination of Iblean magmatic activity as a whole. Volcanites, occurring at various levels in the sedimentary series from late Trias to Quaternary, although characterised by variable volumes of products, always reveal brief periods of magmatic activity.

The oldest magmatic rocks, discovered by borehole data, refer to two magmatic episodes (late Trias and middle Jura; Cristofolini, 1966a, 1966b; Patacca *et al.*, 1979). On the basis of their textural features, these products reveal either powerful submarine effusions or intrusions into unconsolidated, highly water-imbibed sediments. The occurrence of zeolite and clay minerals testifies to strong post- and late-magmatic alteration. Chemically these volcanic products are classified as hawaiite, basanite and alkaline basalt. Parageneses show the presence of olivine, augitic ± titaniferous clinopyroxene, plagioclase, sometimes with albitic edges, ± titaniferous magnetite, and sporadic kaersutite, biotite and apatite.

The subsequent volcanic activity is late Cretaceous in age (67-84 Ma, according to Barberi *et al.,* 1974). Its products are the oldest volcanic terms outcropping in the Iblean area. The map shows them grouped together with the basement units. They outcrop at Costa Saracena and southwards, outside the map, at Gisira, S. Cusumano, Biggemi, Epipoli and Pachino, and consist of volcaniclastic products and subordinately of lava flows. Carveni *et al.* (1991b) hypothesised a single volcanic dorsal, prevalently submarine and at times emerging barely above water level. The outcropping thickness is 150 m, whereas borehole data show from 400 to 600 m, probably near eruptive plugs.

Lavas show compositions ranging from alkali-basalt to basanite. The texture is porphyric, with generally altered olivine, augite-titanaugite, and sometimes labradoritic plagioclase phenocrysts, set in a matrix consisting of the same phases plus magnetite. In some places (e.g., Capo Passero), the lava has a cumulitic character (De Rosa *et al.*, 1991).

Ben-Avraham and Grasso (1990) suggest that Jurassic and Cretaceous volcanism in the eastern Iblean area is related to the setting of a passive margin between the continental Iblean and Ionian basin crusts, later evolving into the Iblean-Maltese escarpment. After a gap of about 55 Ma, there was a renewal of eruptive activity, with the production of Miocene-Quaternary volcanites.

The studied products are those of the late Miocene (7-5.5 to 4.9 Ma), lower-mid Pliocene (4.9 to 3.5 Ma) and mid-Pliocene-early Pleistocene *pro parte* (2.4 and 1.64 Ma).

Late Miocene Volcanism

Tortonian volcanites (7-5.5 to 4.9 Ma) are represented by prevalently volcaniclastic products (*Lower Volcaniclastic Deposits*) and mostly lie between the mid–late Miocene Tellaro Fm. and the early Messinian Mt. Carrubba Fm. In the Palagonia-Militello area, SCHMINCKE *et al.* (1997) note levels of Messinian nephelinitic lavas.

The products of this volcanism outcrop in the north-eastern sector of the area between Lentini, Agnone and Floridia, and unconformably overlie Oligo-Miocene limestone (GRASSO *et al.*, 1982). They are linked to several eruptive centres with presumably asynchronous activity. Three facies are distinguished: 1) an explosion breccia facies proximal to the eruptive centre, corresponding to a high-energy system (LENTINI *et al.*, 1986); 2) a distal parallel lamination facies; 3) a crossed lamination facies, intermediate between the two previous ones.

At Contrada Bosco (near Carlentini), four lava flows with metric thickness interbedded with volcaniclastic products represent emersion episodes during volcanic activity. They are massive, fractured, and present onion-like desquamation associated with columnar structures.

Late Miocene volcanism also gave rise to phreatomagmatic activity, linked to the eruptive systems already reported by LENTINI *et al.* (1986) as diatremes, on the basis of facies distribution and the presence of collapse and slumping structures. Diatreme areas are frequently found along fault or sometimes where they cross. The most evident ones are:

– The Sortino system, which involves an area of about 15 km^2, with its centre at Valle Giardini. This area probably extends even further south as far as Chianazzo, where the edges of the diatreme area are hidden by detritus and alluvial deposits. In the centre of the volcanic edifices, ruditic facies occur with carbonatic blocks sometimes several metres in diameter, whereas arenitic facies prevail in more distally. Biolithites are interbedded in the sequence, testifying to pauses in eruptive activity.

– The two diatreme areas in the high Fiumarella valley and Monti Cuppodia (~ 5 km east of Pedagaggi).

– The diatremes north of Melilli, immediately adjacent to the Cava dei Molini, have a fairly limited volume of products and occupy a total surface area of about 10 km^2. The northernmost edifice in particular shows evidence of landslipping towards the inside, due to slumping of the filling material of the eruptive plug.

– The two diatremes east and south-east of Petraro (~ 5 Km east of Villasmundo), along the Mulinello Valley.

– The area near Torrente Belluzza, south of Villasmundo, identified by two fragments of the diatremic border.

– The large eruptive Guffari system (20-30 Km^2) appears to be rather fragmentary and unclear, except for some small sectors of the crater border which have been tentatively identified in the high Anapo Valley.

Outside the examined area, between Melilli and Solarino, other diatreme systems were observed by LENTINI *et al.* (1984, 1986) at Pozzi di Climiti, Costa S. Lorenzo, Passo di Siracusa and Cugno delle Canne. To the west, others have been reported in the Mineo-Palagonia-Militello V.C. area, and some eruptive centres are reported by CARVENI et *al.* (1991a) in the northern Iblean area.

The petrographic and petrochemical characteristics of the Late-Miocene volcanites show generalised primitive and alkaline affinity (alkaline basalt, basanite, nephelinite, ankaratrite), subordinately subalkaline (ol- or qz-normative tholeiite). Alkaline products have a variable porphyric index (P.I.): 15% and 20% in alkaline basalt and nephelinite, up to 30% in basanite, and up to 35% in ankaratrite.

Paragenesis is olivine, clinopyroxene, plagioclase and opaque minerals and, in more SiO_2-undersaturated products, nepheline and sporadic hauyne. On the other hand the subordinate subalkaline volcanites are generally subaphyric (P.I. < 10%). Phenocrysts, when present, are represented by orthopyroxene in qz-normative tholeiite and by pigeonite in ol-normative tholeiite, olivine and occasionally plagioclase. The groundmass, with an intersertal or intergranular structure, consists of plagioclase and pigeonite microcrysts, opaque minerals and sporadic glass.

The genesis of these products is referred (BIANCHINI, 1996; BIANCHINI *et al.*, 1998) to different rates of partial melting of a lithospheric mantle characterised by heterogeneity due to metasomatic events induced by alkaline-silicatic and/or carbonatitic melts, forming as a result of very low degrees of partial fusion in the sublithospheric mantle.

Lower – middle Pliocene Volcanism

Intense, principally submarine, effusive activity occurred between the early and middle Pliocene, prevalently in the northern Iblean area. The environment was deeper than that connected with the Tortonian volcanism. The products, both sub-alkaline and alkaline, outcrop near Mt. Lauro and mainly north of Licodia Eubea-Vizzini, where they reach several hundred metres in thickness. Some cycles of activity are identified, variously distributed in time and space, as revealed by associated sediments. The products of early-mid-Pliocene volcanism are represented by volcaniclastic products, although pillow, submarine and locally subaerial lavas also occur. The petrographic characteristics are the same as similar late-Miocene products, as well as those of the volcanites of the middle and late Pliocene/early Pleistocene, which will be examined later.

The lack of evidence of eruptive centres may be related, at least in the lower and middle levels, to the environment and to hydrostatic volcanic activity, as well as to basin subsidence. Gravitative reworking (*sensu* SCHMINCKE *et al.*, 1997) may also have obliterated the original eruptive morphology.

Middle-late Pliocene /early Pleistocene Volcanism

Intense subaerial eruptive activity began from the middle Pliocene, as evidenced by stratigraphic and structural analysis. Radiogenic age determinations show that this activity was not rigorously synchronous in the whole area. Products outcrop north of the study area, which had already emerged owing to the mid-Pliocene tectonic phase, and were emitted by many eruptive centres mainly aligned along structural directions.

Uplift in different Iblean sectors presumably occurred at different moments. The Mt. Lauro area probably emerged first, and was followed by the Vizzini and Agnone sectors, and both immediately underwent first severe erosion and then subaerial volcanism. Last to emerge was the Licodia Eubea-Mineo Station area, where there was a marine-littoral environment until the mid-late Pliocene. This evolution was linked to sedimentary-eustatic activity, tectonics and erosion, as testified by the unconformity between the subaerial volcanites and the older units.

To the south, these volcanic products were not involved in Quaternary tectonics, but to the north they were involved, together with the overlying sediments in the Quaternary Scordia-Lentini graben.

On the whole, the subaerial eruptive levels evolved northwards to prevalently shallow submarine volcanites, and the upper chronological limit is defined by early Pleistocene calcarenite and clay. In the Palagonia-Militello area, the eruptive environment evolved from submarine to subaerial by gradual emergence of volcanic systems and the formation of lavic deltas and other exogenous depositional bodies (SCHMINCKE *et al.*, 1997).

Detailed morphological-structural study and lava chemistry analysis of the mid-late Pliocene/early Pleistocene volcanites both define:

- Flow units : single lava flows;
- Volcanic bodies: one or more flow units with similar chemical and petrographical characters, linked genetically and structurally to one or more centres. At times, sequences of different flow units are observable, separated by reddened surfaces;
- Centres or vents: sometimes neck structures with well-oriented columnar lavas;
- Edifices: volcanic structures characterised

by one or more volcanic bodies and by one or more centres.

Although erosion lasted several million years, it is still possible to identify residual volcanic morphologies with effusive centres in the upper part and advancing lava fronts, sometimes dismembered.

West and SW of Mt. Lauro, the broad, thick, lava block deposits at the base of the volcanic escarpment are interpreted as connected with lava fronts resting on clayey sediments, later dismembered by gravitative landslip.

Other important morphogenetic elements are the silty-sandy sediments associated with flat areas near eruptive centres.

Steeply sloping lava fronts occur almost everywhere (i.e., north and SW of Mt. Casenuove, west of Poggio Morbano; north of C. Bordonali, in the upper valley of the Torrente Risicone; at C. Abbadia, on the eastern side of Mt. S. Venere; at Cucuzzedda, at Serra Paradiso, where a crater has also been hypothesised, and in several systems between C. Bordonali, Passanetello and Montagnola).

Scoria bodies occur east of Mt. Casenuove, at Mt. Erbesso, and east of Mass. Passanetello.

The Mt. Altore edifice (2.2 Ma), a few kilometres north of Licodia Eubea, has a single eruptive centre with several flow units, reddened at the base and scoriaceous at the top; its products lie, with noteworthy discordance, on Pliocene volcaniclastic products.

Near Mt. Casenuove, north of Vizzini, are two edifices with strongly dipping lava flows on their northern flanks: the eastern one is associated with scoria products.

Mt. Erbesso is the southernmost edifice and has a scoria crater.

North and west of Ferla, several monocentric edifices have been mapped: the most evident is at Mt. S. Venere, showing locally, along the Buccheri road, columnar lavas and neck-type structures at the centre.

The Serra Paradiso edifice (NE of Pedagaggi) is a polycentric volcanic structure, with a ring of craters with inner depressions characterised by explosion products. It is bounded to the south by a fault plane, and in other directions shows strongly dipping lava flows; at least two of its centres lie along the fault extensions.

Other polycentric structures along fault lines are found 2-4 km SW of Pedagaggi. The Mt. Pancali dorsal (SW of Carlentini) consists of numerous poly- or monocentric edifices aligned NE-SW. They dip strongly northwards with a difference in level of about 100 m.

The Pedagaggi-Mt. Pancali plane corresponds to a graben structure (Casazza) partly covered by later alluvial sediments, and reveals many edifices and centres running NE-SW.

Various polycentric eruptive systems occur in the Monte Carrubba area. Their centres are aligned rigorously NE-SW and are frequently associated with Quaternary sediments in depressed volcanic morphologies.

To the NE, near Castelluccio, a few monocentric systems have been identified, with products flowing mainly eastwards.

A total of 189 centres and 126 eruptive edifices has been identified, although it is not always possible to define the stratigraphic relationships among the various systems.

All volcanic products, classified according to the TAS diagram (Fig. 3) and CIPW normative composition calculated on the basis of FeO/Fe_2O_3 suggested by MIDDLEMOST (1989), are grouped as:

- Qz-normative tholeiitic basalt;
- Ol-normative tholeiitic basalt;
- Weakly alkaline and transitional basalt;
- Alkaline basalt;
- Hawaiite;
- Basanite;
- Ankaratrite.

Selected analysis performed by XRF are reported in tables (1, 2, 3, 4);

The structure of all the volcanites is porphyric or microporphyric with low, variable P.I., according to petrographic type.

Various modal compositions are observable. Qz-normative tholeiitic basalt has olivine (fo = 81-82%), orthopyroxene, plagioclase ± augite phenocrysts, and a groundmass with pigeonite, opaque minerals and small amount of glass. In

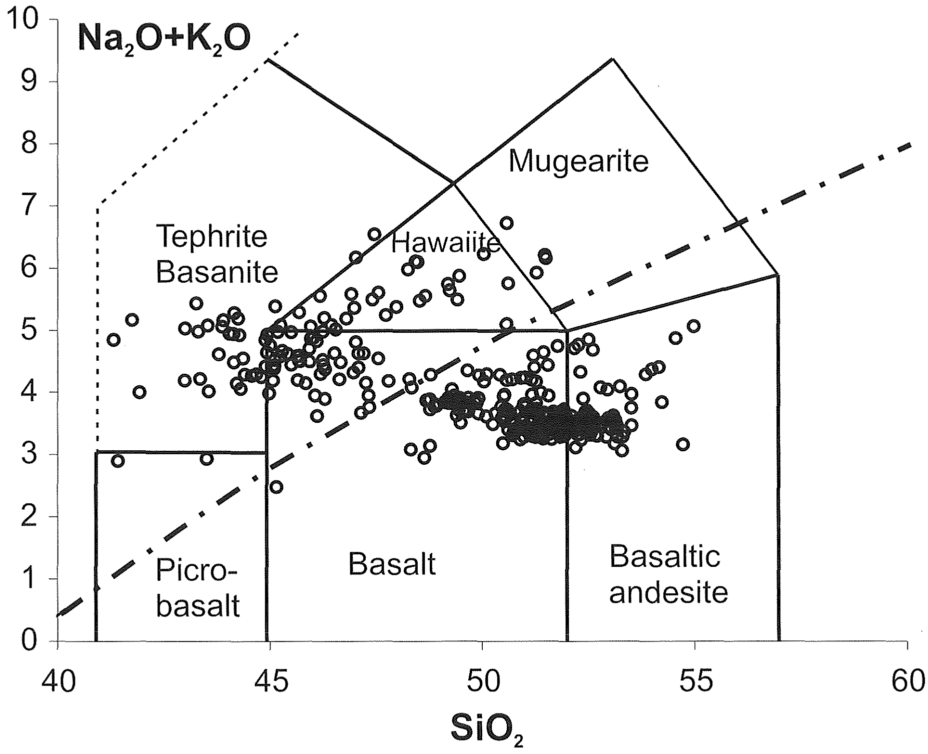

Fig. 3 – Total alkali-silica diagram (after LE BAS *et al.*, 1992) for Iblean Plio-Pleistocene subaerial volcanites. Dotted-dashed line divides subalkaline and alkaline fields (after IRVINE and BARAGAR, 1971).

ol-normative tholeiite, the phenocrysts are olivine, augite and plagioclase; pigeonite is the typical groundmass pyroxene. Alkaline lavas contain olivine (fo = 85-89%), salitic pyroxene and plagioclase phenocrysts to which, in the groundmass, nepheline is associated in variable and increasing amounts from basanite to ankaratrite; the latter contains hauyne and rare amphibole in the ocelli of primary carbonates.

The olivine liquidus temperature (ROEDER and EMSLIE, 1970) ranges between 1165°C (qz-normative tholeiite) and 1260°C (ankaratrite).

Apart from their alkalinity degree, many lavas are relatively undifferentiated. The occurrence of mantle xenoliths in the alkaline terms, together with the low P.I., testifies to rapid magma ascent. The more primitive terms of each lava group have high Mg numbers and Ni contents indicating the primitive character of the magma. Petrological data reveal varying degrees of partial melting, decreasing from tholeiite to ankaratrite, and may mean that these volcanites are associated with independent original magmas.

TECTONICS AND VOLCANISM

The Iblean area reveals the link between magmatism and extensional-transtensional tectonics, the latter mainly linked to the structural NE-SW direction and characterised by both strike-slip and vertical movements (GHISETTI and VEZZANI, 1980; BEN-AVRAHAM and GRASSO, 1990; BARRIER, 1992). The geometrical relationships between volcanites and tectonic elements clarify their chronological evolution and allow us to formulate a petrogenetic model (BECCALUVA *et al.*, 1998).

Tortonian subacqueous volcanism may be considered the immediate consequence of the midle Miocene tectonic phase (later revived in the Pliocene-Quaternary). The diatremes are always found in a clear structural position: either at the intersection of fault lines, sometimes with opposite displacement, or in areas of high-density tectonic lines. Effusive activity followed the tectonics after slight uplift and erosion, as testified by: 1) phreatomagmatic volcanism; 2) the unconformity between volcaniclastic products and Miocene sediments; 3) the absence of any late Miocene continental occurrences; 4) the stratigraphic continuity between mid–late Miocene and Messinian sediments in neighbouring areas where this volcanism did not occur.

Pliocene volcanism was prevalently submarine and occurred during a period of relative tectonic stasis, which allowed mainly subsiding basins to be filled in. This is shown by the lithological and bathymetric features of sediments associated with or overlying the volcanites. In this paleogeographic environment, it is possible to collocate the volcanic facies found to the north by SCHMINKE *et al.* (1997), partly correlated with Pliocene volcanism.

Unlike the Miocene and Pliocene submarine volcanites, field data regarding subaerial Plio-Pleistocene volcanism may contribute to further knowledge of the connection between volcanism and tectonics. In the southern part of the study area, where faults strongly control the carbonate basement, it is clear that these subaerial volcanic products were not affected by Miocene-mid-Pliocene tectonics. On the contrary, they suture the faults, according to tectonic morphology. In addition, the lava flows often follow the direction of pre-existing faults (Petraro, east of Villasmundo; Serra Paradiso, NE of Pedagaggi; near Mass. Manchitta, NW of Melilli; Cucuzzedda, west of Melilli; Pianette, SW of Mt. Carrubba, etc.). A similar situation occurs in the northern flank of the Monterosso-Villasmundo horst, along the large Pedagaggi fault. Eruptive centres along or near faults or along their continuation are frequent (SW of Pedagaggi, Serra Paradiso, near Mt. Carrubba, etc.).

On the whole, these elements are sufficient to hypothesise that the most recent volcanism took place within the framework of the mid-Pliocene extensional tectonics and that magma ascended along the faults, occasionally deviating only in the final tract.

This volcano-tectonic evolution is also supported by the recent hypothesis which considers the mid-Pliocene extensional tectonic phase as linked to strike-slip lines (GHISETTI and VEZZANI, 1981; GRASSO, 1993). Volcanism may also be the consequence of the pull-apart structures previously mentioned.

Comparisons between the axes of tectonic and volcanic directions clearly highlight reciprocal interference. In the structural diagram, shown on the attached map, in which fault lines are incorporated in a single group, the prevailing NE-SW direction of volcanism is evident.

CONCLUDING OBSERVATIONS

Subaerial mid-late Pliocene/early Pleistocene volcanic products are an essential feature of the Iblean geopetrographic and structural evolution. They derive from basic, relatively undifferentiated magmas with compositions ranging from nephelinite-hawaiite to tholeiite (BECCALUVA *et al.*, 1998).

Late Miocene–Quaternary tectonics play a fundamental geodynamic role. In particular, six tectonic phases (fig. 4) are identified in the following periods: 1) middle Miocene (late Serravallian-early Tortonian); 2) late Messinian; 3) middle Pliocene; 4) mid-late Pliocene-early Pleistocene; 5) middle Pleistocene; 6) late Pleistocene-Holocene.

TABLE 1

Selected analyses of Qz-normative tholeiitic basalts

Sample	I 325	I 331	I 341	I 342	I 382	I 383	I 389	I 391	I 393	I 394	I 407	I 419	I 564	I 565	I 566	I 569	I 576	I 608	I 613
SiO_2	51.61	50.47	53.81	54.92	53.40	50.65	51.25	50.19	51.92	52.73	52.65	53.24	52.12	51.76	52.22	51.05	52.81	51.61	52.76
TiO_2	1.58	1.83	1.72	1.62	2.05	2.03	2.05	1.90	1.80	1.85	1.57	1.88	2.04	1.59	1.69	1.81	1.22	1.62	1.53
Al_2O_3	16.85	16.53	15.93	16.22	15.54	16.10	16.15	15.89	15.94	14.80	16.03	16.41	16.08	16.67	16.19	16.97	16.61	16.22	16.53
Fe_2O_3	2.02	4.87	4.12	2.20	3.58	3.42	2.71	4.28	2.96	4.57	3.02	6.74	6.22	4.83	4.32	7.62	4.18	2.42	3.25
FeO	8.11	5.48	5.02	6.36	5.69	7.34	7.07	6.25	6.63	5.62	6.83	2.75	4.31	5.17	5.78	2.76	5.19	7.49	6.56
MnO	0.16	0.14	0.13	0.13	0.12	0.15	0.14	0.14	0.14	0.13	0.14	0.13	0.15	0.13	0.15	0.13	0.13	0.14	0.14
MgO	5.89	5.48	4.62	4.29	5.53	6.04	5.48	5.61	5.65	5.37	5.99	6.07	5.32	5.90	5.48	5.44	6.13	7.00	5.59
CaO	8.90	9.39	7.92	7.62	8.78	9.36	9.06	9.25	9.29	9.14	9.02	8.84	8.77	8.48	8.47	8.53	8.28	8.71	8.70
Na_2O	3.46	3.55	3.85	4.31	3.23	3.37	3.46	3.25	3.58	3.39	3.36	3.41	3.35	3.14	3.17	3.11	3.59	3.43	3.21
K_2O	0.21	0.21	0.62	0.86	0.25	0.20	0.22	0.14	0.26	0.39	0.22	0.23	0.29	0.28	0.29	0.22	0.47	0.11	0.18
P_2O_5	0.24	0.55	0.30	0.33	0.27	0.36	0.31	0.39	0.42	0.50	0.29	0.30	0.25	0.25	0.29	0.22	0.26	0.25	0.24
L.O.I.	0.97	1.50	1.97	1.14	1.54	0.98	2.11	2.72	1.40	1.51	0.89	0.00	1.10	1.80	1.96	2.12	1.13	0.99	1.31
mg*	0.55	0.53	0.51	0.51	0.55	0.54	0.54	0.52	0.55	0.52	0.56	0.59	0.51	0.55	0.53	0.52	0.57	0.60	0.55
Ni	217.4	217.5	139.4	135.5	198.9	177.7	192.3	173.7	200.8	213.6	205.2	211.7	144.9	192.3	168.1	170.7	180.4	254.3	198.5
Co	42.2	40.3	33.9	36.2	37.5	42.8	38.4	40.8	40.9	37.7	41.2	40.3	39.1	40.9	43.1	40.7	39.9	44.7	39.1
Cr	322.9	318.4	243.6	207.8	293.8	354	294.6	309.3	278.3	288.9	288.4	328.3	196.9	269.7	197.9	270.7	286.3	453.4	289.7
V	162.8	150.7	135.5	137.8	143.1	181.3	172.4	176.6	163.6	168.5	167.9	149.3	165.6	144.8	153.2	152.6	143.2	160.5	159.7
Pb	11	16.6	14.6	13.7	17.3	7.9	8.9	9.8	13.2	14.7	6.7	5.5	16.3	12.7	16.3	9.1	12.8	9.5	5.6
Zn	106	107.5	117.6	112.9	109.1	127.8	115.2	117.6	107	111.8	107	101.1	120.4	112.3	117.7	122.6	110.2	108.2	106.6
Th	0	0	4.8	1.4	4.2	0	3.3	3.4	4.2	3.3	3.2	1.4	0.1	0.7	2.1	2.5	4.9	2	2.8
Nb	9.4	21.9	31.3	31	15.3	19.8	11.5	18.5	24	24	13.1	13.1	20.1	16.4	15.5	17.4	23.2	7	9.5
Zr	94.5	129.6	201.9	219.4	152.3	133.5	123.6	141.8	146.6	164.4	107.1	118.6	171.5	141.4	154.3	148.8	171	68.9	78.3
Rb	5.8	2	13	20.1	1.6	5.3	3.8	1.6	5.1	4.8	2.8	5.2	5.5	3.2	5.1	3.6	8.9	1.3	1.6
Sr	200.1	412.4	351.5	346.2	313	336.1	274.3	336.3	349.2	338.6	259.2	324.6	315	310	312.4	280.3	308.6	177	201.5
Ba	104.7	180.5	253	262.7	117.3	145.8	267.6	125.6	178.6	161.9	88.3	170.1	151.9	147.6	175.7	152.3	180.9	84.2	90.8
La	8.8	17.1	12.8	21.4	0	15	8.5	12.6	29.7	10.7	16.9	15.4	13.2	10.1	20.4	10.7	13	1.3	0
Ce	27.5	45.7	49.7	44.2	16.7	36.6	23.7	27.2	26.5	31.6	43.2	43.9	23	21	42	13.4	34.9	15.8	31
Y	24.7	30.4	26.6	26.4	24.7	32.7	29.6	28.5	28.5	34.7	22.4	26.6	31.3	26.6	35.4	28.4	23.2	22.9	26

TABLE 1: *Continued*

Sample	I 325	I 331	I 341	I 342	I 382	I 383	I 389	I 391	I 393	I 394	I 407	I 419	I 564	I 565	I 566	I 569	I 576	I 608	I 613
Q	0.64	0.03	3.97	3.07	5.81	0.06	1.86	1.23	1.44	3.77	2.57	3.61	2.93	2.76	4.00	2.70	1.08	0.26	4.23
Or	1.24	1.25	3.66	5.08	1.48	1.18	1.30	0.83	1.54	2.30	1.30	1.37	1.71	1.65	1.71	1.30	2.78	0.65	1.07
Ab	29.30	30.14	32.58	36.47	27.33	28.57	29.32	27.50	30.29	28.69	28.43	29.02	28.35	26.57	26.82	26.32	30.38	29.06	27.21
An	29.85	28.65	24.36	22.37	27.17	28.27	27.92	28.36	26.66	24.02	28.01	28.95	27.98	30.57	29.09	31.70	27.82	28.57	30.22
Wo/Di	5.33	6.05	5.42	5.54	6.11	6.64	6.29	6.26	6.97	7.54	6.20	5.50	5.80	4.12	4.61	3.84	4.83	5.45	4.78
En/Di	2.81	3.15	2.74	2.79	3.36	3.54	3.38	3.22	3.74	3.87	3.32	3.15	2.94	2.19	2.37	1.96	2.62	3.10	2.52
Fs/Di	2.36	2.73	2.55	2.62	2.52	2.90	2.70	2.87	2.99	3.48	2.67	2.11	2.72	1.81	2.12	1.79	2.04	2.11	2.12
Cpx	10.50	11.93	10.71	10.95	11.99	13.08	12.37	12.35	13.70	14.89	12.19	10.76	11.46	8.12	9.10	7.59	9.49	10.66	9.42
En/Hy	11.87	10.54	8.76	7.89	10.41	11.53	10.29	10.75	10.33	9.50	11.59	12.05	10.31	12.51	11.28	11.59	12.64	14.35	11.43
Fs/Hy	9.99	9.12	8.15	7.41	7.82	9.45	8.22	9.59	8.26	8.53	9.33	8.09	9.53	10.36	10.08	10.59	9.83	9.76	9.64
Opx	21.86	19.66	16.91	15.3	18.23	20.98	18.51	20.34	18.59	18.03	20.92	20.14	19.84	22.87	21.36	22.18	22.47	24.11	21.07
Mt	2.09	2.08	1.90	1.77	1.91	2.19	2.00	2.17	1.99	2.12	2.04	1.86	2.17	2.07	2.09	2.15	1.94	2.03	2.00
Il	3.00	3.49	3.27	3.08	3.89	3.86	3.90	3.61	3.42	3.51	2.98	3.59	3.87	3.02	3.21	3.44	2.32	3.08	2.91
Ap	0.57	1.31	0.71	0.78	0.64	0.85	0.74	0.92	0.99	1.18	0.69	0.71	0.59	0.59	0.69	0.52	0.62	0.59	0.57

TABLE 2

Selected analyses of ol-normative tholeiitic basalts (I 328 – I 578)
and weakly alkaline and transitional basalts (I 345 – I 577)

Sample	I 328	I 333	I 337	I 396	I 398	I 570	I 578	I 345	I 365	I 368	I 517	I 577
SiO_2	50.33	50.53	49.97	50.91	50.95	50.82	50.63	49.53	47.41	49.75	48.42	48.94
TiO_2	1.66	1.58	1.79	1.91	1.48	1.35	1.66	1.76	2.27	2.30	1.85	1.68
Al_2O_3	15.77	17.00	16.5	14.84	16.75	16.41	16.79	16.19	16.01	15.44	16.73	16.02
Fe_2O_3	3.11	2.51	5.51	6.30	2.54	4.08	5.06	4.37	4.82	3.11	10.33	3.35
FeO	6.09	7.42	4.64	4.26	6.95	6.13	4.94	6.47	5.86	7.51	1.54	7.38
MnO	0.14	0.15	0.13	0.15	0.16	0.14	0.15	0.15	0.16	0.15	0.12	0.15
MgO	5.60	6.54	5.94	5.91	6.01	6.38	6.77	5.72	6.48	6.46	4.35	7.43
CaO	8.45	8.88	9.28	9.21	9.07	8.82	9.05	9.41	10.4	9.26	10.01	9.46
Na_2O	4.15	3.78	3.45	3.72	4.04	3.51	3.33	3.74	3.31	3.83	3.82	3.44
K_2O	0.6	0.31	0.33	0.63	0.34	0.44	0.24	0.26	0.87	0.46	0.62	0.42
P_2O_5	0.69	0.49	0.61	0.74	0.58	0.53	0.32	0.75	0.66	0.83	0.70	0.58
L.O.I.	3.42	0.82	1.83	1.42	1.14	1.38	1.07	1.65	1.75	0.91	1.50	1.14
mg*	0.56	0.58	0.56	0.53	0.57	0.56	0.58	0.52	0.56	0.56	0.45	0.59
Ni	145.4	189.7	181.3	166.7	174.2	177.7	189.4	172.3	195.7	196.9	165.7	225.4
Co	38.4	40.8	35.2	41.5	48.1	43.2	43.6	44.4	44.4	45.8	45.6	49.4
Cr	206.6	308.7	293.2	236.6	231.2	255.5	314.9	250.8	280.6	303.2	262.6	280.5
V	146.9	151.1	169.1	175.2	164	172.8	169.8	187.2	222.1	185.8	179.1	179
Pb	14.8	10.1	4.6	10.4	6.3	13.1	12.6	14.5	9.2	11.1	9.4	15.3
Zn	108.4	108.6	110.3	117.9	108	114.6	117.1	125.6	99.2	128.7	104.6	117.8
Th	0	0	0.3	8.2	3.2	4.8	2.9	3.6	0	8.4	5.9	6.2
Nb	44	24.3	30.1	37	21	24.1	20.4	30.7	40.2	34.4	31	31.7
Zr	147.7	118.8	137.5	180.8	111.5	124	137.8	143.9	190.7	168.9	122.7	155.2
Rb	12.8	6	7.9	10.6	4.2	4.2	0	1.3	15.1	2.9	11	8.5
Sr	621.4	381	500.7	547.8	419.4	400.7	356.4	533.4	489.5	593.6	592.4	562.3
Ba	408.5	165.8	216.4	311.2	224.9	198.5	156.9	309.6	401.8	322.7	299.4	266.7
La	47.6	18.2	34.9	39.2	17.6	25.6	12.9	41.9	25.2	38.5	36.5	32.6
Ce	79.7	39.6	62.6	84.6	56.2	54.4	48.4	77.7	61	88.9	64.3	71.2
Y	22.4	23.4	29.9	29.5	28.7	27.2	26.7	35.3	28.8	35.3	25.7	32
Or	3.55	1.83	1.96	3.72	2.01	2.60	1.42	1.54	5.14	2.72	3.70	2.48
Ab	35.18	32.02	29.32	31.48	34.22	29.70	28.18	31.65	28.01	32.41	32.61	29.11
An	22.67	28.54	28.69	21.94	26.6	27.72	30.16	26.62	26.26	23.58	26.91	27.03
Wo/Di	6.18	5.16	5.66	7.90	6.12	5.25	5.28	6.33	8.78	7.07	7.76	6.73
En/Di	3.38	2.86	3.08	4.15	3.34	2.81	2.95	3.21	6.56	3.91	3.48	3.78
Fs/Di	2.58	2.10	2.38	3.52	2.57	2.28	2.12	2.97	1.35	2.90	4.24	2.68
Cpx	12.14	10.12	11.12	15.57	12.03	10.34	10.35	12.52	16.69	13.88	15.48	13.19
En/Hy	5.79	7.40	10.35	8.14	5.98	10.30	11.72	6.11	3.15	5.36	0.18	4.13
Fs/Hy	4.42	5.44	8.01	6.91	4.60	8.36	8.41	5.64	0.65	3.98	0.22	2.93
Opx	10.21	12.84	18.36	15.05	10.58	18.66	20.13	11.76	3.80	9.34	0.40	7.06
Fo/Ol	3.36	4.23	1.00	1.70	3.97	1.95	1.53	3.45	4.51	4.78	5.09	7.43
Fa/Ol	2.83	3.42	0.86	1.59	3.36	1.74	1.21	3.51	1.02	3.91	6.82	5.81
Ol	6.19	7.65	1.86	3.29	7.33	3.69	2.74	6.95	5.53	8.69	11.91	13.24
Mt	1.87	2.03	2.02	2.19	1.94	2.12	2.07	2.25	6.99	2.20	2.30	2.22
Il	3.16	3.00	3.41	3.63	2.81	2.56	3.15	3.34	4.31	4.37	3.55	3.19
Ap	1.64	1.16	1.45	1.75	1.38	1.26	0.76	1.78	1.56	1.97	1.67	1.37

TABLE 3

Selected analyses of alkaline basalts (I 363-I539), ankaratrite (I 623), hawaiites (I 310-I 630) e tephrites (I 319-I 362)

Sample	I 363	I 367	I 412	I 413	I 519	I 535	I 539	I 623	I 310	I 329	I 361	I 385	I 414	I 417	I 552	I 630	I 319	I 362
SiO_2	46.47	46.3	47.37	46.85	46.18	44.18	45.64	40.77	46.21	44.74	46.65	50.55	50.29	48.97	50.03	48.28	47.99	46.80
TiO_2	2.75	2.67	2.48	2.40	1.61	2.30	2.37	2.18	4.14	5.33	2.98	2.53	2.86	2.51	2.26	2.17	2.74	2.77
Al_2O_3	15.26	16.59	15.63	16.36	14.80	15.93	15.01	13.34	15.01	14.49	16.34	16.51	16.13	16.40	16.56	16.16	16.00	16.94
Fe_2O_3	6.99	3.04	5.85	3.89	7.02	4.29	4.45	5.83	4.66	4.25	6.26	6.47	7.79	6.78	4.23	6.00	6.29	5.76
FeO	3.91	7.05	5.08	6.73	3.97	7.10	5.36	5.55	6.77	8.02	5.06	3.59	2.72	3.33	4.79	3.82	3.80	5.14
MnO	0.16	0.16	0.16	0.16	0.15	0.16	0.16	0.18	0.16	0.15	0.17	0.15	0.15	0.15	0.14	0.14	0.14	0.17
MgO	7.31	7.69	7.26	6.49	6.45	8.41	7.66	9.54	6.40	5.96	4.83	3.45	3.60	5.40	5.42	7.87	5.22	5.09
CaO	9.02	8.98	9.83	10.09	11.07	10.05	10.67	13.75	8.93	9.32	8.30	7.53	7.74	8.49	7.58	8.23	8.53	8.35
Na_2O	3.72	2.98	3.61	3.85	3.34	2.78	3.09	3.76	3.64	3.48	3.81	4.39	4.25	4.19	4.59	3.97	4.37	4.48
K_2O	0.93	1.31	1.09	1.12	0.63	1.30	1.34	0.98	1.33	1.35	1.83	1.86	1.64	1.50	2.07	1.80	1.84	1.86
P_2O_5	0.88	0.87	0.78	0.77	1.37	0.76	1.09	1.68	0.99	0.92	1.36	0.93	0.97	0.93	0.95	0.89	1.23	1.47
L.O.I.	2.62	2.37	0.87	1.30	3.40	2.73	3.16	2.43	1.75	1.97	2.42	2.06	1.88	1.36	1.40	0.67	1.85	1.17
mg*	0.58	0.62	0.58	0.57	0.56	0.61	0.63	0.64	0.54	0.50	0.47	0.43	0.41	0.54	0.55	0.64	0.53	0.50
Ni	216.6	197.2	213.2	188.7	165.6	197.5	301.3	260.4	193.5	130.6	98	105.4	93	135.5	107.1	202.9	128.1	87.8
Co	50.1	44.9	49.8	45.7	42.9	49.3	42.2	48.3	45.4	49.1	39.1	32.2	37	37.4	33	41.2	34	35.8
Cr	221.9	287.6	294.4	263.2	207.1	273.3	363	383.8	376.9	159	99.8	158.5	123.6	202.5	141.7	283.7	224.2	100.2
V	246.9	233.2	232.3	224.2	191.3	266.5	197.4	251.4	246.1	330.5	191.6	176.8	211.6	203	160.9	206.1	186	173.1
Pb	16.7	10.1	14.8	9.7	7	7.8	5.3	8.1	6.9	9.5	14.5	6.8	15	8.2	12.4	8.3	5.6	4.2
Zn	118.8	106.8	114.9	104.7	103	96.4	121.3	94.2	127.2	147.6	145.7	133.1	134.2	119.8	123.4	102.6	121.6	134.1
Th	6	0	1.5	2.4	11.5	3.2	7.7	10.7	0.8	4	6.8	0	6.4	7.7	7.1	10.6	2.3	2.1
Nb	62.4	63.2	46.5	45.1	49.3	52.8	76.3	103	79.8	67.9	85	91.1	64.2	70.8	99.9	72.2	103.3	91.4
Zr	292	261.2	194.4	203.2	134.6	189.6	349.8	201.8	377.5	383	409.2	401.7	379.1	326.8	505.2	254.8	437.9	431.7
Rb	12	23.2	18.7	20.1	14.3	23.5	37.6	20	24	22.5	35.7	44.1	26.7	30.1	42.1	30	37	39.1
Sr	724.9	648.4	671.4	601.3	1374.7	618.9	848.8	1328.2	730.2	704.4	1049	787.2	697.7	707.4	1000.1	879.6	936.5	962.2
Ba	432.1	549	469.7	406.6	783.5	338.3	727.6	804.8	422.6	500.1	598.8	543	485.5	491.4	649.1	620.2	591.3	534.7
La	55.4	44.7	18.3	34.6	107	25.1	52	107.9	45.9	38.7	79.1	53.6	45.1	53	65.3	66.7	65.2	75
Ce	88.2	83.4	53.5	63.5	204.4	71.6	104.6	216.6	87.1	95.9	144.7	106	81.6	98	132.4	120.8	114	142.5
Y	32.7	27.8	27.3	31.9	32.7	27	33.3	36.2	39.8	40.3	36.5	35.6	36.1	36.5	34.9	28.3	36.5	37.7

Table 3: *Continued*

Sample	I 363	I 367	I 412	I 413	I 519	I 535	I 539	I 623	I 310	I 329	I 361	I 385	I 414	I 417	I 552	I 630	I 319	I 362
Or	5.50	7.75	6.44	6.63	3.74	7.70	7.94	2.99	7.88	7.98	10.81	11.05	9.69	8.91	12.23	10.69	10.93	11.04
Ab	27.44	25.26	24.82	22.91	26.63	15.72	20.03	0.00	27.59	24.16	28.61	37.33	35.96	32.45	32.31	26.04	29.08	26.66
An	22.20	28.07	23.23	24.11	23.67	27.23	23.2	16.70	20.76	19.93	22.08	19.95	20.09	21.63	18.47	21.06	18.70	20.71
Ne	2.19	0.00	3.10	5.28	0.97	4.26	3.36	17.31	1.79	2.86	1.96	0.00	0.00	1.73	3.54	4.18	4.38	6.18
Wo/Di	7.02	4.54	8.54	8.78	9.43	7.43	9.50	17.04	7.18	8.48	4.27	4.80	5.00	6.10	5.40	5.90	6.58	4.70
En/Di	4.08	2.78	4.89	4.93	5.07	4.40	5.84	10.47	4.25	4.95	2.11	2.20	2.25	3.36	3.02	3.64	3.63	2.45
Fs/Di	2.61	1.50	3.28	3.49	4.04	2.66	3.12	5.59	2.58	3.12	2.08	2.56	2.72	2.51	2.16	1.91	2.71	2.12
Cpx	13.71	8.82	16.71	17.20	18.54	14.49	18.46	33.10	14.01	16.55	8.46	9.56	9.97	11.97	10.58	11.45	12.92	9.27
Fo/Ol	9.89	11.07	9.24	7.90	7.77	11.64	9.32	9.38	8.23	6.93	6.95	3.54	2.78	7.12	7.34	11.25	6.61	7.21
Fa/Ol	6.96	6.59	6.83	6.16	6.83	7.77	5.49	5.52	5.50	4.81	7.56	4.54	3.71	5.87	5.79	6.51	5.44	6.88
Ol	16.85	17.66	16.07	14.06	14.6	19.41	14.81	14.90	13.73	11.74	14.51	8.08	6.49	12.99	13.13	17.76	12.05	14.09
Mt	2.26	2.06	2.26	2.15	2.17	2.31	1.97	2.28	2.31	2.54	2.35	1.99	2.17	1.99	1.87	1.95	2.00	2.18
Il	5.22	5.08	4.71	4.57	3.08	4.38	4.52	4.16	7.89	10.12	5.66	4.83	5.43	4.79	4.29	4.14	5.23	5.28
Ap	2.08	2.06	1.85	1.83	3.26	1.81	2.59	4.00	2.35	2.18	3.22	2.21	2.30	2.21	2.25	2.12	2.93	3.50

TABLE 4

Selected analyses of basanites

Sample	I 304	I 370	I 381	I 395	I 415	I 500	I 530	I 537	I 555	I 559	I 618	I 619	I 620	I 625
SiO_2	43.78	44.45	44.62	44.95	46.35	43.7	42.58	43.27	46.84	42.23	44.71	44.61	43.31	43.72
TiO_2	2.15	3.01	3.09	2.12	2.54	2.51	2.24	2.44	1.99	1.66	2.84	2.27	2.22	1.91
Al_2O_3	15.64	14.84	15.67	14.84	14.67	14.58	14.82	14.73	15.32	13.64	15.67	15.64	14.5	14.77
Fe_2O_3	4.89	5.10	3.96	6.49	5.49	5.27	7.11	4.33	4.91	4.69	4.96	4.45	5.42	4.06
FeO	6.72	6.50	7.56	4.94	4.57	6.28	4.24	7.26	5.03	5.45	6.70	5.97	5.31	6.51
MnO	0.16	0.17	0.16	0.17	0.16	0.17	0.16	0.17	0.15	0.17	0.17	0.15	0.17	0.16
MgO	7.97	8.26	7.30	7.12	7.24	8.34	7.72	8.45	7.84	12.03	7.01	7.81	8.55	7.95
CaO	10.96	10.41	10.54	11.77	10.28	11.52	12.6	11.18	10.10	12.42	9.87	10.57	11.76	12.49
Na_2O	3.16	3.15	3.35	3.57	4.17	3.88	3.30	3.51	4.01	2.44	3.64	4.10	3.59	3.84
K_2O	0.85	1.21	1.27	0.70	1.50	1.16	0.88	1.05	1.43	0.41	1.44	1.43	1.27	0.63
P_2O_5	1.19	0.75	0.78	1.39	1.33	1.23	1.52	1.55	0.81	1.57	1.08	1.39	1.45	1.30
L.O.I.	2.54	2.15	1.69	1.94	1.72	1.36	2.83	2.07	1.58	3.29	1.90	1.63	2.45	2.66
mg*	0.59	0.59	0.57	0.58	0.60	0.61	0.60	0.61	0.62	0.71	0.56	0.62	0.63	0.62
Ni	264.7	192	173.8	257.2	176.6	245.1	252.3	189.6	176.4	297.9	200.7	225	280.2	258.1
Co	49.5	53.5	47.7	46.9	44.8	49.5	47.6	46.1	45	46.7	46.6	44.7	46.9	47.8
Cr	381.6	282.5	221.9	284	292.9	335.4	334.7	259.8	243	446.8	295.9	351.4	473.7	314.6
V	225.8	276	266.7	222	224.6	244.9	237.1	241.6	219.4	227.8	244.9	226.5	235.6	204.9
Pb	6.8	20.6	4.8	6.8	13	8.1	7.9	7.7	7	13.4	7.9	5.9	11.3	8.5
Zn	105.5	119.2	107.7	108.7	110.1	105.1	103.1	99	107.3	91	110.2	95.6	95	103.7
Th	4	7.5	1.3	7.1	9.8	5.5	10.1	9.4	11.6	12.3	6.3	10.3	5.8	8.6
Nb	85.8	56.5	62.4	82.8	82.3	84.4	98	97.6	67.9	93.6	78.8	85.4	66.3	63.3
Zr	200.6	242.3	286.3	172.4	299.9	230	214.4	210.8	274.8	156.3	289.2	228.8	148.3	165.9
Rb	19.1	23.7	24.6	14.5	28.3	24.3	16.2	19.2	27.3	2.2	32.2	26.4	20.3	14.5
Sr	820.6	626.4	619.5	1238.9	970.6	1051.5	1273.6	1165.9	724.7	1221.5	804.2	1007.9	889.5	928.5
Ba	616.1	860.2	498.5	752.6	767.9	619	902.2	683.1	498.1	694.1	648.2	807.9	733.5	646.5
La	74	47.6	39.8	91.1	82.6	74.9	102.7	90.2	61.1	106.6	57.3	79.1	79.8	72.7
Ce	122.8	84.2	76.7	190.5	145.5	143.6	192.9	185.2	82.6	196.1	108	159.8	160.8	149.5
Y	36.1	36.7	34.4	36.1	33.1	32.7	38.2	37.3	27	33.3	35.4	36.3	27.1	35.1

Table 4: *Continued*

Sample	I 304	I 370	I 381	I 395	I 415	I 500	I 530	I 537	I 555	I 559	I 618	I 619	I 620	I 625
Or	5.04	7.15	7.52	4.16	8.86	6.88	5.23	6.22	8.45	2.42	8.54	8.48	7.54	3.73
Ab	16.56	15.65	15.97	19.19	19.97	10.37	10.4	13.68	18.57	10.50	17.94	14.43	9.85	12.16
An	26.07	22.78	24.03	22.51	16.88	19.01	23.16	21.40	19.58	25.06	22.25	20.11	19.78	21.26
Ne	5.56	5.96	6.74	6.05	8.29	12.24	9.58	8.72	8.32	5.50	7.03	11.03	11.19	11.06
Wo/Di	8.64	10.01	9.72	11.30	10.62	12.65	12.41	10.05	10.54	10.99	8.28	9.76	12.23	13.51
En/Di	4.96	5.96	5.65	6.31	6.32	7.51	7.21	5.95	6.30	7.23	4.68	5.86	7.46	7.96
Fs/Di	3.29	3.54	3.61	4.53	3.76	4.50	4.62	3.60	3.70	2.98	3.25	3.39	4.10	4.89
Cpx	16.89	19.51	18.98	22.14	20.7	24.66	24.24	19.60	20.54	21.20	16.21	19.01	23.79	26.36
Fo/Ol	10.48	10.24	8.81	8.06	8.21	9.35	8.49	10.62	9.27	15.93	8.99	9.56	9.75	8.33
Fa/Ol	7.66	6.71	6.21	6.38	5.39	6.17	5.99	7.09	6.00	7.23	6.87	6.10	5.91	5.64
Ol	18.14	16.95	15.02	14.44	13.6	15.52	14.48	17.71	15.27	23.16	15.86	15.66	15.66	13.97
Mt	2.34	2.41	2.34	2.28	2.09	2.32	2.25	2.35	2.06	2.10	2.35	2.10	2.15	2.14
Il	4.10	5.72	5.88	4.05	4.82	4.79	4.28	4.65	3.78	3.15	5.41	4.32	4.23	3.64
Ap	2.83	1.78	1.85	3.31	3.15	2.92	3.62	3.68	1.92	3.72	2.57	3.30	3.45	3.09

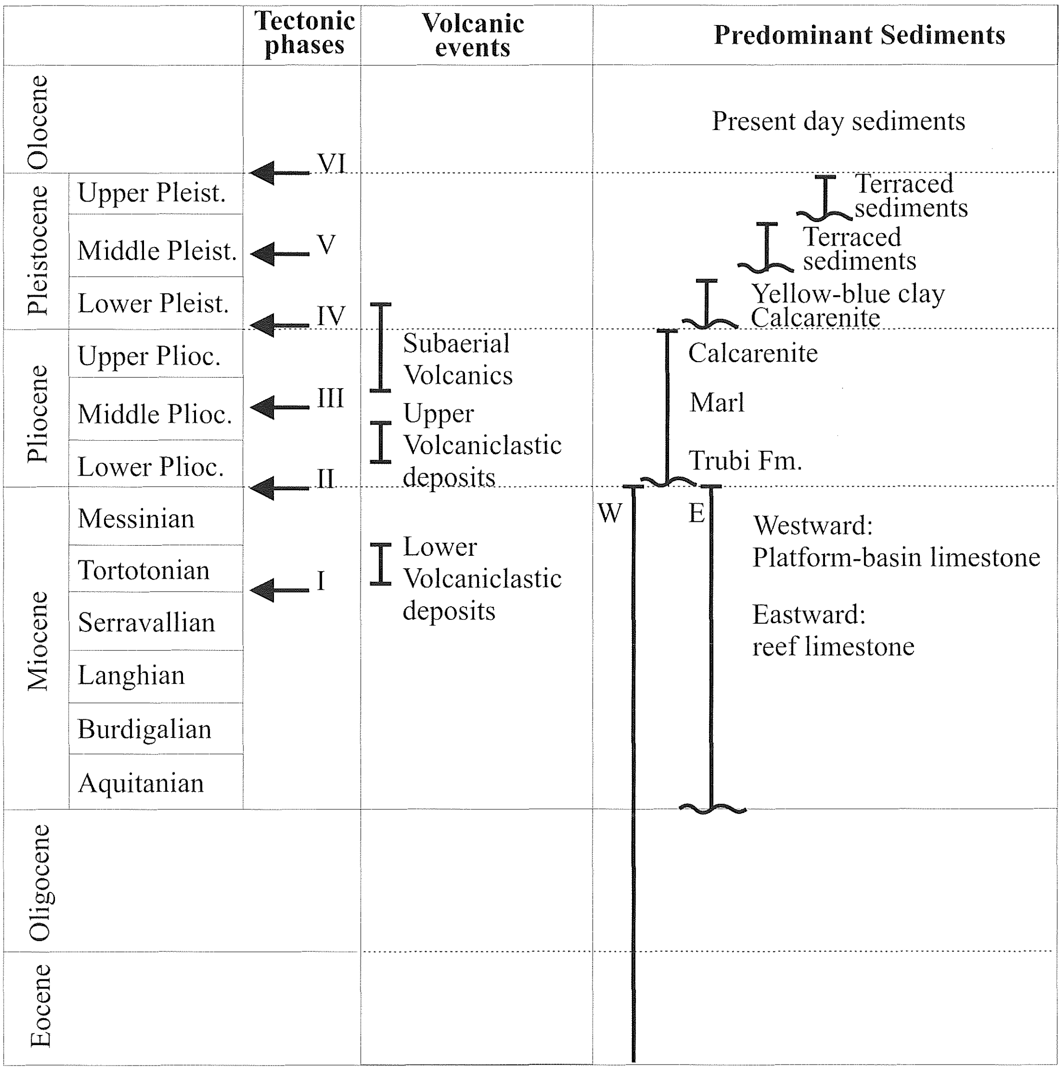

Fig. 4 – Chronological (Eocene-Olocene) relationship between tectonic, volcanic and sedimentary events recognised in the study area.

Sedimentary activity developed in three main cycles. The sediments of the first cycle, to the east, lie on Cretaceous/Eocene-Oligocene units. The second complete early–late Pliocene sedimentary cycle presents littoral facies at bottom and top, and intermediate levels have bathyal facies. The third early Pleistocene cycle is represented by basal littoral deposits, evolving upwards and sideways to neritic-bathyal sediments; upwards the cycle is abruptly interrupted by uplift.

The oldest eruptive products (*Lower Volcaniclastic Deposits*) are interbedded in the topmost levels of the oldest sedimentary cycle and immediately followed the Miocene tectonic phase. After the long late Cretaceous-early Tortonian pause, they represent revival of basic eruptive activity. The latter was submarine, in prevalently diatremic areas. Upwards and locally, activity tended to be subaerial.

The second eruptive episode is seen north of Licodia Eubea–Vizzini and near Mt. Lauro. In the western part, between Palazzolo and Licodia Eubea, it was brusquely interrupted by the mid-Pliocene uplift, whereas it is not represented eastwards. Only to the NW, between Licodia Eubea and Stazione di Mineo Station, did it continue at least until the mid-late Pliocene, when it was replaced by sedimentation of *Yellowish-White Calcarenite*. The distribution of these volcanic products allow us to hypothesise first the uplift of the Buscemi-Agnone area, followed by that of Mt. Lauro and, lastly (terminal mid-late Pliocene), that of Licodia-Stazione di Mineo.

The early-middle Pliocene volcanic products, in a neritic-bathyal marine environment, compositionally cover the tholeiite-ankaratrite range. Lateral relationships between volcanic and sedimentary levels highlight the limited extent in time and space of each volcanic episode.

The volcanism of the fourth group (2-3 Ma), linked to and immediately subsequent to the mid-Pliocene tectonic phase, occurred after the uplift, followed by erosion, of the Giarratana-Vizzini-Francofonte-Agnone area, covering a gradually emerging area (mid-late Pliocene-early Pleistocene?).

In this evolutive and structural context, the central and northern Iblean areas, gradually emerging during the mid-late Pliocene, underwent subaerial eruptive activity. They were flanked north and NW by another sector characterised by prevalently submarine and subaerial products, alternating in time and space (Schminke *et al.*, 1997). Further north, according to Grasso and Bencke (1998), eruptive activity was prevalently submarine.

Iblean eruptive activity ended during the middle Pleistocene (Costa *et al.*, 1993).

The alignment of the eruptive centres and relationships with tectonic features, in view of petrographic characters and geochemical composition, indicate that magma ascended directly from the mantle along fault planes.

Subaerial Plio-Pleistocene volcanism developed preferentially NE-SW and produced 10-15 km^3 of volcanic products, ranging in composition from tholeiite to ankaratrite. Subalkaline products prevail over alkaline ones (tholeiite 62%; basanite 22%; alkalibasalt 8%; hawaiite 4%; transitional basalt 3%; nephelinite and ankaratrite 1%). Chemical variability does not seem to be related with the areal distribution and age of the volcanic products.

Beccaluva *et al.* (1998) proposed a petrogenetic model in which the magmas are the result of partial melting of various metasomatised spinel-peridotite lithospheric sources. The partial melting fraction progressively increases and the source depth decreases from strongly subalkaline to tholeiitic magmas.

Geochemical data defines the characteristics of the source for each type of magmas: tholeiite was produced by partial melting of amphibole-bearing lherzolite; alkaline basalt and basanite derived from amphibole-phlogopite-bearing lherzolite, and nephelinite and ankaratrite were linked to partial melting of a clinopyroxene-rich lherzolitic source bearing amphibole, phogopite and carbonate.

The large modal and geochemical variability of the source is related to several metasomatic events: the first is alkali-silicate in nature and, with different intensities, affected the whole lithospheric mantle, whereas the second, carbonatitic in composition, overlies the first only in the deeper lithosphere, where strongly alkaline magma was generated.

ACKNOWLEDGMENTS

The authors are grateful to two anonymous referees for their constructive review of the manuscript. The study was supported by University of Catania ex 60% found.

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