BOLLETTINO DI GEOFISICA TEORICA ED APPLICATA

SUPPLEMENT TO:
VOL. XXXVI, N. 141-144 - MARCH-DECEMBER 1994

E. BOSCHI, A. BASILI and G. VALENSISE

SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR
Italian research activity (1991-1994) report to IASPEI

INTRODUCTION

The Italian Seismology and Geodynamics have been the object of intense investigations by scientists from all over the world for over a century. Indeed the concentration of many active tectonic features in such a little space has intrigued generations of geologists and seismologists, who have developed tectonic models, established characteristic phenomena and defined new terminologies based on observations of Italian earthquakes and geology. But what makes Italy rather exceptional is the strong interrelation between natural and social history, because virtually every geodynamic paroxysm that has occurred in the country was first studied for its effects on the human environment. Hence it is not a coincidence that Italian seismology has traditionally placed special emphasis on investigations of historical seismicity, on observations and methods for assessing the country's Seismic Hazard, and on seismological surveys at the scale of the main seismogenic structures and of the main volcanoes. The past four years have seen continuing efforts in all these fields, but also the birth and rapid development of two new disciplines which curiously locate at the two far ends of the Seismic Hazard chain. At one end, palaeoseismological studies of Italian seismogenic faults have revealed unexpectedly large recurrence times for the largest earthquakes, raising concerns as to the effectiveness of the historical record for providing a reliable representation of the country's seismogenic potential. At the opposite end of the chain, modeling of the heterogeneity of the seismic response as a function of the surface or near-surface geological features of important urban areas has highlighted the complexity of the relation between ground shaking and damage patterns. Investigations of the response of important historical centers, such as Rome, Naples and Mexico City, to large earthquakes at regional distance show that the vulnerability of each individual building is a function of its design and dynamic properties combined with its location with respect to typically urban geological features, such as stream valleys, recent alluvial or marsh deposits and artificial fills.

Studies of seismic response have relied increasingly more on the improved understanding of the fault mechanics and wave propagation processes. Although no significant earthquakes have occurred in Italy during the past four years, the Italian seismologists have contributed to the investigation of the source properties of recent large and particularly intriguing earthquakes, with special emphasis on California events. The recent efforts, which include the latest models for the catastrophic 1980 Irpinia earthquake, suggest that the understanding of the seismic source must rely on fully interdisciplinary approaches, where observations of permanent geodetic and geologic deformation supply the extra-long period end-member to complement the seismographic evidence for dynamic slip on the fault plane.

Manuscript received December 19, 1994; accepted December 29, 1994.

Istituto Nazionale di Geofisica, Roma, Italy.

But because Italy is the heart of the Mediterranean, which in its turn is one of the most studied and most intriguing geological environments on the planet, during the past four years Italian science has increasingly focused also on unraveling key aspects of the evolution of the peninsula. The problem of understanding this complex evolutionary process has been tackled from two essentially observational and two essentially theoretical standpoints.

Perhaps the most common of the experimental approaches utilizes earthquakes to shed light on the geometry and characteristics of the present stress field, to constrain rates of present day deformation, and to illuminate from below the structure of the lithosphere. The past four years have been characterized by an outburst of tomographic studies exploring such diverse targets as the shallow structure of dormant Italian volcanoes, large-wavelength fluctuations of the Moho discontinuity beneath the peninsula, and the shape and location of major upper mantle discontinuities in the Mediterranean area. Traditional seismographic data have also been widely used to explore details of the Africa-Eurasia convergence, particularly to locate the subduction zone that represents the suture between the two adjoining plates and to constrain kinematics and rates of current plate motions by computing budgets of seismic release from large earthquakes. Current rates of deformation have also been explored by newly established GPS networks linking peninsular Italy with the Hellenic Arc and with stable Europe. The new networks are just now starting to return baseline changes significantly above noise level, and the first results suggest that peninsular Italy is currently undergoing relatively slow deformation in comparison with the rest of the central and eastern Mediterranean.

Recent theoretical studies of Mediterranean geodynamics deal mainly with the evolution and present-day arrangement of the region's plate mosaic and with quantitative modeling of the Tyrrhenian subduction and of its surface effects. Plate motion models are trying to get the most out of the still scant paleomagnetic and space geodesy records to elucidate the history of a most complex plate boundary, and propose non-conventional hypotheses to explain the extreme heterogeneity of the geologic fabric and of the main geodynamic events of the region. Meanwhile, modeling of the rheology of the upper mantle has been successful in simulating the effects of subduction beneath the Calabrian Arc, and particularly in explaining why this region that is undergoing a strong uplift, locates right next to areas currently experiencing significant extension and subsidence.

During the past four years, Italy's fundamental interest in Mediterranean geodynamics has also led to further progresses in the deployment and operation of MedNet, a very broad-band seismographic network that now encompasses virtually all Mediterranean countries. In conjunction with the participation of Italian seismologists to large international projects, such as the pioneering exploration of Antarctica, the progress of MedNet has spurred the development of new instrumentation devoted to simultaneous real-time collection of observations that were previously gathered by separate instruments and institutions. A new integrated station including accelerometric, standard velocity and GPS sensors is currently being tested in view of a large scale application in the framework of the Italian National Network. Further efforts have been devoted to the development of more reliable means of data transmission and processing in order to maximize the capability of current earthquake detection and location procedures.

This report was intended to bring to the attention of the international seismological community a synthesis of the main accomplishments of Italian research in all disciplines that may be of interest for all IASPEI members, and a list of relevant papers that were published between 1991 and 1994. To maximize clarity and conciseness of this presentation, we included only papers that were published in English on refereed journals or conference proceedings, and that may therefore be readily available to a broader international audience.

HISTORICAL SEISMICITY STUDIES

Historical seismicity has traditionally been a major source of information on the location and potential of Italy's seismogenic sources. In the past few years the systematic study of past earthquake has gained new momentum following a series of large earthquakes in many parts of the world, most of which were largely unexpected and had not been forerun by an historical

event at the same location. On the contrary, Italy can count on an almost homogeneous record of past earthquakes throughout the country, with the exception of a few problematic gap areas. These areas are currently under closer inspection to understand whether the observed quiescence is a result of lack of earthquake potential or is simply due to limitations of the historical record.

In the past four years the studies of historical seismicity have focused on such traditional targets as retrieving new information or reinterpreting existing information on previously known earthquakes; reanalyzing natural events that were erroneously reported as earthquakes; and exploring little known and innovative sources, including archeological, epigraphic and historiographic evidence, to bring to light previously unknown earthquakes and update the national record of historical earthquakes. In recognition of its long history and of its central location in the Mediterranean, not only geographically but also from the cultural point of view, during the past few years Italy has been established as the focal point of all Mediterranean and European efforts in Historical Seismology.

A specific international project has addressed the long-standing problem of dealing with cross-national earthquakes and with different ways of assessing the impact of the same event. The project has also promoted the creation of a homogeneous European catalogue. Several recent contributions have also explored advantages and limitations in the current approaches to historical seismicity, stressing on the importance of standardizing the criteria for assessing the macroseismic intensity both for modern and pre-instrumental earthquakes. The outcome of all these studies is perhaps best represented by the new European Macroseismic Scale, that was created as an updated version of the MSK scale.

An important recent accomplishment in the field of Historical Seismology has been the creation of computer databases for the interactive analysis of historical information. These new tools represent for this discipline an innovation of comparable importance as the introduction of digital data in instrumental Seismology. Unlike most of their predecessors, the new computer catalogues allow the reader to access not only the standard parametric information on each earthquake, but also the original information that was used to obtain each individual estimate and parameter, from the macroseismic intensity to the epicentral coordinates.

BIBLIOGRAPHY

Albini P., Moroni A. and Bellani A.; 1991: *The 1846 Orciano (Pisa) earthquake in published and government survey documents.* Tectonophysics, **193**, 117-130.

Albini P. and Vogt J.; 1992: *Landslide or earthquake? Case histories from historical sources.* In: Faccioli E. and Pecker A. (eds), Proceedings French-Italian Conference on "Slope Stability in Seismic Areas", Bordighera (Imperia), Italy, pp. 11-24.

Albini P.; 1993: *Investigation of XVII and XVIII centuries earthquakes in the documents of governors and representatives of the Republic of Venice.* In: Stucchi M. (ed), Materials of the CEC project Review of Historical Seismicity in Europe, CNR, Milano, **1**, pp. 55-74.

Albini P. and Rodriguez de la Torre F.; 1993: *Known and unknown earthquakes through some European periodicals of the eighteenth century.* Terra Nova, **5**, 481-487.

Albini P. and Gutdeutsch R.; 1993: *Historical seismology in the ESC.* Terra Nova, **5**, 461-462.

Albini P. and Moroni A. (eds); 1994: *Materials of the CEC project Review of Historical Seismicity in Europe.* CNR, Milano, **2**, 254 pp.

Albini P., Ambraseys N.N. and Monachesi G.; 1994: *Material for the investigation of the seismicity of the Ionian Islands between 1704 and 1766.* In: Albini P. and Moroni A. (eds), Materials of the CEC project Review of Historical Seismicity in Europe, CNR, Milano, **2**, pp. 11-26.

Albini P., Cecic I., Morelli G., Sovic I. and Zivcic M.; 1994: *A preliminary investigation of the January 4th, 1802 earthquake.* In: Albini P. and Moroni A. (eds), Materials of the CEC project Review of Historical Seismicity in Europe, CNR, Milano, **2**, pp. 205-214.

Barbano M.S., Bellettati D. and Slejko D.; 1994: *Sources for the study of the Eastern Alps earthquakes in the turn of the XVII century.* In: Albini P. and Moroni A. (eds), Materials of the CEC project Review of Historical Seismicity in Europe, CNR, Milano, **2**, pp. 115-132.

Bellettati D., Camassi R. and Molin D.; 1993: *Fake quakes in Italy through parametric catalogues and seismological compilations: case histories and typologies.* Terra Nova, **5**, 488-495.

Camassi R., Mirenna S., Rebez A., Stucchi M. and Zerga A.; 1994: *Problems and pitfalls in the compilation of comprehensive, parametric earthquake catalogues.* In: Albini P. and Moroni A. (eds), Materials of the CEC project Review of Historical Seismicity in Europe, CNR, Milano, **2**, pp. 241-254.

Cergol M. and Slejko D.; 1991: *The Eastern Alps Earthquake of March 26, 1511: state-of-the-art.* In: Kozak J. (ed), Proceedings of the III International Symposium on Historical Earthquakes in Europe, C.A.S., Prague, pp. 197-211.

Chiaruttini C. and Siro L.; 1991: *Focal mechanism of an earthquake of Baroque age in the Regno delle Due Sicilie (southern Italy).* Tectonophysics, **193**, 195-203.

Degasperi C., Slejko D., Rebez A. and Cergol M.; 1991: *Earthquakes felt in Trieste from the Middle Ages to the XVIII century.* Tectonophysics, **193**, 53-63.

De Rubeis V., Gasparini C. and Tosi P.; 1992: *Determination of the macroseismic field by means of trend and multivariate analysis of questionnaire data.* Bull. Seismol. Soc. Am., **82**, 1206-1222.

De Rubeis V., Gasparini C., Maramai A., Murru M. and Tertulliani A.; 1992: *The uncertainty and ambiguity of isoseismal maps.* Earthquake Engineering and Structural Dynamics, **21**, 509-523.

De Rubeis V., Dimitriu P., Papadimitriou E. and Tosi P.; 1993: *Recurrent patterns in the spatial behaviour of Italian seismicity revealed by the fractal approach.* Geophys. Res. Lett., **20**, 1911-1914.

De Rubeis V., Gasparini C. and Tosi P.; 1993: *Statistical comparison of geophysical parameters and seismicity in Central Italy.* Natural Hazards, **7**, 25-39.

De Rubeis V., Maramai A. and Tertulliani A.; 1994: *National border earthquakes: an attempt at intensity data unification.* Annali di Geofisica, **37**, 77-91.

Di Maro R. and Tertulliani A.; 1991: *A statistical approach to the relation between intensity and magnitude for Italian earthquakes.* In: Proceedings of the III International Symposium on Historical Earthquakes in Europe, Prague, pp. 35-40.

Favali P., Frugoni F., Gasperini M., Monna D., Rainone M.L., Signanini P. and Smriglio G.; 1994: *1930 Senigallia earthquake case history (Adriatic coast, central Italy): an integrated approach to seismic risk prevention.* In: Olivera R., Rodriguez L.F., Coelho A.G. and Cunha A.P. (eds), Proceedings VII Congress International Association of Engineering Geology, Balkema, Rotterdam, pp. 1985-1990.

Gasparini C., De Rubeis V. and Tertulliani A.; 1992: *A method for the analysis of macroseismic questionnaires.* Natural Hazards, **5**, 169-177.

Gasparini C., De Rubeis V., Maramai A. and Murru M.; 1993: *The November 23, 1980 Irpinia earthquake: an analysis with the new procedure of intensity evaluation.* Annali di Geofisica, **36**, 35-46.

Guidoboni E., Comastri A. and Traina G.; 1994: *Catalogue of ancient earthquakes in the Mediterranean area up to the 10th century.* Istituto Nazionale di Geofisica (publ.), Bologna, 504 pp.

Grillo P. and Moroni A.; 1991: *Investigating the area of perceptibility: the case of the 1564, Nice earthquake.* In: Kozak J. (ed), Proceedings III ESC Workshop on "Historical Earthquakes in Europe", Liblice (Prague), 4-6 April 1990, pp. 212-223.

Grünthal G., Musson R.M.V., Schwarz J., and Stucchi M. (eds); 1993: *European Macroseismic Scale 1992 (Updated MSK-Scale).* Cahiers du Centre Européen de Géodynamique et de Séismologie, **7**, Luxembourg, 79 pp.

Lambert J., Moroni A. and Stucchi M.; 1994: *An intensity distribution for the 1564, Maritime Alps earthquake.* In: Albini P. and Moroni A. (eds), Materials of the CEC project Review of Historical Seismicity in Europe, CNR, Milano, **2**, pp. 143-152.

Margottini C., Martini G. and Slejko D.; 1991: *An instrumental earthquake catalogue for northeastern Italy since 1900.* Technical Report, ENEA, Roma, 51 pp.

Monachesi G. and Moroni A.; 1993: *Problems in assessing macroseismic intensity from historical earthquake records.* Terra Nova, **5**, 463-466.

Moroni A., Chignola E., Pierulivo M. and Stucchi M.; 1992: *Earthquakes and frontiers of XIX century in the Northern Apennines.* In: Roca A. and Mayer-Rosa D. (eds), Proceedings and Activity report 1988-1990, XXII ESC General Assembly, Barcelona, 17-22 September 1990, **1**, pp. 345-351.

Moroni A., Bellettati D., Chignola E. and Stucchi M.; 1993: *The earthquakes of 1834 in the Northern Apennines.* Annali di Geofisica, **36**, 301-308.

Moroni A. and Stucchi M.; 1993: *Materials for the investigation of the 1564, Maritime Alps earthquake.* In: Stucchi M. (ed), Materials of the CEC project Review of Historical Seismicity in Europe, CNR, Milano, **1**, pp. 101-125.

Panza G.F., Craglietto A. and Suhadolc P.; 1991: *Source geometry of historical events retrieved by synthetic isoseismals.* Tectonophysics, **192**, 173-184.

Postpischl D., Stucchi M. and Bellani A.; 1991: *Some ideas for a databank of macroseismic data.* Tectonophysics, **193**, 215-223.

Riguzzi F. and Tertulliani A.; 1993: *Re-evaluation of minor events: the examples of the 1895 and 1909 earthquakes of Rome.* Natural Hazards, **7**, 219-235.

Slejko D. and Cergol M.; 1991: *The Villach earthquake of December 4, 1690: state-of-the-art.* In: Kozak J. (ed), Proceedings of the 3rd Int. Symp. on Historical Earthquakes in Europe, C.A.S., Prague, pp. 224 - 240.

Stucchi M., Postpischl D. and Slejko D. (eds); 1991: *Investigation of Historical Earthquakes in Europe.* Tectonophysics, **193**, 251 pp.

Stucchi M., Bellani A. and Chignola E.; 1991: *Behind the intensity map: assessing the quality of historical-seismological*

information. In: Kozak J. (ed), Proceedings III ESC Workshop on "Historical Earthquakes in Europe", Liblice (Prague), 4-6 April 1990, pp. 41-57.

Stucchi M., Monachesi G. and Mandrelli F.M.; 1991: *Investigation of XVIII century seismicity in Central Italy in the light of the 1741 Fabriano earthquake.* Tectonophysics, **193**, 65-82.

Stucchi M. and Albini P.; 1992: *New developments in macroseismic investigation.* In: Faccioli E. and Meli R. (eds), Proceedings International Workshop on "Seismology and Earthquake Engineering", Mexico City, April 22-26, 1991, pp. 47-70.

Stucchi M.; 1993: *Historical seismology and seismic hazard.* Annali di Geofisica, **36**, 177-189.

Stucchi M.; 1993: *Through catalogues and historical records: an introduction to the project "Review of Historical Seismicity in Europe".* In: Stucchi M. (ed), Materials of the CEC project Review of Historical Seismicity in Europe, CNR, Milano, **1**, pp. 3-14.

Stucchi M.; 1994: *Recommendations for the compilation of a European parametric earthquake catalogue, with special reference to historical records.* In: Albini P. and Moroni A. (eds), Materials of the CEC project Review of Historical Seismicity in Europe, CNR, Milano, **2**, pp. 181-190.

Tertulliani A. and Maramai A.; 1992: *Macroseismic practice at ING, Rome.* In: Proceedings Second AB Workshop on Macroseismic Methods. Ljubljana, pp. 15-28.

Tertulliani A., Anzidei M., Maramai A., Murru M., Riguzzi F. and Vecchi M.; 1992: *Macroseismic study of the Potenza (Southern Italy) earthquake of May 5, 1990.* Natural Hazards, **6**, 25-38.

Tosi P., De Rubeis V. and Papadimitriou E.; 1994: *Statistical study of epicentre alignment in the broader Aegean Area.* Annali di Geofisica, **37**, 939-948.

ACTIVE FAULTING AND PALEOSEISMOLOGY STUDIES

In the past four years the studies on Italy's active faulting began to focus specifically on identifying large seismogenic sources and on obtaning their recurrence characteristics. In general, studies of Italian active faults have provided new insights into otherwise inaccessible aspects of the seismic cycle. The past decade has been characterized by the innovative Characteristic Earthquake and Fault Segmentation concepts, that were developed in the western United States around the beginning of the '80s. Due to the opportunity to compare and calibrate the geological observations with historical evidence of the location and characteristics of large earthquakes, Italian data and experiences have offered quite unique test cases to support the new models and accomplishments in the long-term behavior of large seismogenic faults.

Most of the research focused on the three largest Italian earthquakes of this century, the 28 December 1908, Messina Straits earthquake (Ms 7.2), the 13 January 1915, Avezzano earthquake (Mw 6.6) and the 23 November 1980, Irpinia earthquake (Ms 6.9), and on adjacent faults that are thought to have ruptured in known historical earthquakes or in prehistoric or currently unreported earthquakes. The results of the past four years can be summarized as follows:

All the large Italian earthquakes of this century occurred on unmapped, hidden or totally blind faults. This conclusion can be extrapolated to the causative faults of most of Italy's largest historical earthquakes. In addition, all the active faults that are known to have generated earthquakes prehistorically also exhibit limited surface expression, while the landscape is dominated by older inactive faults. The current explanation for this seemingly anomalous behavior is that all modern seismogenic faults are extremely youthful as their inception is the result of a major geodynamic change that took place between 0.5 and 1.0 Ma.

Both direct trenching investigations and modeling of landscape features to infer fault slip rates suggest that the largest Italian faults are capable of producing $M \approx 7$ earthquakes with an average repeat time of 1,000-to-2,000 years. These results imply that large earthquakes may be less frequent that previously thought, but also stress the importance of geological investigations as they indicate that the $\approx 1{,}000$ yr-long catalogue of Italian seismicity may be too short to catch even just one large earthquake on all the country's main seismogenic faults.

As a whole, the investigated large seismogenic faults delineate a major seismogenic belt running along the backbone of peninsular Italy and subdivided into 20-40 km-long segments. Support for this geological finding also comes from the historical record, which shows that the mesoseismal areas of the largest earthquakes are almost perfectly juxtaposed one to the other

suggesting a similar arrangement for their causative faults, and that very few events smaller than the assumed characteristic earthquake have occurred along most of the segments. The match between field and historical data strongly supports the Fault Segmentation concept and increases the predictive value of long-term seismic hazard assessment based on geological data.

BIBLIOGRAPHY

Alfonsi L., Funiciello R., Girotti O., Mattei M., Maiorani A., Preite Martines M., Trudu C. and Turi B.; 1991: *Structural and geochemical features of the Sabina strike-slip fault (Central Apennines).* Boll. Soc. Geol. It., **110**, 217-230.

Bosi V., Funiciello R. and Montone P.; 1994: *Fault reactivation: example in Central Apennines (Italy).* Il Quaternario, **7**, 577-588.

D'Addezio G., Pantosti D., Valensise G. and Cinti F.R.; 1993: *Investigating the seismic potential of hidden and semi-hidden faults: the 1908 Messina Straits and the 1980 Irpinia earthquakes (southern Italy).* Z. Geomorph. N. F., **94**, 119-135.

Nardi A. and Salvi S.; 1993: *Landsat synthetic stereo interpretation for morphostructural analysis in the Irpinia area.* Annali di Geofisica, **36**, 303-313.

Pantosti D., D'Addezio G. and Cinti F.R.; 1993: *Paleoseismological evidence of repeated large earthquakes along the 1980 Irpinia earthquake fault.* Annali di Geofisica, **36**, 321-330.

Pantosti D., Schwartz D.P. and Valensise G.; 1993: *Paleoseismology along the 1980 Irpinia earthquake fault and implications for earthquake recurrence in the southern Apennines.* J. Geophys. Res., **98**, 6561-6577.

Pantosti D. and Valensise G.; 1993: *Source geometry and long-term behavior of the 1980 fault based on field geologic observations.* Annali di Geofisica, **36**, 41-49.

Pantosti D. and Yeats R.S.; 1993: *Paleoseismology of great earthquakes of the late Holocene.* Annali di Geofisica, **36**, 237-257.

Salvi S. and Nardi A.; 1991: *Contribution of Landsat synthetic stereopair to morphotectonic analysis in the Irpinia area (Southern Italy).* Il Quaternario, **4**, 107-120.

Valensise G. and Ward S.N.; 1991: *Long-term uplift of the Santa Cruz coastline in response to repeated earthquakes along the San Andreas fault.* Bull. Seismol. Soc. Am., **81**, 1694-1704.

Valensise G. and Pantosti D.; 1992: *A 125 Kyr-long geological record of seismic source repeatability: the Messina Straits (southern Italy) and the 1908 earthquake (MS 71/2).* Terra Nova, **4**, 472-483.

Valensise G.; 1994: *Geologic assessment of the relative contribution of strike-slip faulting, reverse-slip faulting and bulk squeezing in the creation of the Central Santa Cruz Mountains, California.* U.S. Geolog. Survey Professional Papers, **1550 F**, 23-47.

Ward S.N. and Valensise G.; 1994: *The Palos Verdes terraces, California: bathtub rings from a buried reverse fault.* J. Geophys. Res., **99**, 4485-4494.

GEODYNAMICS

The understanding of the recent geodynamic evolution in a complex region such as the Mediterranean must rely on the joint analysis of several types of independent observations on the modern stress field and on modes of contemporary deformation.

Modern GPS surveys have become progressively more established during the past four years. In particular, the TyrGeoNet project is setting up a reliable framework to constrain the results of future baseline measurements between peninsular Italy, Sardinia, the Eolian Islands and the Hellenic Arc. Smaller GPS campaigns have been conducted also across the Alps, in the Himalaya, and in limited areas of particular geodynamic significance such as the Alban Hills volcano near Rome.

Traditional structural geology and offshore seismic reflection data also contributed to unraveling specific aspects of the post-Miocene evolution of peninsular Italy. The observed events can only be interpreted in terms of a complex stress field displaying high spatial variability along any transect perpendicular to the Apennines. The modern stress field has been investigated from well data (borehole breakouts) in the framework of a joint effort between major public research institutions and large oil and geothermal companies (mainly Agip and Enel). New data

have been obtained for the geothermal regions of Tuscany and Latium (central Italy) and for the southern Apennines, and a similar project is underway in Sicily. The stress field inferred from structural, focal mechanism and borehole data suggests that starting in the Lower Pleistocene most of peninsular Italy has been extending in a NE-SW to ENE-WSW direction, and that the strain is predominantly accommodated by normal faulting.

Many investigators have interpreted the available structural information in conjunction with paleomagnetic measurements and space geodesy observations to develop innovative plate motion models for the Mediterranean. The proposed models explain the structure and general characteristics of the Apennines in terms of progressive eastward extrusion of large lithospheric blocks as a result of the Africa-Eurasia convergence.

BIBLIOGRAPHY

Achilli V., Anzidei M., Baldi P., Marsella M., Salemi G. and Vespe F.; 1991: *The TYRGEONET project.* In: Mader G. (ed), Permanent Satellite Tracking Networks for Geodesy and Geodynamics, Springer Verlag, **109**, pp. 81-94.

Achilli V., Anzidei M., Baldi P., Gasparini C., Marsella M. and Riguzzi F.; 1993: *TYRGEONET: a global positioning system geodetic network for the geodynamical survey of the Italian peninsula.* Annali di Geofisica, **36**, 191-200.

Achilli V., Anzidei M., Baldi P., Donati F., Marsella M., Maseroli M., Pierozzi M., Riguzzi F., Salemi G., Santoro E. and Stoppini A.; 1994: *Comparison between GPS and I.G.M. coordinates in the Italian area.* Boll. di Geodesia e Scienze Affini, **53**, 1-23.

Anzidei M., Marchetti M., Riguzzi F., Achilli V. and Baldi P.; 1991: *GPS and tilt surveys in the Albani Hills area, (Rome, central Italy).* In: Proceedings Workshop on Geodynamical instrumentation applied to volcanic areas, Cahiers du Centre Européen de Géodynamique et de Séismologie, Luxembourg, Vol. **4**, pp. 87-96.

Anzidei M.; 1994: *GPS surveys in eastern Nepal.* Terra Nova, **1**, 82-89.

Anzidei M., Briole P. and Chery J.; 1994: *The GPS Alps Project.* Boll. di Geodesia e Scienze Affini, **5**.

Argnani A., Favali P., Frugoni F., Gasperini M., Ligi M., Marani M., Mattietti G. and Mele G.; 1993: *Foreland deformational pattern in the Southern Adriatic Sea.* Annali di Geofisica, **36**, 229-247.

Della Vedova B., Marson I., Panza G.F. and Suhadolc P.; 1991: *Upper mantle properties of the Tuscan-Tyrrhenian area: a key for understanding the recent tectonic evolution of the italian region.* Tectonophysics, **195**, 311-318.

De Rubeis V., Gasparini C., Solipaca A. and Tosi P.; 1992: *Seismotectonic characterization of Italy using statistical analysis of geophysical variables.* J. of Geodyn., **16**, 103-122.

Ebblin C.; 1991: *Present-stress Orientation Estimates in Abruzzo, Central Italy.* Boll. Geof. Teor. Appl., **33**, 130-131.

Favali P., Funiciello R., Mattietti G., Mele G., Montone P., Salvini F. and Tozzi M.; 1992: *Seismotectonic identity of the Southern Adriatic area.* In: Carmignani L. and Sassi F.P. (eds), Contributions to the Geology of Italy with special regard to the Paleozoic basements, IGCP Project, 276, Newsletter, **5**, pp. 339-343.

Favali P., Funiciello R., Mattietti G., Mele G. and Salvini F.; 1993: *An active margin across the Adriatic Sea (central Mediterranean Sea).* Tectonophysics, **219**, 109-117.

Funiciello R., Montone P., Parotto M., Salvini F. and Tozzi M.; 1991: *Geodynamic evolution of an intra-orogenic foreland: the Apulia Case History (Italy).* Boll. Soc. Geol. It., **110**, 419-425.

Mantovani E., Albarello D., Babbucci D. and Tamburelli C.; 1993: *Post Tortonian deformation pattern in the central Mediterranean: a result of extrusion tectonics driven by the Africa-Eurasia convergence.* In: Boschi E., Mantovani E. and Morelli A. (eds), Proceedings of conference "Recent evolution and seismicity in the Mediterranean region", Kluwer Academic Publishers, The Netherlands, pp. 65-104.

Mantovani E., Albarello D., Babbucci D. and Tamburelli C.; 1993: *Main constraints on the recent geodynamic evolution of Sicily and surrounding regions.* In: proceedings XII Annual Meeting GNGTS, pp. 641-650.

Mantovani E., Albarello D., Babbucci D. and Tamburelli C.; 1994: *Extrusion tectonics in the Mediterranean region.* Boll. Geof. Teor. Appl., **36**, 141-144.

Panza G.F., Prozorov A. and Pazzi G.; 1993: *Areas of tectonic shortening in the Italian region are marked by high frequency seismic sources.* Acta Geod. Geoph. Mont. Hung., **28**, 289-298.

Suhadolc P., Marson I and Panza G.F.; 1993: *Crust and upper mantle structural properties along the active Tyrrhenian rim.* Acta Geod. Geoph. Mont. Hung., **28**, 307-321.

TECTONOPHYSICS

Research in Tectonophysics deals mainly with modeling of the rheology of the Earth through the observation and analysis of contemporary stress and strain patterns.

Post glacial rebound

The effects of the viscosity increase across the transition zone between 420 and 670 km discontinuities have been analyzed. This transition plays a crucial role on the pattern of the horizontal motions at the Earth surface induced by post-glacial rebound. The effects of this viscosity - layering on the whole set of geophysical and geodetic signatures induced by post-glacial rebound - have been analyzed.

Mantle density anomalies and earth rotation

The long-term rotational signatures induced by density anomalies within the mantle and on the Earth surface have been considered; subduction plays a crucial role in driving the true polar wander, as inferred on the basis of paleomagnetic studies. The influence of the true polar wander on eustatic sea-level fluctuations and on the figure of the Earth has been considered.

Numerical models of tectonic processes in the Mediterranean area

Two-dimensional numerical models (vertical and horizontal) based on finite element approaches have been built to simulate the effects of tectonic processes active in the Mediterranean area. In particular, the investigations focused on the effects of the Africa - Eurasia collision on the stress pattern in the Tyrrhenian area and surrounding chains, and the effects of subduction underneath Calabria. The effects of basal dragging beneath the lithosphere have also been modeled.

BIBLIOGRAPHY

Albarello D., Mantovani E., Babbucci D. and Tamburelli C.; 1993: *Africa-Eurasia kinematics in the Mediterranean: an alternative hypothesis.* In: Boschi E., Mantovani E. and Morelli A. (eds), Proceedings of conference "Recent evolution and seismicity in the Mediterranean region", Kluwer Academic Publishers, The Netherlands, pp. 105-116.

Albarello D., Mantovani E. and Viti M.; 1993: *Numerical modeling of the present deformation pattern in Sicily and surrounding regions.* In: Proceedings XII Annual Meeting GNGTS, pp. 651-662.

Bassi G. and Sabadini R.; 1994: *The importance of subduction for the modern stress field in the Tyrrhenian area.* Geophys. Res. Lett., **21**, 329-332.

Boschi E., Spada G., Yuen D.A. and Sabadini R.; 1991: *Lower-mantle viscosity constrained by seismicity around deglaciated regions.* Nature, **351**, 53-55.

Boschi E., Mantovani E., Albarello D., Babbucci D. and Mucciarelli M.; 1991: *Regularities in time and space distribution of seismicity in the Periadriatic regions: tectonic implications.* Tectonophysics, **188**, 349-356.

Caputo M.; 1992: *Laboratory results, stress field and rheology of the crust and upper mantle.* Rend. Accad. Naz. Lincei, **9**, 3, 81-96.

Caputo M.; 1993: *The stress field in crust and the sinking of mountains.* J. Phys. Earth, **41**, 109-12.

Dragoni M., Santini S. and Tallarico A.; 1993: *A viscoelastic shear zone model of compressional and extensional plate boundaries.* PAGEOPH, **3**, 471.

Gasperini P., Yuen D.A. and Sabadini R.; 1992: *Postglacial rebound with a non-newtonian upper mantle and a newtonian lower mantle rheology.* Geophys. Res. Lett., **19**, 1711-1714.

Giunchi C., Gasperini P., Sabadini R. and D'Agostino G.; 1994: *The role of subduction on the horizontal motions in the Tyrrhenian basin. A numerical model.* Geophys. Res. Lett., **21**, 529-532.

Mantovani E., Albarello D., Babbucci D. and Tamburelli C.; 1993: *Migration of seismicity in the Anatolian-Aegean Region.* In: Proceedings XII Annual Meeting GNGTS, pp. 619-629.

Ricard Y., Doglioni C. and Sabadini R.; 1991: *Differential rotation between lithosphere and mantle: a consequence of lateral mantle viscosity variations.* J. Geophys. Res., **96**, 8407-8415.

Ricard Y., Sabadini R. and Spada G.; 1992: *Isostatic deformations and polar wander induced by redistribution of*

mass within the Earth. J. Geophys. Res., **97**, 223-14, 236.

Ricard Y., Spada G. and Sabadini R.; 1993: *Polar wandering of a dynamic Earth.* Geophys. J. Int., **113**, 284-298.

Sabadini R., Giunchi C., Gasperini P. and Boschi E.; 1992: *Plate motion and dragging of the upper mantle: lateral variations of lithospheric thickness and their implications for intraplate deformation.* Geophys. Res. Lett., **19**, 749-752.

Sabadini R., Spada G. and Ricard Y.; 1993: *Time-dependent density anomalies in a stratified, viscoelastic mantle: implications for the geoid, Earth's rotation and sea-level fluctuations.* Surveys in Geophysics, **14**, 537-553.

Sabadini R. and Giunchi C.; 1993: *Viscous drag and lateral viscosity heterogeneities: implications for intraplate deformation.* European Journal of Mineralogy, **5**, 1065-1071.

Spada G., Sabadini R., Yuen D.A. and Ricard Y.; 1992: *Effects on post-glacial rebound from the hard rheology in the transition zone.* Geophys. J. Int., **109**, 683-700.

Spada G., Ricard Y. and Sabadini R.; 1992: *Excitation of true polar wander by subduction.* Nature, **360**, 452-454.

Spada G., Sabadini R. and Boschi E.; 1994: *True Polar Wander affects the Earth dynamic topography and favours a highly viscous lower mantle.* Geophys. Res. Lett., **21**, 137-140.

DEVELOPMENT OF SEISMOGRAPHIC INSTRUMENTATION

Fundamental support to seismological studies in Italy derived from an unprecedented effort devoted to increase and improve seismographic instrumentation. The very-broadband seismographic Mediterranean Network has been expanding since 1991. It is a cooperative initiative involving most of the Countries in the area, collecting continuous high quality records. It is member of the Federation of Digital Seismographic Networks. Most recent developments include realtime data transmission, either through telephone lines or via satellite. An automated data collection system transfers data on trigger.

The development in design of seismological instrumentation resulted in the installation of three multi-sensor stations which include seismometric, accelerometric, and GPS geodetic instrumentation in Southern Italy. Advantages of co-location of instruments consists of cost efficiency and increase in effective dynamic range.

Artificial neural networks have been applied to the problem of recognition and automatic processing of seismic signals. These experiments have shown to be a very promising way to greatly reduce computational time and increase the effectiveness of seismic detection and location algorithms.

BIBLIOGRAPHY

Beranzoli L., Giardini D. and Pino N.A.; 1993: *Seismograms processing at MedNet.* Computers and Geoscience, **19**, 167-174.

Boschi E., Giardini D. and Morelli A.; 1991: *MedNet: The Very Broad-Band Seismic Network for the Mediterranean.* Il Nuovo Cimento, **14**, 79-99.

Boschi E. and Morelli A.; 1994: *The MEDNET Program.* Annali di Geofisica, **37**, 1066-1070.

Boschi E., Morelli A. and Gasperini P.; 1994: *A network of multi- sensor stations for continuous monitoring of ground motion and deformation.* Phys. Earth Planet. Int., **84**, 289-298.

Calderoni G., De Simoni F.M., Merucci L. and Saracino C.; 1994: *Satellite Seismic Network.* In: Proceedings XXIV General Assembly of the European Seismological Commission, Athens, pp. 19-24.

Chiarabba C., Malagnini L. and Amato A.; 1994: *Three-dimensional velocity structure and earthquake relocation in the Alban Hill volcano, central Italy.* Bull. Seismol. Soc. Am., **84**, 295-306.

Giardini D., Boschi E., Mazza S., Morelli A., Ben Sari D., Najid D., Benallou H., Bezzeghoud M., Trabelsi H., Hfaidh M., Kebeasy R.M. and Ibrahim E.M.; 1992: *Very-broadband seismology in Northern Africa under the MEDNET Project.* Tectonophysics, **209**, 17-30.

Mazza S. and Morelli A.; 1992: *Background seismic noise from MEDNET very-broad band stations.* In: Proceedings XXII General Assembly of the European Seismological Commission, Barcelona, I, pp. 197-202.

Morelli A.; 1991: *MEDNET: data management.* In: Boschi E., Giardini D. and Morelli A. (eds), Workshop on MEDNET, the broad-band seismic network for the Mediterranean., Il Cigno Galileo Galilei, Roma, pp. 34-62.

Morelli A., Romeo G., Meloni A. and Palangio P.; 1991: *The permanent unmanned very-broad band seismic station: installation, tests, and perspectives.* Mem. Soc. Geol. It., **46**, 575-583.

Morelli A., Romeo G., Meloni A. and Palangio P.; 1994: *Contribution of the permanent seismograph station at Terra Nova Bay to global seismological research.* Terra Antartica, **1**, 184.

Romeo G.; 1994: *Seismic signals detection and classification using artificial neural networks.* Annali di Geofisica, **37**, 343-353.

FAULT MECHANICS

Recent research activities on fault mechanics deal with two main issues: investigations on source kinematics, by means of waveform modeling and geological studies, and theoretical studies on fault dynamics. Recent investigations demonstrate that the earthquake mechanics is becoming increasingly interdisciplinary, as confirmed by the numerous studies concerning the 1980 Irpinia earthquake.

Waveform modeling

The analysis of seismic radiation from regional and teleseismic events is routinely performed to estimate source parameters, such as the moment tensor or the source time function. Several studies have been addressed to the inversion of ground motion waveforms to image the rupture history of moderate-to-strong earthquakes. Other studies proposed the analysis of rupture propagation by analyzing the S-wave polarization. Different approaches have been proposed to compute the Green functions, such as complete solutions or empirical methods, to be used in inversion procedures or forward waveform modeling attempts.

Fault dynamics

Several investigators focused on the study of fault mechanics. In particular, quasi-static models for the propagation of Somigliana dislocations along fault with nonuniform friction have been proposed. The effect of spatial variations of fault friction have been studied using rate and state dependent constitutive laws in order to model the faulting process during the seismic cycle. The postseismic evolution of fault surface has been studied employing either a linear viscous rheology for the shallow fault zone or laboratory derived frictional laws. The coupling between seismic and aseismic fault areas has been investigated in order to study the arrest of dynamic ruptures and the pattern of seismicity during the whole seismic cycle.

Propagation

The effects of lateral heterogeneities on the waveforms of strong-motion records have been studied, and it has been shown that most of the motion peculiarities can be inferred by taking into account the existing nearsurface information, when appropriate modelling techniques are used. Applications have been made for Mexico City, Rome, Friuli basin (NE Italy) and Benevento city (Italy). In an empirical approach, instrumental measurements of the effects of topography irregularities and near-surface soft layer were performed. A particular attention was devoted to check the feasibility of using weak motions and artificial sources to determine site response.

BIBLIOGRAPHY

Beranzoli L., Giardini D. and Boschi E.; 1993: *Determination of source parameters using broad-band seismograms.* Annali di Geofisica, **36**, 181-186.

Bernard P., Zollo A., Trifu C.I. and Herrero A.; 1993: *The details of the rupture kinematics and mechanisms of the Irpinia 1980 earthquake: new results and remaining questions.* Annali di Geofisica, **36**, 71-81.

Boatwright J. and Cocco M.; 1994: *The effect of lateral variation of friction on crustal faulting.* Annali di Geofisica, **37**, 1391-1410.

Del Gaudio V., Pierri P. and Calcagnile G.; 1994: *Source parameters and rupture process study from macroseismic and seismosynthetic data.* In: Proceedings XXIV General Assembly of the European Seismological Commission, Athens.

Di Bona M. and Boatwright J.; 1991: *Single-station decomposition of seismograms for subevent time histories.* Geophys. J. Int., **105**, 103-117.

Giardini D. and Beranzoli L.; 1991: *Waveform modelling of the May 20, 1990 Sudan Earthquake.* Tectonophysics, **209**, 105-114.

Giardini D.; 1992: *Moment tensor inversion from MedNet data: (1) large worldwide earthquakes of 1990.* Geophys. Res. Lett., **19**, 713-716.

Giardini D.; 1993: *Teleseismic observation of the November 23, 1980 Irpinia earthquake.* Annali di Geofisica, **36**, 17-25.

Giardini D., Boschi E. and Palombo B.; 1993: *Moment tensor inversion from MedNet data: (2) earthquakes of the Mediterranean.* Geophys. Res. Lett., **20**, 273-276.

Giardini D., Palombo B. and Boschi E.; 1993: *The determination of earthquake size and source geometry in the Mediterranean Sea.* In: Boschi E., Mantovani E. and Morelli A. (eds), Proceedings of the conference "Recent evolution and seismicity in the Mediterranean region", Kluwer Academic Publishers, The Netherlands, pp. 213-238.

Giardini D., Malagnini L., Palombo B. and Boschi E.; 1994: *Broad-band moment tensor inversion from single station, regional surface waves for the 1990, NW-Iran earthquake sequence.* Annali di Geofisica, **37**, 1645-1658.

Iannaccone G., Zollo A., De Matteis R. and Deschamps A.; 1994: *Rupture characterization of a low magnitude earthquake of central Apennines (Italy).* Phys. Earth Planet. Int., **82**, 347-360.

Panza G.F., Sileny J., Campus P., Nicolich R. and Ranieri G.; 1993: *Point source moment tensor retrieval in volcanic, geothermal and orogenic areas by complete waveform inversion.* Int. J. Appl. Geophys., **30**, 98-118.

Pavoni N., Ahjos T., Freeman R., Gregersen S., Langer H., Leydecker G., Roth Ph., Suhadolc P. and Uski M.; 1992: *Seismicity and focal mechanisms.* In: Blundell D., Freeman R. and Mueller St. (eds), A Continent Revealed: The European Geotraverse. Atlas of Compiled Data, Cambridge University Press, pp. 14-19.

Sileny J. and Panza G.F.; 1991: *Inversion of seismograms to determine simultaneously the moment tensor components and source time function for a point source buried in a horizontally layered medium.* Atti Accad. Naz. Lincei, **2**, 107-116; Studia Geophysica et Geodetica, **35**, 166-183.

Sileny J., Panza G.F. and Campus P.; 1992: *Waveform inversion for point source moment tensor retrieval with optimization of hypocentral depth and structural model.* Geophys. J. Int., **108**, 259-274.

Siro L. and Chiaruttini C.; 1991: *Comment on Source complexity of the 1980 Southern Italian Earthquake from the Analysis of Strong-Motion S Wave Polarization. (Reply).* Bull. Seismol. Soc. Am., **81**, 282-288.

Zollo A. and Bernard P.; 1991: *How does an asperity break ? New elements from the waveform inversion of accelerograms for the 23:19, October 15, 1979 Imperial Valley aftershock.* J. Geophys. Res., **96**, 21549-21573.

Zollo A. and Bernard P.; 1992: *Nonlinear inversion of S-wave polarization for constraining the source mechanism of small earthquakes.* In: Gasparini P. et al. (eds), Volcanic Seismology, pp. 248-266.

STRONG MOTION SEISMOLOGY

Research activities in this field deal with two main issues: source properties and wave propagation in laterally heterogeneous media.

Source

Studies on seismic source were addressed to the waveform inversion of local and regional events for the estimate of earthquake source parameters, and to the direct modelling with particular interest to simulation of ground motions in the high-frequency band (1-10 Hz), using both deterministic and stochastic methods. The Friuli 1976 and Irpinia 1980 earthquakes were studied in detail by modelling the accelerometric signals recorded at close distance. The results permit to determine the parts of the faults that have contributed most to the seismic moment release. New methods were proposed for estimating fault plane solution by non-linear inversion of body waves, and for inferring rupture velocity and directivity of moderate to large size events by deconvolution of the medium response with the empirical Green's functions. These methods were applied to study the source properties of several moderate and small size events in different tectonic provinces.

Propagation

The effects of lateral heterogeneities on the waveforms of strong-motion records have been studied, and it has been shown that most of motion peculiarities can be inferred by taking into account the existing near-surface information, when appropriate modelling techniques are used. Applications have been made for Mexico City, Friuli basin (NE Italy) and Benevento City (Italy). The assessment of potential strong ground motions in the city of Rome has been object of a detailed study, requiring a large cooperative effort from experts in urban geology, geotechnical engineering and seismology. The result of this research project was the integration of classical field-survey methods with the collection of data from numerous drillings available for the city of Rome. This allowed to achieve a detailed 3-D reconstruction of the subsurface geology using automatic procedures. The reconstruction of buried geometries in the urban area of Rome as well as the evaluation of associated elastic and anelastic parameters for each lithostratigraphic layer represented the input data for microzonation and numerical simulation of site effects in the city. In an empirical approach, instrumental measurements of the effects of topography irregularities and near-surface soft layers were performed. A particular attention was devoted to check the feasibility of using weak motions and artificial sources to determine site response. Innovative methodologies that make use of surface waves generated by small explosive sources were also developed to make inferences on velocity and attenuation structures of soft soils. Results of these experiments are useful for obtaining realistic estimates of ground shaking variations within a study area, even within an urban environment. Shear-wave velocities and attenuation factors are in fact very difficult to be obtained for soft soil coverages, although they strongly characterize the behavior of sites during earthquakes.

BIBLIOGRAPHY

Bonamassa O. and Vidale J.E.; 1991: *Directional site resonances observed from aftershocks of the Loma Prieta earthquake sequence.* Bull. Seismol. Soc. Am., **80**, 1945-1958.

Bonamassa O., Vidale J.E., Houston H. and Schwartz S.Y.; 1991: *Directional site resonances and the strong influence of near-surface geology on ground motion.* Geophys. Res. Lett., **18**, 901-904.

Capuano P., Gasparini P., Peron M. and Scarpa R.; 1992: *Strong ground motion and source parameters of earthquakes in the Apennines, Italy.* Earthquake Spectra, **8**, 529-554.

Cocco M. and Boatwright J.; 1993: *The envelope of acceleration time-histories.* Bull. Seismol. Soc. Am., **83**, 1095-1114.

Cocco M. and Pacor F.; 1993: *The rupture process of the 1980 Irpinia, Italy, earthquake from the inversion of strong-motion waveforms.* Tectonophysics, **218**, 157-177.

Cocco M. and Pacor F.; 1993: *The 1980 Irpinia earthquake: space-time evolution of the rupture process from the inversion of strong-motion waveforms.* Annali di Geofisica, **36**, 109-130.

Costa G., Panza G.F., Suhadolc P. and Vaccari F.; 1992: *Zoning of the Italian region with synthetic seismograms computed with known structural and source information.* In: Proceedings X WCEE, July 1992, Madrid, Balkema, pp. 435-438.

Costa G., Panza G.F., Suhadolc P. and Vaccari G.; 1993: *Zoning of the Italian territory in terms of expected peak ground acceleration derived from complete synthetic seismograms.* Int. J. Appl. Geophys., **30**, 149-160.

Faeh D., Suhadolc P. and Panza G.F.; 1991: *Estimation of strong ground motion in laterally heterogeneous media: modal summation-finite difference approach.* In: Proceedings Europ. Conf. on Earthquake Engineering, Kucherenko Tsniisk USSR Gosstroy, Moscow, 1990, **4A**, pp. 100-109.

Faeh D., Suhadolc P. and Panza G.F.; 1991: *Estimation of strong ground motion in one- and two-dimensional media.* In: Proceedings Seismed Workshop II on Seismic Vulnerability and Risk Assessment, Trieste 1990, UNDRO/UNDP(OPS)-SEISMED, Switzerland, pp. 619-634.

Faeh D., Iodice C., Suhadolc P. and Panza G.F.; 1993: *A new method for the realistic estimation of seismic ground motion in megacities: the case of Rome.* Earthquake Spectra, **9**, 643-667.

Faeh D., Suhadolc P. and Panza G.F.; 1993: *Variability of seismic ground motion in complex media: the case of a sedimentary basin in the Friuli (Italy) area.* Int. J. Appl. Geophys., **30**, 131-148.

Faeh D., Suhadolc P., Mueller St. and Panza G.F.; 1994: *A hybrid method for the estimation of ground motion in sedimentary basins: Quantitative modelling for Mexico City.* Bull. Seismol. Soc. Am., **84**, 383-399.

Florsch N., Faeh D., Suhadolc P. and Panza G.F.; 1991: *Complete synthetic seismograms for high-frequency multimode SH-waves.* PAGEOPH., **136**, 529-560.

Funiciello R., Boschi E., Di Bona M., Malagnini L., Marra F., Rovelli A. and Salvi S.; 1992: *Local seismic amplifications in the city of Rome inferred from observations of damage in monuments of imperial age: ground motion estimates*

based on subsurface geology data. In: Proceedings of International Symposium on "The Effects of Surface Geology on Seismic Motion", ESG March 25-27, Odawara, Japan, pp. 341-346.

Gresta S., Cosentino M. and Di Grande A.; 1992: *Microzoning of Carlentini (Eastern Sicily) after the December 13, 1990 earthquake.* In: Proceedings XXIII ESC General Assembly, pp. 444-447.

Hough S.E., Seeber L., Rovelli A., Malagnini L., De Cesare A., Selvaggi G. and Lerner-Lam A.; 1992: *Ambient noise and weak motion excitation of sediments resonances: results from the Tiber valley, Italy.* Bull. Seismol. Soc. Am., **82**, 1186-1205.

Malagnini L., Rovelli A., Hough S.E. and Seeber L.; 1993: *Site amplification estimates in the Garigliano valley, central Italy, based on dense array measurements of ambient noise.* Bull. Seismol. Soc. Am., **83**, 1744-1755.

Mao W.J., Panza G.F. and Suhadolc P.; 1994: *Linearized waveform inversion of local and near regional events for source mechanism and rupturing process.* Geophys. J. Int., **116**, 784-798.

Panza G.F.; 1991: *The theory and some appplications of synthetic seismograms to strong motion data and macroseismic informations.* In: Fantechi R. and Almeida-Teixeira M.E. (eds), Earthquake hazard assessment. Proceedings European School, Athens, May 1988, Commission of the European Communities, pp. 65-78.

Panza G.F., Suhadolc P. and Harabaglia P.; 1993: *Uncertainties in the estimate of strong ground motion in the surroundings of a large earthquake.* In: Nemec J. et al. (eds), Prediction and Perception of natural Hazards. Kluwer Academic Publishers, The Netherlands, pp. 153-158.

Panza G.F.; 1993: *Synthetic seismograms from multimode summation-theory and computational aspects.* Acta Geod. Geoph. Mont. Hung., **28**, 197-247.

Rovelli A., Singh S.K., Malagnini L., Amato A. and Cocco M.; 1991: *Feasibility of the use of microtremors in estimating site response during earthquakes: some test cases in Italy.* Earthquake Spectra, **7**, 551-561.

Rovelli A., Malagnini L. and Di Bona M.; 1991: *Investigations on site effects in Italy.* In: Proceedings of the International Workshop on Seismology and Earthquake Engineering, Centro Nacion. Preven. Desas., Mexico City, pp. 265-286.

Rovelli A., Cocco M., Console R., Alessandrini B. and Mazza S.; 1991: *Ground motion waveforms and source spectral scaling from close-distance accelerograms in a compressional regime area (Friuli, northeastern Italy).* Bull. Seismol. Soc. Am., **81**, 57-80.

Rovelli A., Malagnini L., Biella G., De Franco R., Di Bona M. and Selvaggi G.; 1992: *Evidence for large amplification of ground motion during an explosion experiment: a comparison with earthquake recordings.* In: Proceedings of the International Symposium on the Effects of Surface Geology on Seismic Motion, Odawara, Japan, ESG 1992, **1**, pp. 317-322.

Rovelli A., Caserta A., Malagnini L. and Marra F.; 1994: *Assessment of potential strong ground motion in the city of Rome.* Annali di Geofisica, **37**, 1745-1769.

Salvi S., Boschi E., Di Bona M., Funiciello R., Malagnini L., Marra F. and Rovelli A.; 1991: *Subsurface geology and variations of seismic response in the city of Rome.* In: Proceedings of the IV International Conference on Seismic Zonation, Stanford (California), pp. 115-122.

Sirovich L. and Chiaruttini C.; 1993: *The influence of source complexity on the polarization and azimuthal radiation of S-waves, and a simplified synthesis of the macroseismic field.* Annali di Geofisica, **36**, 81-92.

Sirovich L. and Del Grosso A.; 1993: *State-of-the-art in seismic microzonation, advances in Italy from 1980 to the present.* Annali di Geofisica, **36**, 133-144.

Sirovich L.; 1994: *A case of the influence of radiation pattern on peak acceleration.* Bull. Seismol. Soc. Am., **84**, 1658-1664.

Suhadol C.P., Harabaglia P. and Panza G.F.; 1991: *Deterministic modeling and estimate of strong ground motion: the Irpinia, Italy, november 23, 1980 earthquake.* In: Proceedings Europ. Conf. on Earthquake Engineering, Kucherenko Tsniisk USSR Gosstroy, Moscow, 1990, **4A**, pp. 110-120.

Vaccari F., Suhadolc P. and Pazzi G.; 1992: *The macroseismic field of the Irpinia (Italy) 1980 earthquake: modeling with synthetic isoseismals.* In: Cecic I. (ed), Proceedings Second AB Workshop on Macroseismic Methods, Seismological Survey of the Republic of Slovenia, Ljubljana, pp. 83-91.

Vaccari F., Harabaglia P., Suhadolc P. and Panza G.F.; 1993: *The Irpinia (Italy) 1980 earthquake: Waveform modelling of accelerometric data and macroseismic considerations.* Annali di Geofisica, **36**, 93-108.

Vidale J.E., Bonamassa O. and Houston H.; 1991: *Directional Site Resonances Observed from the 1 October 1987 Whittier Narrows Earthquake and the 4 October Aftershock.* Earthquake Spectra, **7**, 107-126.

Zollo A.; 1991: *Study of earthquake source mechanism from high frequency seismic radiation.* Soil Dynamics and Earthquake Engineering, **10**, 30-41.

Zollo A. and Bernard P.; 1991: *Fault mechanisms from near source data: joint inversion of S polarizations and P polarities.* Geophys. J. Int., **104**, 441-451.

SEISMIC RISK

Recent studies for the mitigation of seismic hazard and risk belong to two different but complementary groups. The first group deals with models of earthquake occurrence based on historical or geological evidence for large earthquakes. These models describe the long-term potential and shakeability of the national territory as a function of its known seismicity record. The second group includes all studies on geophysical phenomena that can be intepreted in terms of short-term earthquake precursors.

Models of earthquake occurrence

During the last years a great effort at national level has been done to the seismic hazard assessment of the Italian territory for the revision of the seismic zonation. Standard approaches as well as new methods have been investigated and their application to the Italian situation has been evaluated. Futhermore, the experience developed in Italy has been exported to other European regions, such as Bulgaria and Greece. The examples of performed applications cover various aspects of seismic source definition (seismogenic areas, linear elements, etc.), consider probabailistic models with and without memory, face the problem of attenuation, and explore different ways of seismicity rate definition.

An interesting exercise was organized in the framework of the activities of the European Seismological Commission: different teams of experts, among which some Italians, produced hazard maps for two European regions (one with high and the other with low seismicity) starting from a common data base and the results were, then, compared.

In addition, Italian researchers are involved in the UN's Global Seismic Hazard Assessment Program (GSHAP), which is expected to produce worldwide seismic hazard calculations on a common basis.

Earthquake precursors

Studies have been carried out on the subject of seismicity patterns used as short and medium term earthquake precursors. In the classification of earthquake precursors, reference is made to the time interval elapsed between the observation of some phenomenon, sometimes called anomaly, and the occurrence of the earthquake associated to that observation. This interval can range from a few minutes to many years, so that seismologists are used to subdivide precursors in three large categories: long, medium and short term ones, depending on whether such interval is respectively of the order of magnitude of years, months or days.

Numerous other studies have pointed out meaningful correlations between seismic release patterns and ground deformation or stress changes. Observations of tilts, of water level variations in wells and of changes of hydrological and geochemical parameters have been interpreted as a function of deformation associated with recent earthquakes or with stress variations in preparation for future seismic activity.

A limitation in the practical application of precursors in the mitigation of earthquake risk consists in the scarce availability of observations to statistically correlate such precursors with earthquakes. Therefore developing efficient alarm systems against earthquakes is an uncertain and far task at present. Nevertheless, at least for some cases (e.g. the correlation between foreshocks and mainshocks) enough observation data do exist to evaluate statistically the probability that a given precursor is followed by a seismic event or, conversely, that a seismic event is preceded by a precursor.

BIBLIOGRAPHY

Albarello D., Ferrari G., Martinelli G. and Mucciarelli M.; 1991: *Well-water variations as a seismic precuror: a statistical assessment from Italian historical data.* Tectonophysics, **193**, 385-395.

Bella F., Biagi P.F., Caputo M., Della Monica G., Ermini A., Sgrigna V. and Terra V.; 1992: *On the mitigation*

of precursors of strong earthquakes. Research, **4**, 676-681.

Bella F., Biagi P.F., Caputo M., Della Monica G., Ermini A. and Sgrigna V.; 1993: *Ground tilt variations detected in the Central Apennines (Italy) in the period 1986-1989 and their correlation with seismicity.* Il Nuovo Cimento, **16C**, 303-311.

Bella F., Biagi P.F., Caputo M., Della Monica G., Ermini A. and Sgrigna V.; 1993: *Ground tilt anomalies accompanying the main earthquakes occurred in the Central Apennines (Italy) during the period 1986-1989.* Il Nuovo Cimento, **16C**, 393-406.

Caputo M.; 1992: *Velocity of propagation of precursors of strong earthquakes and reduction of alarm area.* Rend. Accad. Naz. Lincei, **9**, 5-10.

Console R., Alessandrini B., Mele F. and Murru M.; 1991: *Real time observation of seismic activity and earthquake precursors in Italy.* In: Proceedings of the International Seminar on Earthquake Prediction and Hazard Mitigation, Technology, Tsukuba Science City (Japan), pp. 523-541.

Console R., Murru M. and Alessandrini B.; 1991: *Statistical analysis of foreshocks in Italy.* In: Proceedings International Conference on Earthquake Prediction, State of the art, Strasbourg 1991, pp. 22-26.

Console R., Alessandrini B. and Murru M.; 1991: *A scientific approach to the problem of utilizing foreshocks as earthquake precursors.* IDNDR Summit Conference on Earthquake and Natural Disaster Countermeasures , Tokyo 1991, (Japan), pp. 245-252.

Console R., Murru M. and Alessandrini B.; 1991: *Recognition of foreshocks as earthquake precursors.* Proceedings X Annual Meeting GNGTS, pp. 221-229.

Console R., Favali P. and Mattietti G.; 1992: *Observation of seismic precursors in real time.* In: Boschi E. and Dragoni M. (eds), Proceedings International School of Solid Earth Geophysics V course "Earthquake prediction", Erice 1989, Il Cigno Galileo Galilei, Roma, pp. 379-401.

Console R., Murru M. and Alessandrini B.; 1993: *Foreshock statistics in the Italian seismicity.* In: Proceedings of XXIII General Assembly of the European Seismological Commission, Prague, **1**, pp. 126-130.

Console R., Murru M. and Alessandrini B.; 1993: *Foreshock statistics and their possible relationship to earthquake prediction in the Italian region.* Bull. Seismol. Soc. Am., **83**, 1248-1263.

Costa G., Panza G.F. and Rotwain I.M.; 1992: *Time of increased probability for earthquakes with $M>5.6$ in Central Italy.* In: Proceedings International Conference on Earthquake Prediction, State of the art, Strasbourg 1991, pp. 27-36.

Giardini D., Basham P.W. and Berry M.J.; 1992: *The Global Seismic Hazard Assessment Program.* Terra Nova, **6**, 623-627.

Giardini D. and Basham P.; 1993: *The Global Seismic Hazard Assessment Program for the UN/IDNDR.* Special Issue of the Annali di Geofisica, **36**, 3-4, 257 pp.

Giardini D. and Zhang P.; 1993: *The Global Seismic Hazard Assessment Program in Central-Southern Asia.* In: Ding G. and Chen Z. (eds), Continental Earthquakes, Seismological Press, Beijing, pp. 432-437.

Giardini D.; 1994: *Toward global seismic hazard assessment.* In: Proceedings Conference on Disaster management in metropolitan areas for the XXI century, Nagoya, pp. 409-417.

Giardini D., Basham P. and Berry M.; 1993: *The ILP's Global Seismic Hazard Assessment Program for the UN/IDNDR.* In: Merrimanand P., Browitt C. and Telford T. (eds), Natural Disasters: Protecting Vulnerable Communities, London, pp. 225-237.

Gresta S., Marzocchi W. and Mulargia F.; 1994: *Is there a correlation between larger local earthquakes and the end of eruptions at Mt. Etna volcano, Sicily?.* Geophys. J. Int., **116**, 230-232.

Guidoboni E. and Stucchi M.; 1993: *The contribution of historical records of earthquakes to the evaluation of seismic hazard.* Annali di Geofisica, **36**, 201-215.

Mantovani E., Boschi E., Albarello D., Babbucci D. and Mucciarelli M.; 1991: *Regularities in time and space distribution of seismicity in the PeriAdriatic regions: tectonic implications.* Tectonophysics, **188**, 349-356.

Mayer-Rosa D., Barbano M., Egozcue J., Garcia Fernandez M., Kijko A., Lapajne J., Schenk V., Schenkova Z., Slejko D. and Zonno G.; 1991: *TERESA Project: earthquake hazard assessment in Sannio Matese, Southern Italy.* In: Proc. 4th Int. Conf. on Seismic Zonation, EERI, **1**, pp. 591-603.

Mayer-Rosa D., Slejko D. and Zonno G.; 1993: *Assessment of the seismic hazard for the Sannio - Matese area, southern Italy (Project 'TERESA').* Annali di Geofisica, **36**, 199-209.

Monachesi G., Peruzza L., Slejko D. and Stucchi M.; 1994: *Seismic hazard assessment using intensity point data.* Soil Dynamics and Earthquake Engineering, **13**, 219-226.

Mucciarelli M. and Albarello D.; 1991: *The use of historical data in earthquake prediction: an example from water level variations and seismicity.* Tectonophysics, **193**, 247-251.

Mulargia F., Achilli V., Broccio F. and Baldi P.; 1991: *Is a destructive earthquake imminent in southeastern Sicily?.* Tectonophysics, **188**, 399-402.

Mulargia F. and Gasperini P.; 1992: *Evaluating the statistical validity beyond chance of 'VAN' earthquake precursors.* Geophys. J. Int., **111**, 32-44.

Orozova - Stanishkova I. and Slejko D.; 1994: *Seismic hazard of Bulgaria.* Natural Hazards, **9**, 247-271.

Papoulia J. and Slejko D.; 1992: *Cautious neotectonic hypotheses for assessing the seismic hazard in northeastern Italy.* Natural Hazards, **5**, 249-268.

Papoulia J. and Slejko D.; 1992: *Hazard assessment of two Greek regions with different seismotectonic knowledge.* In: Atti 11° Conv. Naz. GNGTS, Esagrafica, Roma, pp. 7-18.

Papoulia J. and Slejko D.; 1992: *Shakebility assessment in the gulf of Corinth and surrounding region using different models.* In: Schenk V. and Mayer-Rosa D. (eds), ESC 23rd General Assembly Activity report 1990-1992 and Proceedings, Czech. Ac. Sciences, Praha, pp. 135-138.

Papoulia J. and Slejko D.; 1994: *Seismic hazard assessment based on observed macroseismic intensities.* In: Papadopoulos G.A. and Makropoulos K.C. (eds), Proceedings 2nd Workshop on statistical models and methods in seismology, Cephalonia 2 - 5 June 1993, Athens, pp. 122-131.

Peruzza L., Petrini V. and Slejko D.; 1992: *Renewal process approach for hazard assessment in Italy.* In: Schenk V. and Mayer-Rosa D. (eds), ESC 23rd General Assembly Activity report 1990-1992 and Proceedings, Czech. Ac. Sciences, Praha, pp. 364-367.

Peruzza L., Siro L. and Slejko D.; 1994: *Spectral characteristics of the seismic hazard between the Alps and the Dinarides.* Soil Dynamics and Earthquake Engineering, **13**, 213-217.

Peruzza L. and Slejko D.; 1993: *Comparison of different approaches to seismic hazard assessment.* Natural Hazards, **7**, 133-153.

Scalera G., Favali P., Smriglio G., Frugoni F. and Vinci L.; 1993: *Seismic hazard in Irpinia and considerations about the seismogenic area.* Annali di Geofisica, **36**, 337-343.

Slejko D.; 1992: *Seismic hazard assessment for the Italian seismic code.* In: Schenk V. and Mayer-Rosa D. (eds), ESC 23rd General Assembly Activity report 1990-1992 and Proceedings, Czech. Ac. Sciences, Praha, pp. 383-386.

Slejko D.; 1993: *Considerations on the seismic risk.* Annali di Geofisica, **36**, 169-175.

Slejko D. and Kijko A.; 1991: *Seismic hazard assessment for the main seismogenetic zones in the Eastern Alps.* Tectonophysics, **191**, 165-183.

Slejko D. and Zonno G.; 1993: *Seismic hazard in Italy.* In: McGuire R.K. (ed), The practice of earthquake hazard assessment, IASPEI and ESC, pp. 158-162.

Stanishkova I. and Slejko D.; 1991: *Seismic hazard of the main Bulgarian cities.* In: Atti 10° Conv. Naz. GNGTS, Esagrafica, Roma, pp. 123-134.

Strakhov V., Ulomov V. and Giardini D.; 1993: *Seismic hazard assessment in northern Eurasia: past experience and future plans.* Annali di Geofisica, **36**, 3-4, 83-92.

Vorobieva I. and Panza G.F.; 1993: *Prediction of the occurrence of related strong earthquakes in Italy.* Pure Appl. Geophys., **141**, 25-41.

Zadro M. and Rossi G.; 1991: *Long-term strain variations in Friuli (NE-Italy) seismic area.* In: Technical Contributions to the International Conference on 'Earthquake Prediction: State-of-the Art', Strasbourg, France, 15-18 October 1991, pp. 435-441.

Local scale seismological studies

The continuous increase in the number of seismic stations installed in the past four years allowed the basic features of the seismicity distribution in Italy to be outlined with more and more detail and precision on a local scale.

The seismic networks of several scientific institutions and universities detect more than 2,000 earthquakes per year with a minimum magnitude threshold equal to 2. The well located earthquakes recorded in these years revealed some main characteristics not emphasized in the past.

A better delineation of the southern Tyrrhenian subduction zone has been reached thanks to the considerable amount of data supplied by the Italian Centralized Seismological National Network. In particular, the deep and intermediate-depth seismicity that characterizes this active region has been geometrically better constrained. In addition, previously unreported intermediate-depth earthquakes have been located beneath the Northern Apennines, providing new insights into the geodynamic modelling of Italian peninsula.

It has been also observed that the crustal seismic release is mainly concentrated in a narrow belt running along the Apenninic arc. This belt is 30 to 50 km wide and follows the highest elevations. It coincides with the portion of the Apenninic chain where the largest earthquakes (M 7) have occurred during historical time.

The results obtained from the continuous monitoring by the national network have been complemented by detailed images of the upper crust deriving from the temporary and permanent local networks that have been in operation during the last four years in Italy. In particular, it has been monitored the Quaternary volcanic belt that runs along the Tyrrhenian coast (e.g.

Alban Hills, Vulsini, Latera-Amiata), some seismogenic areas in the Apennines (e.g. Potenza and Benevento) and Sicily. The availability of local networks allows the most important seismicity features to be resolved quantitatively. These include the determination of the thickness of the seismogenic layer in the different tectonic environments, fault plane solutions and the identification of peculiar seismic release patterns.

BIBLIOGRAPHY

Amato A., Chiarabba C., Malagnini L., and Selvaggi G.; 1992: *Three-dimensional P-velocity structure in the region of the MS=6.9 Irpinia, Italy, normal faulting earthquake.* Phys. Earth Planet. Int., **75**, 111-119.

Amato A., Chiarabba C., Malagnini L. and Selvaggi G.; 1992: *3-D P-velocity structure in the Irpinia region.* Phys. Earth Planet. Int., **75**, 111-119.

Amato A. and Selvaggi G.; 1993: *Aftershock location and P-velocity structure in the epicentral region of the 1980 Irpinia earthquake.* Annali di Geofisica, **36**, 3-15.

Azzara R., Basili A., Beranzoli L., Chiarabba C., Di Giovambattista R., and Selvaggi G.; 1993: *The seismic sequence of Potenza (5 May 1990).* Annali di Geofisica, **36**, 237-243.

Boschi E., Giardini D. and Velonà M.A.; 1992: *The compilation of the instrumental seismic catalogue of Italy: 1975-1984.* Phys. Earth Planet. Int., **75**, 131-143.

Cimini G.B., Chiarabba C., Amato A. and Iyer H.M.; 1994: *Large teleseismic P-wave residuals observed at the Alban Hills volcano, Central Italy.* Annali di Geofisica, **37**, 969-988.

Cocco M., Selvaggi G., Di Bona M. and Basili A.; 1993: *Recent seismic activity and earthquake occurence along the Apennines.* In: Boschi E., Mantovani E. and Morelli A (eds), Proceedings VIII Workshop on 'Recent Evolution and Seismicity of the Mediterranean Region', Kluwer Academic Publishers, The Netherlands, pp. 295-312.

Console R., Di Giovambattista R., Favali P. and Smriglio G.; 1992: *Seismogenic structures along the Adriatic coast activated in the 1987 seismic sequences.* Geophys. J. Int., **108**, 379-386.

Console R., Di Giovambattista R., Favali P. and Smriglio G.; 1992: *Methodological approach to earthquake location procedures: application to Italian seismicity.* Phys. Earth Planet. Int., **75**, 153-164.

Console R., Di Giovambattista R., Favali P., Presgrave B.W. and Smriglio G.; 1993: *Seismicity of the Adriatic microplate.* Tectonophysics, **218**, 343-354.

Cucci L. and Di Maro R.; 1992: *A geological, seismic and hydrogeological survey of the February 23, 1991 Cassino earthquake.* Il Nuovo Cimento, **15**, 227-236.

Giardini D.; 1992: *Lateral Heterogeneity and Earthquake Location.* Special Issue, Phys. Earth Planet. Int., 75, Elsevier (ed.), 198 pp.

Peruzza L., Rebez A., Slejko D. and Padoan G.; 1991: *Weighted uncertainties used to detect seismogenic structures.* Boll. Geof. Teor. Appl., **33**, 25-45.

Regional and global scale seismological studies

A considerable effort of the Italian seismological community has been devoted to the study of the complex structure, kinematics, and dynamics of the Mediterranean area. The Africa-Eurasia convergence, and the resulting tectonic environment, were subject of studies that employed seismological observations to reconstruct Earth structure and earthquake source characteristics. The expansion of modern seismographic instrumentation in this area during the past few years yielded an unprecedented set of high-quality broadband data.

The upper mantle structure of this region has been investigated using various techniques, ranging from body waveform modelling, to surface wave dispersion studies, to travel time tomography. The efforts have been focused, on one side, to derive detailed vertical structure, for instance to constrain sharpness and location of the major upper mantle discontinuities. By using waveform modelling, wave propagation at regional distance and crustal receiver functions have been studied. Proposed models show a structure tipical of tectonically active areas, able to produce slower than average vertical travel times, which had been previously observed on a global scale. Better vertical models provide a better reference for studies of lateral heterogeneity. These studies are mainly conducted with the use of body wave delay time tomography, and surface wave tomography. The deep characters of the structure show clear images of past and

active subduction. Also, correlations appeared between upper mantle structure and volcanism. In turn, account for lateral heterogeneity improves earthquake location.

Earthquake sources for events in the Mediterranean and surrounding areas have been studied using waveform fitting and moment tensor inversion. The use of long period data allows stable reconstructions of source characteristics even when few records are available, and the use of empirical source-station terms limits the effect of heterogeneity. Available moment tensor solutions have been used to quantify the seismic contribution in deforming belts running between African and Eurasian plates. This is an important contribution to regional tectonic studies, to complement geodetic measurements currently under way. The geometry of seismic deformation shows to be very similar to expectations based on global scale kinematic models and on local geological studies. Other studies investigated seismicity regularity patterns, and seismotectonic analysis and reconstruction of evolutionary patterns, with geodynamic interpretation.

Seismic source properties have also been studied on a global scale, using normal mode summation and broadband bodywave analysis for moment tensor and source time function calculation. Also, contributions have been published on the determination of deep global structure, regarding three dimensional travel time tomography and spherically symmetric reference structure. Lateral variations in the structure of lower mantle and core have shown to be stronger in lower harmonic degree. The effect of heterogeneous models on earthquake location has also been investigated.

REFERENCES

Amato A., Alessandrini B., Cimini G.B., Frepoli A. and Selvaggi G.; 1993: *Active and remnant subducted slabs beneath Italy: evidence from seismic tomography and seismicity.* Annali di Geofisica, **36**, 201-214.

Amato A., Alessandrini B. and Cimini G.B.; 1993: *Teleseismic wave tomography of Italy.* In: Iyer H.M. and Hirahara K. (eds), Seismic Tomography-theory and practice, Chapman and Hall, London, pp. 361-396.

Boschi E., Giardini D. and Palombo B.; 1993: *Moment tensor inversion from Mednet data for regional earthquakes of the Mediterranean.* Geophys. Res. Lett., **20**, 273.

Boschi E., Morelli A., Mazza S. and Pino N.A.; 1993: *Seismological studies of upper mantle structure below the Mediterranean with a regional seismograph network.* In: Boschi E., Mantovani E. and Morelli A. (eds), Proceedings of the conference "Recent evolution and seismicity in the Mediterranean region", Kluwer Academic Publishers, The Netherlands, pp. 189-211.

Boschi E., Giardini D. and Palombo B.; 1993: *The determination of earthquake size and source geometry in the Mediterranean sea.* In: Boschi E., Mantovani E. and Morelli A. (eds), Proceedings of the conference "Recent evolution and seismicity in the Mediterranean region", Kluwer Academic Publishers, The Netherlands, pp. 213-238.

Boschi E. and Morelli A.; 1993: *Peaceful use of nuclear explosions for fundamental research on the interior of the Earth.* In: Zichichi A. (ed), "International Seminar on Nuclear War and Planetary Emergencies", World Scientific Publishing Co.

Calcagnile G.; 1991: *Deep structure of Fennoscandia from fundamental and higher mode dispersion of Rayleigh waves.* Tectonophysics, **196**, 139-149.

Calcagnile G., Pierri P., Del Gaudio V. and Mueller S.; 1992: *The upper mantle beneath Fennolora and surrounding area from seismic surface and body waves.* In: Roca A. and Mayer-Rosa D. (eds), Proceedings XXII General Assembly of the European Seismological Commission, Barcelona, pp. 909-914.

Caputo M.; 1993: *The splitting of seismic rays due to dispersion in the Earth's interior.* Rend. Fis. Accad. Naz. Lincei, **9**, 279-286.

Cimini G.B. and Amato A.; 1993: *P-wave teleseismic tomography: contribution to the delineation of the upper mantle structure of Italy.* In: Boschi E., Mantovani E. and Morelli A. (eds), Proceedings of the conference "Recent evolution and seismicity in the Mediterranean region", Kluwer Academic Publishers, The Netherlands, pp. 313-331.

Del Ben A., Finetti I., Rebez A. and Slejko D.; 1991: *Seismicity and seismotectonics at the Alps-Dinarides contact.* Boll. Geof. Teor. Appl., **33**, 155-176.

Di Maro R. and Marchetti A.; 1994: *Detection capability of the Italian network for teleseismic events.* Annali di Geofisica, **37**, 415-431.

Favali P., Funiciello R. and Salvini F.; 1993: *Geological and seismological evidence of strike-slip displacement along the E-W Adriatic-Central Apennine belt.* In: Boschi E., Mantovani E. and Morelli A. (eds), Recent evolution and Seismicity of the Mediterranean Region, Kluwer Academic Publishers, The Netherlands, NATO. ASI Series, Series C: Mathematical and Physical Sciences, **402**, pp. 333-346.

Giardini D. and Velonà M.; 1991: *The deep seismicity of the Tyrrhenian Sea.* Terra Nova, **3**, 57-64.

Giardini D.; 1992: *Space-time distribution of deep seismic deformation in Tonga.* Phys. Earth Planet. Int., **74**, 75-88.

Latini G., Marson I., Panza G.F. and Suhadolc P.; 1991: *Fine modeling of elastic and anelastic parameters of the earth crust by synthetic seismograms.* In: Giese P. et al.(eds), Joint Interpretation of Geophysical and Geological Data Applied to Lithospheric studies, Kluwer Academic Publishers, The Netherlands, pp. 93-107.

Li D., Giardini D. and Woodhouse J.H.; 1991: *Large-scale three-dimensional even-degree structure of the Earth from splitting of long-period normal modes.* J. Geophys. Res., **96**, 549-575.

Li D., Giardini G. and Woodhouse J.H.; 1991: *The relative amplitudes of mantle heterogeneity in P-velocity, S-velocity and density from free-oscillation data.* Geophys. J. Int., **105**, 649-657.

Lundgren P.R. and Giardini D.; 1992: *Seismicity, shear failure and modes of deformation in deep subduction zones.* Phys. Earth Planet. Int., **74**, 63-74.

Lundgren P.R. and Giardini D.; 1994: *Isolated deep earthquakes and the fate of subduction in the mantle.* J. Geophys. Res., **99**, 15833-15842.

Mao W.J. and Suhadolc P.; 1992: *Simultaneous inversion of velocity structures and hypocentral locations: application to the Friuli seismic area NE Italy.* PAGEOPH, **138**, 267-285.

Margottini C., Martini G. and Slejko D.; 1993: *Instrumental seismological data since 1900 for northeastern Italy.* Eart. Eng. Struct. Dyn., **22**, 1017-1030.

Megna A. and Morelli A.; 1994: *Determination of Moho depth and dip beneath MEDNET station AQU by analysis of broadband receiver functions.* Annali di Geofisica, **37**, 913-928.

Mohan G., Rai S.S. and Panza G.F.; 1992: *Seismic heterogeneities in the Indian lithosphere.* Phys. Earth Planet. Int., **73**, 189-198.

Morelli A., Mazza S., Pino N.A. and Boschi E.; 1993: *Seismological studies of upper mantle structure below the Mediterranean with a regional seismograph network.* In: Boschi E., Mantovani E. and Morelli A. (eds), Recent Evolution and Seismicity of the Mediterranean Region, NATO ASI Series, Kluwer Academic Publishers, The Netherlands, pp. 189-211.

Morelli A. and Dziewonski A.M.; 1993: *Body wave traveltime and a spherically symmetric P- and S-wave velocity model.* Geophys. J. Int., **112**, 178-194.

Morelli A.; 1993: *Teleseismic tomography: core-mantle boundary.* In: Iyer H.M. and Hirahara K. (eds), Seismic Tomography: Theory and Practice, Chapman and Hall, London, pp. 163-189.

Morelli A. and Amato A.; 1994: *Seismological contributions to a better knowledge of deep crustal and upper mantle structure beneath Antarctica.* Terra Antartica, **1**, 531-532.

Panza G.F., Prozorov A. and Suhadolc P.; 1991: *Is there a correlation between lithosphere structure and statistical properties of seismicity?.* Terra Nova, **2**, 585-595.

Panza G.F. and Prozorov A.; 1991: *High frequency seismic sources characterize the areas of tectonic shortening in the Italian region.* Atti Accad. Naz. Lincei, **2**, 107-116.

Panza G.F., Prozorov A.G. and Pazzi G.; 1992: *Extension of global creepex definition (MS-mb) to local studies (Md-ML): the case of the Italian region.* Terra Nova, **5**, 150-156.

Panza G.F.; 1993: *Structure of the lithosphere inferred from surface waves.* Acta Geod. Geoph. Mont. Hung., **28**, 257-288.

Pino N.A.; 1994: *Long-period P waveform modeling of upper mantle phases in the west Mediterranean basin.* Annali di Geofisica, **36**, 109-120.

Romanelli F. and Panza G.F.; 1994: *Extension of Love wave transformation theory to laterally heterogeneous structures.* Atti Accad. Naz. Lincei, **5**, 5-16.

Russi M., Febrer J., Costa G., Nieto D.Y. and Panza G.F.; 1994: *Analysis of digital waveforms recorded at seismographic station Esperanza.* Terra Antartica, **1**, 162-166.

Selvaggi G. and Amato A.; 1992: *Subcrustal Earthquakes in the Northern Apennines (Italy): Evidence for a Still Active Subduction?.* Geophys. Res. Lett., **19**, 2127-2130.

Slejko D.; 1993: *Seismotectonic model of the Eastern Alps - Northern Dinarides.* In: Boschi E., Mantovani E. and Morelli A. (eds), Recent evolution and seismicity of the Mediterranean region, Kluwer Ac. Publishers, Dordrecht, pp. 251-260.

Stanishkova I. and Slejko D.; 1991: *Seismotectonic model of Bulgaria.* Boll. Geof. Teor. Appl., **33**, 187-210.

Vaccari F. and Panza G.F.; 1993: *Vp/Vs estimation in south-western Europe from P-wave tomography and surface wave tomography analysis.* Phys. Earth Planet. Int., **78**, 229-237.

VOLCANIC SEISMOLOGY

Recent significant eruptions of Mount Etna have spurred numerous experimental studies and the development of new theoretical models eruptive and seismic release patterns. Studies of focal mechanisms have shown that the flank eruptive activity of Mount Etna is strictly related to the regional stress field. This finding was also confirmed by the time evolution of

microearthquake swarms occurring before the beginning of the eruptions. Conversely, the largest earthquakes occurring at Mount Etna have been shown to be related to the ending phases of an eruption, rather than to its onset.

The Etna eruptions also allowed the reliability of some seismological precursors for eruptions to be statistically tested.

Polarization properties of both volcanic tremor and shocks were studied at Mount Etna and at the Stromboli and Vulcano islands. Their source was often located in the summit crater areas, even if some significant variation with time of either direction of polarization or linearity content has been observed to relate to the eruptive activity.

Attenuation and local site effects have been found to strongly influence seismic signals at Mount Etna. The determination of these effects has allowed a correct estimation of the earthquake source parameters. Splitting phenomena of S-waves due to anisotropy were also observed.

The internal structure of Mount Etna, Vesuvius and Vulcano as well as that of quiescent volcanoes such as the Alban Hills was investigated by large seismic tomography projects using both natural seismicity and artificial sources.

REFERENCES

Amato A., Chiarabba C., Cocco M., Di Bona M. and Selvaggi G.; 1994: *The 1989-1990 seismic swarm in the Alban Hills volcanic area, Central Italy.* J. Volcanol. Geotherm. Res., **61**, 225-237.

Aster R., Meyer R.P., De Natale G., Zollo A., Scarpa R., Del Pezzo E., Martini M. and Iannaccone G.; 1992: *Seismic investigation of the Campi Flegrei: A summary and synthesis of results.* In: Gasparini P. et al. (eds), Volcanic Seismology, pp. 462-483.

Boschi E. and Bonafede M.; 1992: *A porous-flow model of flank eruptions on Mount Etna.* J. Volcanol. Geotherm. Res., **49**, 349-363.

Cardaci C., Falsaperla S., Gasperini P., Lombardo G., Marzocchi W. and Mulargia F.; 1993: *Cross-correlation analysis of seismic and volcanic data at Mt Etna volcano, Italy.* Bull. Volcanol., **55**, 596-603.

Carveni P., Romano R., Caltabiano T., Grasso M.F. and Gresta S.; 1994: *The exceptional explosive activity of 5 January 1990 at the SE-Crater of Mt. Etna volcano (Sicily).* Boll. Soc. Geol. It., **113**, 613-631.

Del Pezzo E., De Martino S., Gresta S., Martini M., Milana G., Patanè D. and Sabbarese C.; 1993: *Velocity and spectral characteristics of the volcanic tremor at Etna deduced by a small seismometer array.* J. Volcanol. Geotherm. Res., **56**, 369-378.

De Natale G., Pingue F., Allard P. and Zollo A.; 1991: *Geophysical and geochemical modelling of the 1982-1984 bradyseismic phenomena at Campi Flegrei caldera (Southern Italy).* J. Volcanol. Geotherm. Res., **48**, 199-222.

Distefano G. and Gresta S.; 1991: *Energy releases at Etna volcano during 1983-1987.* Acta Vulcanologica, **1**, 39-42.

Ferrucci F., Gresta S., Patanè D. and Rasà R.; 1992: *Inferences on the magma feeding system at Mt. Etna volcano from seismological, structural and volcanological data.* In: Proceedings XI Annual Meeting GNGTS, pp. 455-460.

Gasperini P., Gresta S., Mulargia F. and Distefano G.; 1992: *Time and space clustering of Etna volcano earthquakes during the period May 1983-February 1987.* J. Volcanol. Geotherm. Res., **53**, 297-307.

Gresta S., Montalto A. and Patanè G.; 1991: *Volcanic tremor at Mount Etna (January 1984-March 1985): its relationship to the eruptive activity and modelling of the summit feeding system.* Bull. Volcanol., **53**, 309-320.

Marzocchi W. and Mulargia F.; 1993: *Patterns of hot spot volcanism.* J. Geophys. Res., **98**, 14029-14039.

Marzocchi W., Scandone R. and Mulargia F.; 1993: *The tectonic setting of Mount Vesuvius and the correlation between its eruptions and the earthquakes of the Southern Apennines.* J. Volcanol. Geotherm. Res., **58**, 27-41.

Mulargia F., Gasperini P. and Marzocchi W.; 1991: *Pattern recognition applied to volcanic activity: Identification of the precursory patterns to Etna recent flank eruptions and periods of rest.* J. Volcanol. Geotherm. Res., **45**, 187-196.

Mulargia F., Marzocchi W. and Gasperini P.; 1992: *Statistical identification of physical patterns which accompany eruptive activity on Mount Etna, Sicily.* J. Volcanol. Geotherm. Res., **53**, 289-296.

Napoli R., Ferrucci F. and Gresta S.; 1994: *Polarization of tremor wavefield at Mount Etna and some open questions on type and dynamics of the source: comparison between the 1989 and 1991-1993 eruptions.* Special issue of Acta Vulcanologica on the 1991-1993 Mt. Etna eruption, 57-61.

Patanè D., Caltabiano T., Del Pezzo E. and Gresta S.; 1992: *Time variation of b and Qc coefficients at Etna volcano (1981-1987).* Phys. Earth Planet. Int., 137-140.

Patanè D., Privitera E., Ferrucci F. and Gresta S.; 1994: *Seismic activity leading to the 1991-1993 eruption of Mt. Etna and its tectonic implications.* Special issue of Acta Vulcanologica on the 1991-1993 Mt. Etna eruption, 47-55.

Patanè G., Montalto A., Imposa S. and Menza S.; 1994: *The role of regional tectonics, magma pressure and gravitational spreading in earthquakes of the eastern sector of Mt. Etna volcano (Italy).* J. Volcanol. Geotherm. Res., **61**, 253-266.

Patanè G., Frasca A., Agodi A. and Imposa S.; 1994: *Earth tides and Etnean volcanic eruptions: an attempt of correlation between the two phenomena during the 1983, 1985 and 1986 eruptions.* Phys. Earth Planet. Int., **6**.

Quareni F. and Mulargia F.; 1993: *Modeling the closure of volcanic conduits with an application to Mount Vesuvius.* J. Geophys. Res., **98**, 4221-4229.

Acknowledgements. Thanks are due to Ms Silvia Nardì for editing the manuscript.