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Effects of basement structural and stratigraphic heritages on volcano behaviour and implications for human activities

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Abstract Volume

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MEETING PROGRAMME

9 July 2001 morning

9,30 *Registration of participants*

10,30 **A. Tibaldi** *Introduction to the IGCP project "Basement-volcanoes interplay and human activities".*

11,00 **V. Ponomareva, O. Braitseva, L. Sulerzhitsky & I. Melekestsev** *Eruptive histories of Kamchatka volcanoes: methods of reconstruction, temporal and spatial patterns of Holocene eruptive activity, proposed data base, and possible contributions to the IGCP Project 455.*

11,30 **A.F.M. Lagmay** *The Anatomy of a strike-slipped volcanic cone.*

12,00 *lunch*

9 July 2001 afternoon

14,00 **L.B. Marinoni** *The Monte Somma dyke swarm and its host rock: possible clues to a flank collapse on Monte Somma (Naples, Italy).*

14,30 **C. Corazzato, A. Tibaldi & T. Apuani** *Analysis of a collapsed (or collapsing) volcano: Stromboli.*

15,00 **A. Tsegaye** *Volcanism in the Ethiopia Rift.*

15,30 *coffee break*

16,00 **D. Rust** *Structural and neotectonic investigations in the Etnean area, Sicily.*

16,30 **G. Groppelli, G. Pasquaré, S. Calvari, L. Capra, C. Corazzato, E. De Beni, T. Diliberto, J.L. Macias, A. Misuraca, E. Natoli, G. Norini, L.H. Tanner, I. Valiakos & N. Zouros** *Volcano flank collapse: the case of Etna Volcano (Italy), Nevado de Toluca (Mexico), Lesvos (Greece).*

Meeting dinner

10 July 2001 morning

9,30 **A. Borgia**, **E. Koenig & J.H. Fink** A planetary perspective of gravitational spreading: from small volcanic cones to large crustal plates.

10,00 **O. Ordoñez Carmona & M. Martins Pimentel** *Rb-Sr and Sm-Nd isotopes and the source of young (<11 Ma) magmas of the northern Andes.*

10,30 *coffee break*

11,00 **F. Gomez & J. Martí** *Tenerife: a case study on the volcanological and structural evolution of a volcanic island.*

11,30 **L. Ferrari & L. Capra** *Quaternary normal faulting south of Mexico City and its role in controlling Holocene monogenetic volcanic activity and sector collapse of stratovolcanoes.*

12,00 *lunch*

10 July 2001 afternoon

14,00 General discussion on the 2001-2005 project plans.

Introduction to the IGCP project "Basement-volcanoes interplay and human activities"

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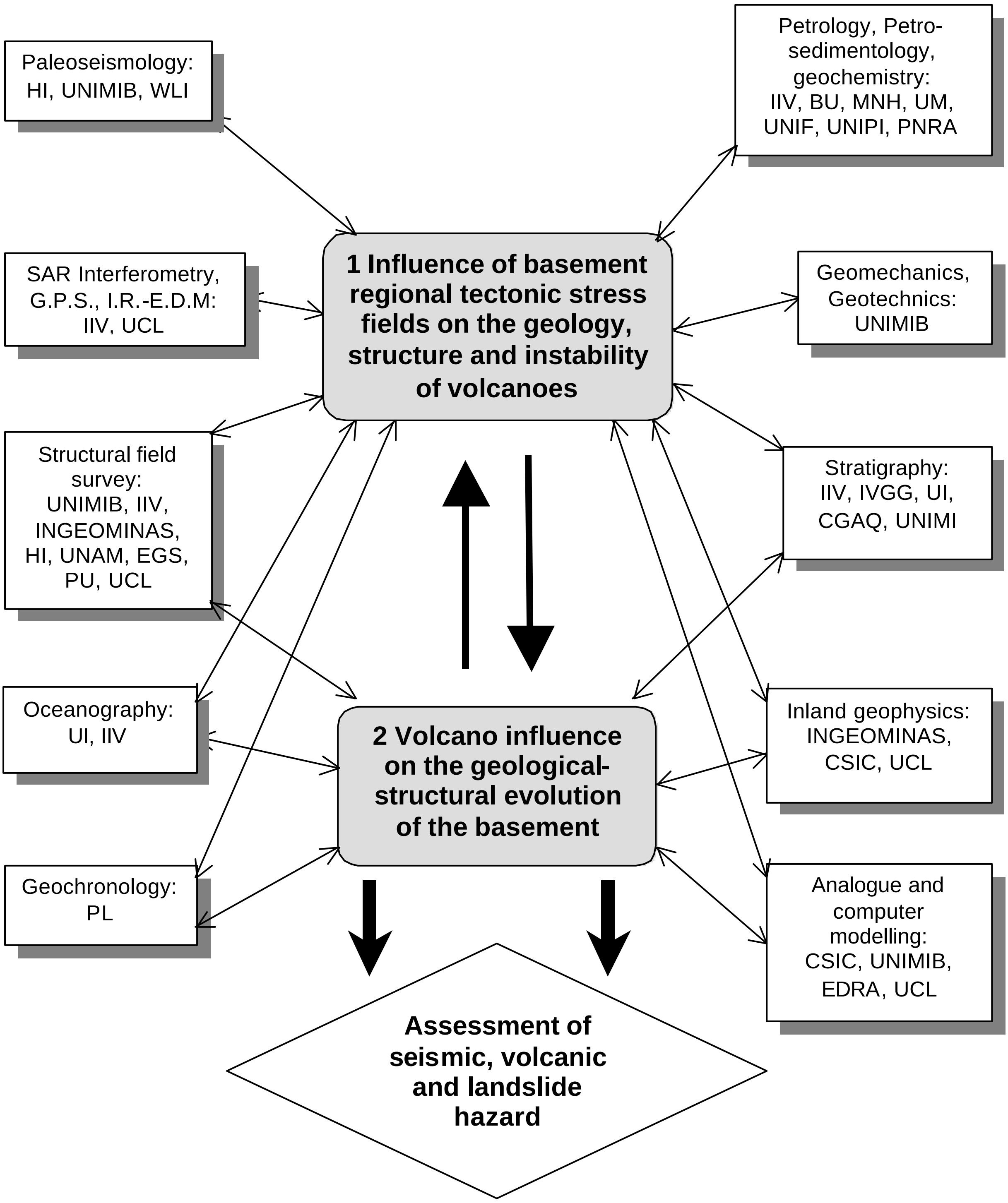
The project intends to understand the reciprocal influence exerted by volcanoes on their substrate and by the basement on the volcanoes in different geodynamic settings, and to assess the role of this influence in determining natural geological hazards such as eruptions, landslides and earthquakes. The geologic-tectonic control of the substrate on the volcanoes has been usually considered questionable or less important than the conditions of the deep magma source, whereas the control of volcanoes on their basement has even received no attention, apart a few recent publications. In particular, collapse of volcanoes and influence of volcanic cones on the fault-fold architecture and depositional evolution of the basement are research topics that are still far away to be understood. New achievements will be reached only by a strong interdisciplinary approach that ties data on the various geological conditions and heritages of the basement with the deformation processes and geological evolution of different volcanic edifices. A database will be compiled to perform a statistical analysis of selected parameters, to compare the peculiarities of different zones, and to propose new general models. This project will make accessible to the research community these data, obtained with stratigraphic, structural, geophysical, geotechnical, petro-geochemical, and geochronological techniques, which usually are scattered and managed by specific and local groups of research. The task forces responsible for the various methodologies are resumed in the following flow chart; the project at the beginning involves 51 researchers from 27 different institutes of 10 nations. Both recent and active volcanic areas, as well as older, deeply eroded volcanic remnants, will be investigated. The studied zones will include: circum-Pacific plate converging zones, East Africa rift, oceanic and continental intra-plate volcanic regions of Atlantic and Asia, Antarctica, and plate boundary complex sectors in the Mediterranean region. Expected results include hazard maps in densely populated target areas, whereas the societal aspects of the project embrace also applications useful for geothermal energy, and mineral and water resource exploration.

The estimated duration of the project is five years (2001-2005). The work schedule comprises the compilation of a reference list on published and unpublished papers already available on the subject; the set up and updating of a web-site of the project; the organisation of an active exchange of information among the participants in the project to establish task forces devoted to single targets of research; the organisation of this first meeting and of other workshops and symposium during international congresses; the preparation of one or more special issues of papers containing the results of the project to be published in international scientific journals and the preparation of the IGCP Annual Reports.

FLOW CHART OF TASK FORCES AND PROJECT OBJECTIVES



BU Bloomsburg Univ., USA; **CGAQ** Quat. Alp. Geodyn. Centre, Italy; **CSIC** Consejo Sup. Inv. Cient., Spain; **EDRA** European Development Res. Agency; **EGS** Ethiopian Geological Survey; **HI** Hydroproject Inst., Moscow Russia; **IIV** Intern. Inst. Volcanol.; **INGEOMINAS** Inst. Geol. Min. y Nuclear de Colombia; **IVGG** Institute of Volcanic Geology and Geochemistry; **MNH** Museum Natural History of Italy; **PU** Philippines University; **PL** Professional Labor.; **PNRA** Programma Nazionale di Ricerche in Antartide (ENEA), Italy; **UCL** Univ. College London, UK; **UI** Univ. Insubria, Italy; **UL** Univ. Lancaster, UK; **UM** Univ. Medellin, Colombia; **UNAM** Univ. Nacional Autonoma Mexico; **UNIF** Univ. Florence, Italy; **UNIMI** Univ. Milan I, Italy; **UNIMIB** Univ. Milan-Bicocca, Italy; **UNIPI** Univ. Pisa, Italy; **WLI** West London Institute, UK.

A planetary perspective of gravitational spreading from small volcanic cones to large crustal plates

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Summary: We identify gravitational spreading as a fundamental process on Earth, Mars and Venus. This framework for the evolution of volcanic constructs extends the concepts of plate tectonics from the planetary scale down to the scale of small volcanoes.

Introduction: The interaction between gravity and thermal effects largely determines the structural and magmatic evolution of volcanic constructs at scales spanning several orders of magnitude, from small volcanic cones to crustal plates [1]. Though some effects (such as symmetry) may change with scale, the basic mechanical processes of gravitational spreading remain the same, and produce a characteristic distribution of structural features. Rifts and grabens result from extension and collapse of topographic summits; basal thrust faults and folds at the periphery of the volcanic construct are related to lateral flank displacement. Observations of volcanic constructs on Earth, Mars, and Venus show that this distribution of structures is found over a wide range of scales, indicating that gravitational spreading may be a fundamental tectonic process. Knowledge of the mechanics of gravity-driven tectonics will allow us to understand the geometry and distribution of surface structures, and to infer relationships between thicknesses and rheological properties of volcanic substrate layers.

We describe an analytical solution to relate the location of peripheral compressional structures to gravitational spreading processes. We will apply this model to selected examples from Earth, Mars, and Venus, and compare our analytical model to numerical model predictions.

Analytical model: Due to the gravitational acceleration (g), volcanic constructs and their basements tend to be stratified and to have a characteristic horizontal length (L) much larger than the characteristic vertical dimension. With these approximations the most simple system is represented by a brittle volcanic construct (of height H_v) resting on a ductile layer (of thickness H_d), with often a brittle layer (of thickness H_b) interposed between the two. In practice, the ductile layer of a smaller volcano may be constituted by sedimentary clay or salt beds, or altered volcanic rocks. In larger volcanoes, this layer may be made of metamorphic rocks like marbles or schists. At the scale of planetary crustal plates the weak layer is the asthenosphere.

The deformation of this model system may be described by a free-surface lubrication approximation of the Navier-Stokes equation such as (see [2]):

$$\frac{\partial \boldsymbol{h}}{\partial \boldsymbol{t}} = \frac{\partial}{\partial \boldsymbol{x}}\left\{ \boldsymbol{h}^3 \frac{\partial}{\partial \boldsymbol{x}}\left[\left(\frac{\boldsymbol{r}_d}{\boldsymbol{r}_v}\right)\boldsymbol{h} + \boldsymbol{h}_v\right]\right\} \quad (1)$$

In Eq. (1) $\boldsymbol{h} = h/H_v$ is the scaled thickness of the brittle layer, $\boldsymbol{x} = x/L$ is the scaled horizontal x-coordinate, $\boldsymbol{t} = t\bigg/\frac{c m_d L^2}{r_v g H_v^3}$ is scaled time, r_v is the density of the volcano, r_d and m_d are the density and the viscosity of the ductile layer, respectively, and c is a geometric constant. $\boldsymbol{h}_v$ is an arbitrary scaled function of the topography of the volcanic construct, for instance, given by $\boldsymbol{h}_v = e^{-\boldsymbol{x}(L/L_e)}$, where L_e is a fitting geometric parameter.

With these hypotheses, we may compute the distance L_t from the summit area to the peripheral compressional structures as:

$$L_t = -L_e \ln\left(\frac{1 - 2N_f \frac{H_b}{H_d}\frac{H_b}{H_v}\frac{r_b}{r_v}}{1 + 2N_f \frac{H_b}{H_d}}\right) \qquad (2),$$

where N_f is a function of the angle of the internal friction of the brittle layer. Thus, spreading occurs only if $2N_f \frac{H_b}{H_d}\frac{H_b}{H_v}\frac{r_b}{r_v} < 1$.

We are using the commercial finite element analysis package ANSYS to compare analytical predictions of peripheral thrust fault locations with numerical results.

<u>Examples on Earth, Mars, and Venus:</u> We illustrate the prevalence of gravitational spreading as a key process with examples of constructs on Earth, Mars, and Venus that exhibit characteristic summit extension and peripheral compression. Small volcanoes include Concepciòn and Maderas on Earth, Tharsis Tholus on Mars, and many coronae of Themis Regio on Venus. These systems all tend to maintain a radial symmetry. For larger volume intermediate cases, such as Hawaii on Earth, Olympus Mons on Mars and Artemis Chasma on Venus, we still observe peripheral compressional features, and note that these larger systems show a more pronounced bilateral symmetry. Crustal plate scale constructs include the Pacific plates on Earth, Tharsis Rise on Mars, and Aphrodite Terra on Venus; these features tend to have bilateral symmetry on spherical shells.

<u>Implications:</u> Gravitational spreading complements existing models of planetary tectonics. It adds a component of lateral displacement (which is characteristic of plate tectonics on Earth) to models of Mars and Venus that are based on crustal bulging only [3, 4]. It also extends the concepts of plate tectonics from the planetary scale down to the scale of small volcanoes. The advantage of this approach is that the knowledge about a process occurring at one order of magnitude may be quantitatively extrapolated to the neighboring orders.

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Analysis of a collapsed (or collapsing) volcano: Stromboli

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In the framework of the IGCP project we present the objectives and the first results of the "Hazard assessment of Stromboli volcano" project, financed for 2001-2003 by the Italian National Group of Volcanology (GNV). This project aims at the evaluation of the various hazards of Stromboli volcano. This project is strongly interdisciplinary and is a good example of co-operation between researchers from different fields: stratigraphy, structural geology, sedimentology, petrography, geochemistry, engineering geology, geomorphology and oceanography. In particular, Milan research unit will focus on the understanding of how volcano sector collapses develop at Stromboli and on the evaluation of the instability of the present volcanic edifice, moreover we will collect data for a subsequent unstable areas monitoring. Our research unit is both interdisciplinary and innovating: we will apply different methodologies such as lithostratigraphy, structural geology, geomorphology, sedimentology, rock and soil mechanics. Stability analyses by means of limit equilibrium methods and numerical modelling will be performed, together with the geological hazard assessment. The application of rock and soil mechanic principles and techniques to an active volcano is deeply innovating.

Stromboli volcano experienced four large sector collapses in the Holocene, affecting the NW flank in the past 13 ka, alternating with growth phases (Tibaldi, 2001). In particular, the initial lateral collapse took place 13 ka BP, involving Vàncori edifice, the second affected Neostromboli edifice 5 ka BP and the other two acted in very recent times (<5 ka BP), affecting the Pizzo Sopra la Fossa edifice and later the more recent one, creating present Sciara del Fuoco horseshoe shaped depression. The collapse scarps are concentric and younger sliding planes become more superficial and decrease their areal extent (Tibaldi, 2001). In the first three collapses, sliding surfaces cut the main magma conduit, while in the last collapse the upper scarp coincided with the conduit location. Since 100 ka BP the edifice presents dyking along a main NE-trending weakness zone across the volcano summit. After ~13 ka BP the strain field interplayed with deformations related to unbuttressing along the shoulders of the first collapse, as well as along the shoulders of the following three sector collapses, with intrusion of dykes along the scarp (Tibaldi, 2001).

NE-SW weakness direction opens some questions on the interplay between Stromboli volcano and its basement. Actually there are geophysical evidences (Gabbianelli et al., 1993) of normal faults in the basement testified by a deepening of the Tyrrhenian basin toward NW. Is the weakness zone related to the shape of the edifice with a self-sustaining mechanism? Or is it related with a propagation of regional strain into the cone as could be suggested (Falsaperla et al., 1999) by evidences of tectonic seismic events in the area? In this context it would be very useful for example to co-operate with geophysicists. Moreover, how do sector collapses develop? In November 2000 we discovered new fractures in the upper part of Sciara del Fuoco depression following the last collapse scarp. In April 2001 these fractures showed evidences of additional extension and others opened in the same area, while in June 2001 no further deformation was observed. Can this be an evidence of a future collapse? In the framework of the IGCP project it would be useful to compare Stromboli with other multiple-collapsed volcanoes in order to answer these questions.

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Quaternary normal faulting south of Mexico City and its role in controlling Holocene monogenetic volcanic activity and sector collapse of stratovolcanoes

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Mexico City, the largest metropolitan agglomerate in the world, is built in a valley-like depression bounded to the south by Quaternary volcanic centers underlain by a major normal fault system. We present a review of this volcano-tectonic structure and its potential risk for the nearby large populated area.

The southern part of the valley of Mexico is formed by the active Popocatepetl stratovolcano (to the SE), the Sierra Chichinautzin volcanic field (to the S) and the historically active Nevado de Toluca volcano (to the SW). Sierra Chichinautzin (SCN) consists of 220 monogenetic volcanoes and small shields cones, emplaced during the last 40,000 years, for a total volume of about 470 km^3. SCN has a marked E-W elongation and, together with Popocatepetl and Nevado de Toluca, form a 100 km long topographic high at the volcanic front of the central Trans-Mexican Volcanic Belt that bounds the central high plateau. This E-W volcanic chain is thought to be underlain by a complex of extensional structures named "La Pera fault system". Because of the intense volcanic activity fault scarps are rare. The best outcrops are E–W en-echelon normal faults, with throws to the north of up to 50 m, exposed at the western limit of SCN. The existence of this fault system, however, is substantiated by other geologic and geophysical observations. (1) Four seismic zones with an E-W orientation and shallow events (5-15 km depth) have occurred in the SCN region in the last few decades. The available focal mechanisms indicate N-S extension along E-W trending planes. (2) Analysis of volcanic cone alignment detected 22 lines with more than 15 centers in the SCN. The dominant trend is E–W and the secondary one is N60E. (3) A morphologic discontinuity of 1,300-1,500 m exists between the high plain of Mexico city and Toluca and the region to the south of SCN. This sudden change in altitude occurs along the proposed extensional fault system. (4) Popocatepetl and Nevado de Toluca underwent catastrophic explosive eruption with sector collapse directed to the south. The La Pera fault system has likely controlled the collapses both passively (topography and gravitational instability) and actively (seismic triggering).

The latter phenomeno is definitely the more dangerous in the region. In the case of Popocatepetl volcano three distinct debris-avalanche deposits were recognized up to at least 70 km south of the crater, covering 600 km^2 and with a volume of 27 km^3. The youngest collapse occurred 22,875 +/- 915 yrs BP.

In the case of Nevado de Toluca two debris-avalanche deposits extending E-SE from the volcano occurred during Pleistocene time. The younger sector collapse produced deposits which reached 75 km from the edifice, covering an area of 220 km^2 with a total volume of 2.8 km^3 . Based on the textural and sedimentological characteristics the collapse of Nevado de Toluca volcano occurred due to the intense alteration (hydrothermal and weathering) and tectonic dissection of the edifice.
Studies on volcanic hazard have been traditionally devoted to the eruptive activity Popocatepetl volcano whereas seismic hazard studies mainly dealt with the ground motion associated to earthquakes along the subduction zone. Although less hazardous the combined tectonic and volcanic risk associated with the La Pera fault system should be also taken into account in future studies.

Tenerife: a case study on the volcanological and structural evolution of a volcanic island

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Tenerife is one of the world's largest and best exposed intraplate volcanoes. Tenerife is a superb natural laboratory for studying alkaline volcanism, hosting an active basanite-phonolite magmatic system that has experienced multiple episodes of caldera collapse and giant landslides, for which a mechanical relationship has been proposed. A considerable quantity of data concerning the on-land and offshore geology and geophysics have been acquired during the last decade by the volcanology group at the Institute of Earth Sciences in Barcelona, in collaboration with many other working groups. The existence of an extensive network of over 1500 km of water galleries, (narrow, sub-horizontal tunnels) allows the integration of surface and shallow surface geologic data to a degree of detail not possible elsewhere and offers a unique opportunity to obtain a three-dimensional picture of the subsurface geology of the island.

The research to be undertaken by the Barcelona volcanology group in Tenerife during the next four years addresses to obtain a combined structural-petrological model of the evolution of the central volcanic complex in order to predict its potential for future activity. A combination of field studies, mainly addressed to determine the tectonic structure of the island, laboratory studies including classical petrology and geochemistry and experimental petrology of the phonolitic rocks, geophysical and geochemical monitoring, and physical modelling, will be used to obtain the data necessary to continue the construction of a comprehensive data base specifically designed for volcano forecasting. Results obtained from this study will be of general applicability to other volcanic islands which show an evolution similar to that of Tenerife. We also expect to obtain valuable information on the tectonic constraints of the petrological evolution and, consequently, of the eruption style, an important aspect that is still not sufficiently well known.

Volcano flank collapse: the case of Etna Volcano (Italy), Nevado de Toluca (Mexico), Lesvos (Greece)

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We present some geological works about volcano flank collapse which the University of Milan and the CNR-CSGAQ are carrying on. Here we explain three different cases, one in Italy (Etna Volcano) and two others in Mexico and Greece.

Etna Volcano

Until 1997, no avalanche deposits had been identified on Etna, although a sector-collapse mechanism has often been invoked in explaining the formation of the Valle del Bove, a horseshoe-shaped depression 7 km long, 5 km wide, and up to 1 km deep, cut into the eastern flank of the volcano. We recognized debris-avalanche deposits on the eastern slopes of Mt. Etna in two locations downslope from the open end of the Valle del Bove. These outcrops comprise unstratified, ungraded deposits of metre-scale lava blocks in a matrix of weathered and fractured lava clasts. The avalanche deposits are unconformably overlain by matrix- to clast-supported conglomerates, representing debris-flow and interbedded fluvial deposits, that constitute most of the Milo Lahar sequence.

We present evidence that the Milo Lahar sequence, that crops out just at the exit of the Valle del Bove, formed during the opening and enlargement of this depression. The presence of the avalanche deposits at the base of the Milo Lahar sequence indicates that catastrophic landslides have been involved in the formation of the Valle del Bove. Radiocarbon dates of 8400 and 5300 yr BP from the base and top, respectively, of the debris-flow sequence indicate that the Milo Lahars are correlative with the exposed part of the Chiancone deposit. The basal lahars of the Chiancone, which contain lava blocks whose compositions partially overlap that of blocks in the avalanche deposits, may have formed by dilution of the distal end of the avalanche causing transformation to debris, or alternatively by reworking of the avalanche deposit.

Nevado de Toluca Volcano

The Nevado de Toluca volcano is located in the central sector of the Mexican Volcanic Belt and is built upon the intersection of three main structural lineaments with different orientations (Taxco-Querétaro, San Antonio and Tenango). The edifice is an early large andesitic to recent dacitic stratovolcano; in the literature the activity age is attributed to Late Pleistocene to Holocene. A sample from the feeding system of the early volcano indicates that the Nevado de Toluca volcano activity began at least 2,6 Ma ago. The volcano evolution is complex and characterized by some collapse events, individuated both by the morphological escarpments and by volcanoclastic debris deposits. The study aims at increasing the information about the volcano evolution and at defining the lateral collapses characteristics. We will especially study the age and the relationship between flank collapses and stratigraphic and structural volcano evolution. The analyses of the deposits regard the sedimentological characteristics and the volume determination; in order to define the volcano evolution we will apply stratigraphy, structural geology, morphology by way of aerial photography and digital elevation model and the petrographical and geochimical data of the litostratigraphic units recognized during the field work.

Lesvos Island

Lesvos Island, in the North-Eastern Aegean Sea, can be geologically divided in two areas: the eastern one is characterized by Palaeozoic and Mesozoic rocks (metamorphic basement); the western one is characterized by Tertiary volcanic products datable between 16 and 21 Ma.
In the western area we obtained a new geological map of about 50 km^2 at a 1:10.000 scale. We recognized a metamorphic basement and a large subvolcanic body that uplifted the metamorphic basement. These units are covered by the so called "*Sigri Pyroclastic Formation*". Subsequently these units were intruded by domes, subvolcanic bodies and dikes.

The *Sigri Pyroclastic Formation* crops out widely and it is formed by primary pyroclastic flows, pumice flows, ash flows, debris flows and debris avalanches. Some of the debris avalanche deposits can be related to two different flank collapses: Agra and Vatusa volcanoes. The aim of this work is to detail the stratigraphy and the sedimentological data of the *Sigri Pyroclastic Formation* in order to understand the different facies of the volcanoclastic deposits and their provenance.

In the upper ashy part of the Sigri Pyroclastic Formation we found a large number of petrified trees in their natural location and with their roots systems intact.

The Anatomy of a strike-slipped volcanic cone

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Ancestral Mount Bao (AMB) is a stratovolcano in Leyte, Philippines, directly overlying the active left-lateral Philippine fault. Deformational structures of the AMB were investigated to determine the structural anatomy of a strike-slipped volcano. Identified structures and related deformational features were compared with previous analogue sand cone models of volcanoes on top of strike-slip faults, models which describe a unique pattern of structural deformation. The deformation features recognized in AMB include: a summit graben, sigmoidal surface features, normal faults, thrust faults, and cone elongation. Consequent to the formation of these structures and continuous strike-slip movement, landslides occur on the flanks of the cone. In plan view, these landslides are found at positions slightly offset from the surface projection of the underlying strike-slip fault. Continuous landslide occurrence in these regions, have resulted in intense erosion of the north-northwest and south-southeast flanks of the volcano. The strong erosion of the volcanic flanks reveal the structural and surface deformation of a volcano that has been subjected to at least 340,000 years of strike-slip fault movement at its base. These features identified in the field and in satellite imagery are identical to all the structures found in the analogue sand cone models.

The Monte Somma dyke swarm and its host rock: possible clues to a flank collapse on Monte Somma (Naples, Italy)

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Due to the complete lack of research funds, no planning can be made on the future 5-year activity in the framework of the IGCP project n. 455. Consequently, the presentation will deal with results obtained in previous years of research [1]. The Monte Somma-Vesuvius is an active stratovolcano located on the Bay of Naples (Italy). Vesuvius is the most recent active cone which stands inside the horseshoe-shaped caldera cut in the Monte Somma, the old volcanic ridge exposed on the northern and eastern flanks of the volcano. This volcano is tragically famous due to several well-known eruptions, the most famous of which is the 79 AD Plinian eruption that destroyed Pompeii and Herculaneum. Unexpectedly, the intrusive complex of this volcano is poorly known. The presentation will focus on the moderate-intensity dyke swarm that crops out along the caldera wall cut in the Monte Somma and its host rock. A detailed field survey of 101 individual intrusions consisted of the recording of about 20 parameters for each intrusion according to a standardised method [1, 2]. In addition, the intrusions were located in the framework of a new geological map drawn for the caldera wall at a scale 1:2000 [3]. The Monte Somma intrusions that crop out from 780 to 1055 m above the sea level, are mostly monogenetic steeply-dipping segmented dykes; inclined sheets are also present, generally dipping towards the outer periphery of the volcano. Apparent crosscut due to dyke segmentation is common; true intersections show ambiguous alternation of dyke strikes. Indicators of initial intrusive flow (opening stage of the dyke-hosting fracture) often differ in direction and sense from late-stage indicators. Frequently, dykes intruded sub-horizontally in an early stage and later sub-vertically. The peak extension for Monte Somma, computed according to a standardised method [4], is 81.7 m in the direction N90°, based on 96 exposed sheets. Very likely, most of Monte Somma sheets intruded within ~12 ka, giving a time-averaged minimum extension rate of ~7 mm a^{-1}. On Monte Somma-Vesuvius, the azimuth pattern and the azimuth of peak extension are different in the two portions in which the caldera wall can be divided, east and west of Canale dell'Arena. This difference may indicate that two fault systems affecting the basement underneath the volcano exert their influence on the feeding system [1]. On the other hand, three main dyke sets (among which the set trending NE-SW is prevalent) exist on Monte Somma, and inclined sheets form a significant portion of the intrusions. In addition, the peak extension and the percentage extension are comparable quantitatively in the two different sections of the caldera. Moreover, the cumulative minimum extension (in direction N25°) corresponds to 75% of the maximum extension (in direction N90°). This value is similar to that computed for Etna (78%; [4]), where the influence of self-induced stresses on dyke emplacement is well-assessed [5]. This may suggest that self-induced stresses constrained the emplacement of the sheet swarm exposed along the Monte Somma caldera wall. Therefore, interplay of the regional stress field from the basement, with the self-induced radial stress field may be envisaged for Monte Somma.

From the stratigraphic study of the host rock exposed along the caldera wall of Monte Somma, several main angular unconformities are identified in the succession, indicating a complex history of construction and demolition episodes before the formation of the present escarpment. In particular, it appears that the Monte Somma succession cannot be classified as a single monotonous sequence of lava flows belonging to a single central edifice, as proposed in very recent works. Pyroclastic deposits, that have never been described before, are interbedded in the Monte Somma succession and indicate highly explosive activity (flows and surges containing pumice, magma chamber wall fragments, and basement xenoliths). These deposits are grouped into two main units exposed along the caldera wall. In addition, tilted megablocks included in the succession are mapped together with palaeocaldera surfaces.

This reconstruction shows a long history of edifice instability that, together with structural data of mesofaults affecting the caldera wall and with the apparent asymmetry of the volcano, provides clues to the possibility of past flank failures directed towards W-SW.

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Rb-Sr and Sm-Nd isotopes and the source of young (<11 Ma) magmas of the northern Andes

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The magmatism younger than 11 Ma in Colombia is associated with the subduction of the Nazca oceanic plate below the Andes. The Combia Formation comprises volcanic rocks formed between 11 and 6 Ma, and is located in the Cauca-Patía inter-Andean graben, which this limited by the Romeral (to the east) and Cauca (to west) fault systems. During the last 5 Ma the volcanic activity migrated from the graben towards the axis of the Central Cordillera and also towards the southern part of the Western Cordillera, originating more than 55 volcanic complexes, with ca. 15 still active.

The Central Cordillera this comprises of igneous and metamorphic rocks of continental character, and the Western Cordillera the basement rocks are part of an allochthonous oceanic sequence of basic volcanics intercalated with marine sediments.

Petrographic, geochemical and isotopic studies indicate the presence of primitive andesites and dacites of calc-alkaline character. Commonly, tholeiitic basalts and associated rocks also found in the Combia Formation.

According to several authors the present magmatic activity (<5 Ma) represents the continuity of the event that generated the Combia Formation, however some geological features need to be clarified before one accepts such proposal. Among them are:

- The presence of tholeiitic basalts and associated rocks in the Combia Formation.
- The Combia volcanics are found from the border with Ecuador up to $6^0$30' N, while the present volcanism only appears up to 5^0N.
- The Combia Formation is located along of the Cauca-Patía inter-Andean graben and the present volcanism is located mainly in the Central Cordillera with a few volcanoes near the Ecuadorian border, in the Western Cordillera.

The migration of the magmatism during the last 11 Ma, the restricted latitudinal location, the type of basement for each volcanic suite and the presence of the Romeral and Cauca regional faults, are aspects that must be influence the final products of the volcanic centers.

The investigation of the relative roles of each of these processes in the final volcanic product requires geophysical, petrographic, geochemical and isotopic studies. These tools were useful to: (i) understanding the geodynamic processes involved in the generation of the Andean magmatism in Colombia, during the last 11 Ma, and (ii) assess how these aspects can be evaluated in respect to the human activities.

In the context of the project "Effects of basement structural and stratigraphic heritages on volcano behavior and implications for humans activities" our proposal includes the detailed characterization of the sources of volcanism to evaluate interaction (contamination and assimilation) of the primitive magmas with melts derived from the basement of the volcanic complexes. The study can start with geochemical and isotopic Rb-Sr and Sm-Nd studies, which will be with rocks of the Combia Formation and of the main volcanic centers of Colombia: Azufral, Cumbal, Chiles, Doña Juana, Galeras, Bordoncillo, Puracé, Tolima and Nevado del Ruiz.

Eruptive histories of Kamchatka volcanoes: methods of reconstruction, temporal and spatial patterns of Holocene eruptive activity, proposed data base, and possible contributions to the IGCP Project 455

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The lithospheric plates have been moving uniformly during the last thousands of years such that we may assume that magma in subduction zones is generated continuously at a constant rate. In this case, we might expect continuous, uniform output of magma at the surface, along linear zones of different melting regimes, sub-parallel to the trench. Eruptions of magma at the surface, however, are apparently episodic, or clustered, rather than constant or periodic in time. Furthermore, the volcanic belt extending along the trench, consists of intricately scattered vents, spread out over a much wider zone than anticipated by a simple model of trench generated magma flow. Are observed temporal and spatial patterns of volcanism a manifestation of uniform random processes, with the underlying mass flux uniform in time and space, or is there a deeper process at work, organizing magma flux in spurts? What is the cause for alternating calm and active volcanic periods? Are they controlled by local changes in stress fields in the upper crust or is there a deeper source for the outbreaks of volcanism along the entire volcanic belt? We propose to address these questions with the help of data base with GIS-project on Holocene Kamchatka volcanism, which will include the data on locations, ages, volumes and compositions of erupted products.

Kamchatka Peninsula hosts about 30 recently-active volcanoes and hundreds of monogenetic vents which form a 700-km long volcanic belt from Shiveluch (56.65^o N 161.36^o E) in the north to Kambalny (51.30^o N, 156.87^o E) in the south. Kamchatkan volcanism as well as that of adjacent Aleutian and Kurile island arcs is produced by subduction of the Pacific plate at (modern) rate of 9-10 cm/yr (Minster and Jordan, 1978). Recent polygenetic volcanoes vary from typical basaltic stratocones to dominantly andesitic stratovolcanoes with extrusive domes and rhyolitic extrusive volcanoes. Some monogenetic vents form clusters at various scales: from lava fields with areas of more than 1000 km^2, including tens of vents, to smaller groups numbering 10-15 vents.

Volcanism in Kamchatka is mainly explosive in character. Multiple Holocene ash layers, separated by soils, form the soil-pyroclastic cover that blankets most of Kamchatka. This ash cover provides a continuous record of Holocene explosive eruptions. Earlier ash layers in Kamchatka were almost everywhere destroyed during the Late Pleistocene glaciation and occur as isolated beds. Good preservation of Holocene deposits and landforms favours detailed studies of the eruptive histories of Recent volcanoes.

Systematic studies since 1972 have allowed the reconstruction of the Holocene eruptive histories of most Kamchatka volcanoes. The studies of each volcano included:

- detailed geologic mapping using the large-scale air photos with identification of main and adventive vents, individual lava and pyroclastic flow units, debris avalanche deposits and other volcanic and non-volcanic landforms;
- studies of the Holocene soil-pyroclastic cover around the volcano and compilation of the summary stratigraphy of fall deposits that records the explosive activity of the volcano;
- radiocarbon dating of the organic matter associated with the volcanic deposits;
- fitting the lava and pyroclastic flows and other volcanic and non-volcanic deposits into the overall stratigraphic succession through the study of the soil-pyroclastic cover overlying each of the units;

- compilation of the summary stratigraphy of all the erupted products of a volcano including both tephra and lava and reconstruction of a volcano's past activity.

As a result of more than 30 years of study, our research group has accumulated an extensive data set on Holocene volcanism in Kamchatka, which has allowed us to reconstruct the eruptive histories of most of active volcanoes in Kamchatka, identify and date their largest eruptions, active and repose periods, flank eruptions and other related events. The largest Holocene explosive eruptions were documented and dated; probable correlations with acid peaks in the Greenland ice-cores have been suggested (Braitseva et al., 1997a). Ash layers of these eruptions were identified as excellent marker horizons which allowed us to correlate stratigraphies of individual volcanoes (Braitseva et al., 1997b).

Initial attempts at analyzing the extended data set resulted in identification of two distinct sequential peaks of explosive volcanism, each entailing voluminous eruptions. The more impressive first one included "a century" of catastrophes, lasting from 6600 to 6400 BC and comprising two calderas and numerous other eruptions with a total magma volume of at least 245-292 km^3 (Melekestsev et al., 1998). These eruptions completely devastated an area greater than 5000 km^2 and influenced global climate patterns (Braitseva et al., 1997a). Similar intriguing episodic concentrations of volcanism are known also from historical record in other volcanic regions, e.g. along the boundary of the Caribbean Plate and in the western Bismark arc (Simkin,Siebert, 1994).

Some historic eruptions seem to be clustered around large earthquake activity (e.g. Darwin, 1840). Initial comparisons of our paleovolcanic record with some other geologic records (tsunami, landslides, sea level changes) showed that at least the second of the two peaks of explosive volcanism in Kamchatka (2000-1400 ^{14}C yrs BP) seemingly coincides in time with a period of especially frequent tsunami (Pinegina et al., in press) and also with the time interval of intensified co-seismic landslides (Pinegina, in press). We see this as a first step in determining a correlation of paleoseismic events and episodes of volcanism.

We expect that along with global and regional peaks of explosive arc volcanism, documented on a Eocene to Quaternary scale based on deep-sea cores (Cambray and Cadet, 1996), there existed smaller volcanic peaks, which should be well seen on a Holocene scale and are important for our understanding of near future. Immediate reasons for them were deep crustal or upper mantle intrusions, which break through to the surface producing mafic volcanism, but also intrude shallow silicic chambers triggering silicic eruptions (Sparks and Sigurdsson, 1977; Volynets, 1979, 1989, 1999). Peaks of volcanic activity seem to coincide in time with general intensification of tectonic processes as seen by earthquake-triggered landslides and locally-generated tsunami. While changes in local stress fields may explain synchronous behavior of adjacent volcanoes if we find expected spatio-temporal patterns in volcanism throughout Kamchatka, coupled with paleo-seismic peaks, this will indicate "deeper-seated" causes reflecting fundamental tectonic events.

Joint analyses of diverse data sets hopefully will provide quantitative constraints on dynamic models of subsurface tectonics and explain spatial, temporal and compositional variations of Kamchatka volcanism. We are going to involve geophysicists (J.Lees and his students, USA) and mathematicians (A.Gusev and his students, Russia) to help us to analyze the data set. We expect that our effort will contribute significantly to an improved understanding of island-arc volcanism and forecast of future eruptions.

Rift magmatism in the Ross Sea Region, Antarctica: control of magma genesis and emplacement by intraplate strike-slip tectonics

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Widespread volcanism characterizes the West Antarctic Rift System (WARS) since Oligocene. The magma genesis has been thought to be linked to the activity of Cenozoic plume(s) based on the OIB-like basalt geochemistry, the doming of Marie Byrd Land, the modest Cenozoic extension in the WARS, the lack of plate tectonic mechanisms to produce rifting and volcanism. However, the distribution of plutons and dike swarms found on the western Ross Sea rift shoulder casts doubts on the plume scenario. This pluton-dike association documents the middle Eocene inception of magmatism, coeval with a plate tectonic setting suitable to trigger rifting and volcanism: the middle Eocene increase of Australia-Antarctica spreading rate. Plutons and dike swarms emplaced at 48-35 Ma in the area between Campbell and Icebreaker glaciers, and at 31-18 Ma between Icebreaker and Borchgrevink glaciers. In the former area the intrusive and volcanic activity are separated by about 20 myr, whereas north of Icebreaker Glacier no significant time gap exists between the youngest intrusions and the oldest lavas. The age distribution brings evidence for activation of magmatism in different crustal blocks at different time, a pattern not compatible with the activity of a mantle plume. The internally isotropic plutons are weakly elongated parallel to and located in correspondence of the main Cenozoic NW-SE strike-slip fault systems. The overall strike of the dikes cluster on NW-SE and NS directions. Dikes on the two trends have the same age: NW-SE dikes emplaced along the main NW-SE strike-slip fault systems, while N-S dikes emplaced along the N-S transtensional faults which developed or were re-activated in the western Ross Sea as a kinematic consequence of the dextral transcurrence. In the adjoining area of southern Victoria Land emplacement of widespread Cenozoic dikes is also ruled by the right-lateral transtensional tectonics. Additional evidences question the plume hypothesis: (i) the prolonged subsidence of Ross Sea basins in Cretaceous and Cenozoic time -a plume is generally carrying higher-than-normal mantle temperatures, (ii) the elevated linear rift shoulder of northern Victoria Land, with no evidence of doming, (iii) the amount of Cenozoic extension in the Ross Sea area, for which values larger than previously thought have been recently reported. Finally, the geochemical features of the magma source, when compared to the long duration and wide areal extent of magmatism, appear poorly variable, and do not show any systematic change in space or time. In addition, comparable first-order geochemical signature are reported for the magma source of the most OIB-like products from within-plate setting, either from oceanic islands, continental rifts or mixed settings. The new data for the early rift magmatism highlight a chronological-structural link between magmatism, regional tectonics and plate dynamics. This allows to propose a model alternative to the mantle plume hypothesis. The mid-Eocene increase of differential velocity along the Southern Ocean fracture zones is related to the reactivation of Paleozoic tectonic discontinuities in northern Victoria Land as intraplate dextral strike-slip fault systems. The activity of these lithospheric deformation belts promoted local decompression melting of a sub-plate, weak, enriched mantle that was brought close to the solidus by decompression during the amagmatic late Cretaceous extensional rift phase. The magma rose and emplaced along the main NW-SE discontinuities and, mainly, along the N-S transtensional faults arrays departing from the master NW-SE systems. This model relates the driving forces of events such as uplift, active faulting, magmatism and seismicity to the dynamics of the Antarctic plate rather than to deep-source forces such as mantle plumes.

Structural and neotectonic investigations in the Etnean area, Sicily

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Researchers at Brunel University, including those involved in the former West London Institute and often in collaboration with the International Institute of Volcanology in Catania, have been carrying out work in the Mount Etna area for approximately the past 20 years. Much of this work is relevant to the IGCP now under discussion and, in order to highlight potential future contributions and aid possible collaboration with other groups, can usefully be reviewed under the following subheadings: regional tectonics, edifice stability, uplift patterns and geodetic monitoring.

Regional tectonics. This work has concentrated on the Timpe fault system as an on-land extension of the Maltese Escarpment and proposes interactions with the Messina fault system as a mechanism for producing E – W extension beneath the eastern flank of Mount Etna.

Edifice stability. Work is underway aimed at better understanding the role of the distinct set of radially-arranged faults which cut the Etnean volcanic edifice. Of these faults the active Ragalna system is of particular interest since it appears to be related to lithological contrasts within the Etnean basement.

Uplift patterns. Using uplifted marine notches and terraces this ongoing work has documented systematic variations in uplift within eastern Sicily, notably along the coastlines defined by the Maltese Escarpment and the Messina fault system.

Geodetic monitoring. More recent work under this subheading has established and re-measured EDM and GPS networks across the system of flank faults on Mount Etna, as well as monitoring several devices to record movement within disrupted cultural features that span these faults. Movement patterns recorded by these networks are correlated with seismic and eruption data with the aim of identifying interactions important for volcanic and edifice behaviour.

Volcanism in the Ethiopia Rift

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The Great East African Rift (GEAR) is famous world wide for its active rifting and volcanism in sub-aerial conditions, ranging from developed (nearly with oceanic crust) to early rifting (continental crust) stages. The northern part of GEAR is known as the Ethiopian Rift System, in which it is also divided in to the Afar and the Main Ethiopian Rift (MER), from North to South respectively. The Afar rift is more developed, with almost oceanic crust while the MER has still a thick continental crust. Volcanism and volcanic products in the Afar and MER vary Accordingly.
Generally, intensive volcanism in the Ethiopian Volcanic Province is accepted to have commenced at about 31 Ma ago, Hoffman et al., (1997) and references therein. Pre-rifting or Plateau volcanism, generally were fissural type and sometimes attain a thickness of over 2000 m. The older units (Ashange and Aiba) are dominantly basaltic flows and the younger units (Alaje and Tarmaber) are predominantly intermediate - acid pyroclastics, lava domes and thick but short flows.

Volcanic activities within the Afar rift is more fissural type and the products are series of layers of basaltic lava flows dominantly with subordinate acid pyroclastics and lava flows. The volcanic products in the Afar Rift quantitatively tend to be more basic with time, where as in the MER the products are more evolved with trachytic-rhyolitic lava flows, domes and pyroclastic deposits.

Although there is a general tendency of rift-ward younging of volcanic products in both the Afar and MER, marginal volcanics in the Afar gave an age of about 25 Ma and those of the MER area dated at only about 15 Ma. Along the axial parts of both rifts, there are reported Quaternary- Recent and even subhistoric-historic volcanic eruptions. In these areas there are active geothermal manifestations, like fumaroles, hot springs, hot grounds, gysers. Ertale, in the Northern Afar Rift is an active lava lake.

Due to the active volcanism of the axial and marginal parts of the rifts, there are induced earthquakes, land slides, rock falls, and pollution of air, water and soil. These have incurred tremendous problems to the settlers within and around the rifts. In particular, the earthquake hazards expected in Addis Ababa and Nazret are becoming more alarming due the rapid population growth of the cities in a short time.

Recently world seismic hazard assessment has shown that, Addis Ababa is one of the first 5 cities that are prone to high seismic risk. Within the radius of 150 km from Addis Ababa, epicentres of at least 4 major earthquakes (> 5 Richter) are known since the last 100 years. Registered casualties were insignificant, because the citizens were few and the city had not tall buildings, complex electricity, sewerage, fuel and gas line networks. Currently the situation is very alarming, because all the above mentioned networks have been lain without the awareness of seismic hazards. Moreover, the fire brigade stations, hospitals, ambulance vehicles and other necessary organisations and equipment to reduce the effect are lacking. Citizens of neither Addis Ababa nor Nazret are aware of the possibilities of devastating earthquakes, hence residences, schools, governmental and non-governmental offices and other structures are constructed with heavy masonry which are not seismic resistant.

Institutions that deal with the rift development and related studies are:
1. the Geology and Geophysics Department of the Addis Ababa University,
2. the Geophysical Observatory of the Addis Ababa University,
3. the Geological Survey of Ethiopia of the Ministry of Mines and Energy,
4. the Ethiopian Science and Technology Commission (ESTC) and
5. the Non-Governmental Organisations (NGOs), that deal with minerals and water exploration.

The first 3 are directly engaged in research works and produce data to be used either by the NGOs (5), or other Governmental structures. The ESTC (4), offers local research grant and other initiatives through the National Council for Mines, Geo-information, Water and Energy sector.