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ABSOLUTE GRAVIMETRY AND GRADIOMETRY ON ACTIVE VOLCANOES OF SOUTHERN ITALY

Abstract. The aim of the paper is to outline the role played by absolute and gradiometric gravimetry in the investigation of volcano dynamics. High precision gravity networks operate on the active volcanoes of Southern Italy to detect changes in the gravity field indicating mass variations correlated with the volcanic activity. A combination of absolute and relative gravimetry is needed; absolute gravity measurements check the base stations and may reveal long term variations or confirm stable zones. Moreover, they permit continuous calibration checks and a comparison for relative gravimeters. Therefore in 1986 a program of measurement of the absolute value of g, and its vertical gradient, was started in the active volcanic areas of Southern Italy. In addition, the Free Air Gradient (FAG) is directly measured in the investigated areas to better define gravity changes produced by sources at shallow depth. The results obtained so far are presented and discussed.

INTRODUCTION

High precision gravity networks have been established on active volcanoes to monitor the time variations of the local gravity field produced by the volcanic activity.

In volcanic areas, knowledge of gravity changes, after the effects of external sources (tides and atmosphere) have been removed, furnishes information about variations in the mass distribution underground (movements of magma, fluid migration, water table variations, etc.) and about vertical ground movements produced by volume variations beneath the earth's surface. The gravity surveys must be associated with altimetric measurements (levellings or satellite surveys) to separate the effects of ground movements from those produced by mass variations. The rate of change of gravity with height (the Free Air Gradient FAG) at a station is computable, as a function of the geographic coordinates, for every earth model (Torge, 1989), and the residual gravity changes left after the FAG correction are imputable to sub-surface mass change. Because the theoretical FAG value does not take into account the effects of local heterogeneities in the earth's crust, the use of an experimentally determined value of FAG is strongly recommended (Berrino et al., 1992). Changes through time in gravity can be ascertained by repeated gravity measurements referenced to "base stations" in which the gravity is assumed to be at zero level. The repetition rate has to be adapted to the temporal evolution of the volcano dynamics.

Relative measurement networks must be adjusted to constrained networks by ties to points in which the gravity is considered unchanging in time; a precision of adjusted gravity values or gravity differences of $\pm\ 10^{-7}\ \mathrm{ms}^{-2}$ (10 μGal), or better, is required.

A combination of absolute and relative gravimetry is necessary. The absolute gravity mea-

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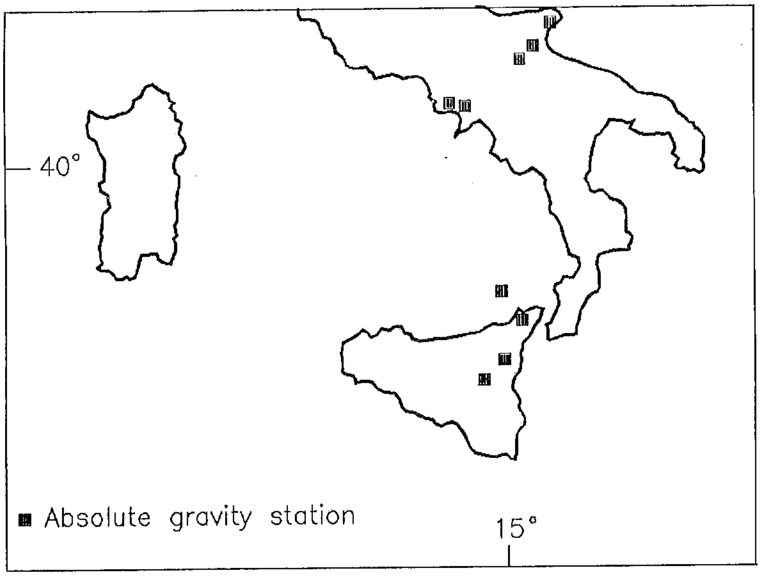


Fig. 1 — Distribution of the absolute gravity stations in Southern Italy.

surements check the base stations and may reveal long term variations or confirm stable zones. Moreover, they permit continuous calibration checks and comparisons for relative gravimeters.

The present paper is devoted to giving a picture of the role played by absolute gravimetry and gradiometry in investigations of the dynamics of active Italian volcanoes. Moreover, it furnishes data on absolute gravimetry at some sites in Southern Italy, which are useful for geodetic purposes and for applied geophysics research.

GRAVITY OBSERVATIONS

Southern Italy (Fig. 1) is the site of intense dynamics, as demonstrated by the presence of shallow and intermediate seismicity, and of active volcanoes (Vesuvio, Campi Flegrei, Ischia, Aeolian Islands, Etna and Pantelleria); the Apulian area only is relatively stable, although some seismogenetic sources are present in Gargano (Alessio et al., 1990).

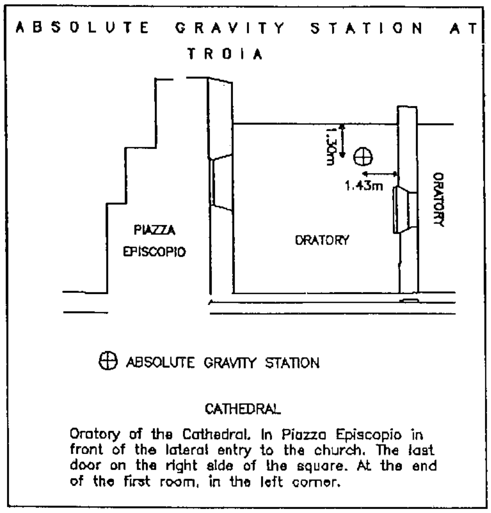
High precision gravity networks have been established on the active Italian volcanoes to study their dynamics, and for surveillance purposes. They are associated with altimetric networks periodically surveyed to measure the vertical ground movements (Sanderson et al., 1983; Berrino et al., 1984; Berrino et al., 1988b; Budetta et al., 1988; Berrino and d'Errico, 1990; Berrino et al., 1993; Berrino, 1992; 1993a; Rymer et al., 1993).

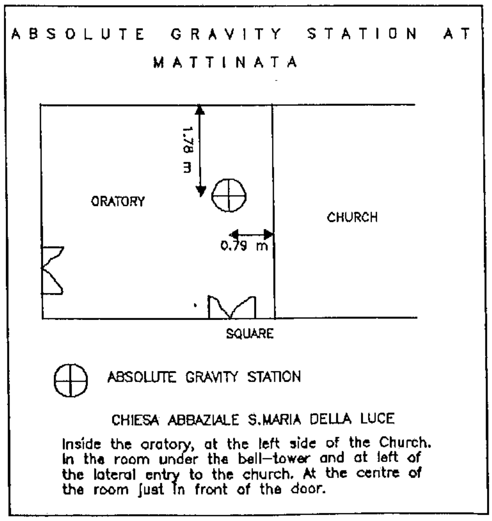
Since 1986, an absolute gravimetry research program has been ongoing in the active volcanic areas of southern Italy; the Istituto di Metrologia "G. Colonnetti" (IMGC) of the Italian National Research Council also cooperates in the program. The aim of the program is to create absolute reference bases for the gravity networks already operating on the volcanoes. Moreover, three absolute stations have been established in Apulia (Mattinata, Foggia and Troia) as the starting point of a new calibration line for relative gravimeters (Berrino et al., 1988a). This new line is needed because the calibration line Bologna-Ferrara, already operative since 1952 (Morelli, 1952; Gantar and Morelli, 1959), is no longer utilizable, mainly because of temporal gravity variations detected in some intermediate stations.

Absolute gravity stations have been made up to now in the following sites (Fig. 1):

a) Naples as reference for Vesuvio, Campi Flegrei and Ischia island.

b) Vesuvio.





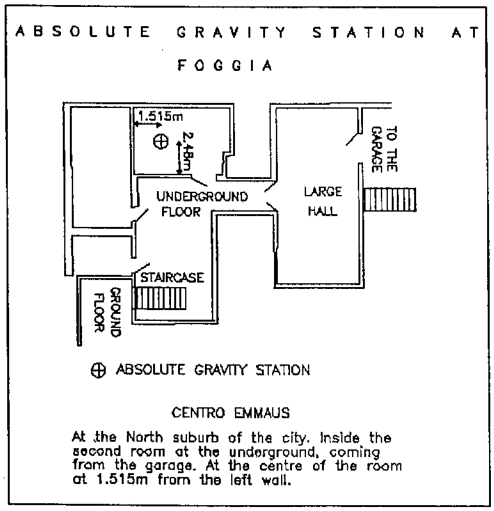


Fig. 2 — Monographs of the absolute gravity stations in Apulia.

c) Milazzo (Sicily) as reference for the Aeolian Islands.

d) Vulcano island.

e) Centuripe (Sicily) as reference for Etna.

f) Etna.

Moreover, the creation of two new absolute stations is in process on Pantelleria.

The gravimeter used for the measurement of the absolute value of g was built by the IMGC (Alasia et al., 1982).

Because the value of g measured by the absolute gravimeter is not referenced to ground level, the local FAG value is needed; therefore at each site, the FAG has been experimentally measured using a LaCoste & Romberg (LCR), model D n. 136, gravimeter equipped with an LCR feed-back system (Harrison and Sato, 1984). The meter was checked against the line Mattinata-Foggia-Troia, and at the Bureau International de Poids et Mesure in Sevres (Becker et al., 1990).

From each absolute station, one or more satellite stations have been derived and established close to the main station to retrieve the absolute value in the case of unavailability or

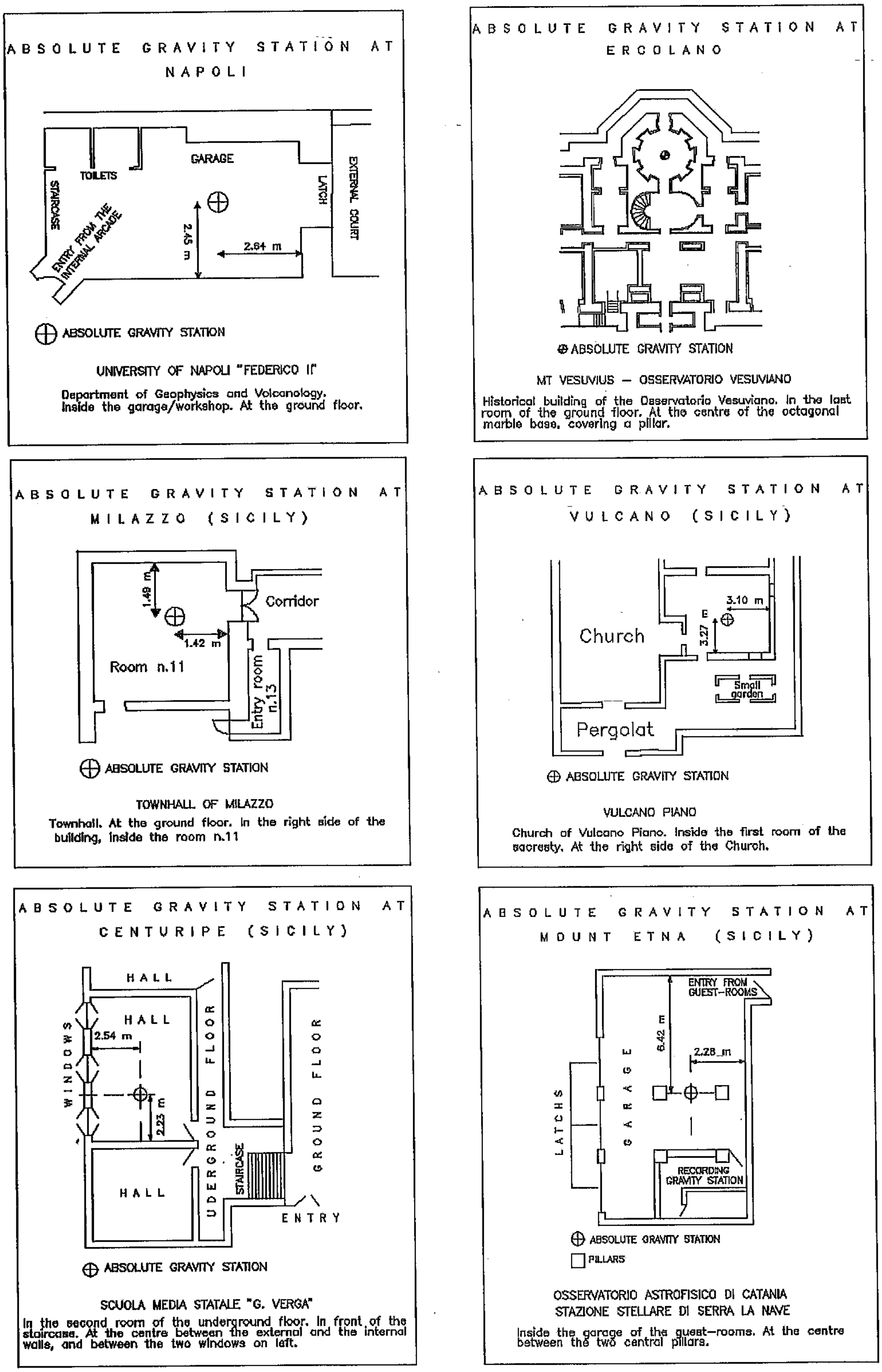


Fig. 3 — Monographs of the absolute gravity stations on active volcanoes of Southern Italy.

Table 1 — Troia.

ABSOLUTE GRAVITY STATION TRO-g0

Oratory of the Cathedral. In Piazza Episcopio in front of the side entry to the church; the last door on the right side of the square. At the end of the first room, in the left corner.

Lat. = 41°21'33" Long. = 15°18'34" h = 439 m

Date	4-5 July 1988
Average atmospheric pressure	P = 965 mbar
Gravity measured value	g_H = 980 198 678 ± 3 μGal
Height of measurement	H = 0.966 ± 0.001 m
Vertical gravity gradient	$\delta g/\delta h$ = —288 ± 3 μGal/m
GRAVITY VALUE AT THE GROUND	**g = 980 198 956 ± 4 μGal**

ABSOLUTE GRAVITY VALUES AT SATELLITE STATIONS

TRO-g1

Piazza Episcopio. Side entry to the Cathedral. On the second step, on the right corner.

g = 980 199 086 ± 6 μGal

TRO-g2

Piazza Giovanni XXIII. In front of the principal entry to the Cathedral. On the marble threshold of the Scuola Materna "S. Benedetto", on the left corner.

g = 980 199 308 ± 6 μGal

Table 2 — Foggia.

ABSOLUTE GRAVITY STATION FGG-g0

Centro EMMAUS in the city suburbs. In the second room, coming from the garage, on the underground floor. In the center of the room and at 1.515 m from the left wall.

Lat. = 41°29'27" Long. = 15°35'51" h = 100 m

Date	22 October 1991
Average atmospheric pressure	P = 1016 mbar
Gravity measured value	g_H = 980 340 111 ± 1 μGal
Height of measurement	H = 0.924 ± 0.001 m
Vertical gravity gradient	$\delta g/\delta h$ = —279 ± 7 μGal/m
GRAVITY VALUE AT THE GROUND	**g = 980 340 369 ± 7 μGal**

ABSOLUTE GRAVITY VALUES AT SATELLITE STATIONS

FGG-g1

Centro EMMAUS. At the entry to the garage. On the pavement, in front of the center of the door-latch, leaned against the marble threshold.

g = 980 340 361 ± 8 μGal

Table 3 — Mattinata.

ABSOLUTE GRAVITY STATION MTT-g0

Chiesa Abbaziale S. Maria della Luce. In the oratory, at the left side of the restructured church. In the room under the bell-tower and on the left of the side entry to the church. At the center of the room just in front of the door.

Lat. = 41°42'37" Long. = 16°03'23" h = 75 m

Date	1-2 July 1988
Average atmospheric pressure	P = 998 mbar
Gravity measured value	g_H = 980 398 150 ± 3 μGal
Height of measurement	H = 0.978 ± 0.001 m
Vertical gravity gradient	δg/δh = —307 ± 2 μGal/m
GRAVITY VALUE AT THE GROUND	**g = 980 398 450 ± 3 μGal**

ABSOLUTE GRAVITY VALUES AT SATELLITE STATIONS

MTT-g1

Chiesa Abbaziale S. Maria della Luce. Entry to the sacristy on the left side of the bell-tower. On the 3rd marble step, on the right corner leaned against the bell-tower.

g = 980 398 528 ± 7 μGal

MTT-g2

Chiesa Abbaziale S. Maria della Luce. Side entry to the right of the principal one. On the left corner of the first step, at the center of the slab.

g = 980 398 693 ± 4 μGal

Table 4 — Napoli.

ABSOLUTE GRAVITY STATION NPL-g0

University of Napoli "Federico II". Department of Geophysics and Volcanology. In the garage/workshop. On the ground floor.

Lat. = 40°50'48" Long. = 14°15'31" h = 24 m

Date	14-15 July 1986
Average atmospheric pressure	P = 1013 mbar
Gravity measured value	g_H = 980 257 805 ± 4 μGal
Height of measurement	H = 0.982 ± 0.001 m
Vertical gravity gradient	δg/δh = —266 ± 3 μGal/m
GRAVITY VALUE AT THE GROUND	**g = 980 258 066 ± 5 μGal**

ABSOLUTE GRAVITY VALUES AT SATELLITE STATIONS

NPL-g1

University of Napoli "Federico II". Department of Geophysics and Volcanology. In the geophysical laboratory, adjacent to the garage. In the room on the ground floor. At the center of the marble base of the left niche in the wall.

g = 980 258 111 ± 5 μGal (1986)

g = 980 258 112 ± 5 μGal (5/1987)

Table 5 — Ercolano.

ABSOLUTE GRAVITY STATION ERC-g0

Mt Vesuvius. Historical building of the Osservatorio Vesuviano. In the last room of the ground floor. At the center of the octagonal marble base.

Lat. = 40°49'37" Long. = 14°23'52" h = 609 m

Date		9-10 July 1986
Average atmospheric pressure		P = 953 mbar
Gravity measured value		g_H = 980 132 784 ± 3 μGal
Height of measurement		H = 0.953 ± 0.001 m
Vertical gravity gradient	1986	δg/δh = —354 ± 3 μGal/m
	1988	δg/δh = —352 ± 3 μGal/m
GRAVITY VALUE AT THE GROUND		**g = 980 133 121 ± 4 μGal**

ABSOLUTE GRAVITY VALUES AT SATELLITE STATIONS

ERC-g1

Mt Vesuvius. Historical building of the Osservatorio Vesuviano. At the IGMI altimetric benchmark on the right side of the guardian's entry, on the ground floor. At the center of the slab, on the incised small ring used as secondary altimetric benchmark.

g = 980 133 769 ± 5 μGal

Table 6 — Milazzo.

ABSOLUTE GRAVITY STATION MLZ-g0

Town-hall. On the ground floor. In the right side of the building, inside room n. 11.

Lat. = 38°13'13" Long. = 15°02'33" h = 0 m

Date	26-28 June 1990
Average atmospheric pressure	P = 1015 mbar
Gravity measured value	g_H = 980 103 994 ± 2 μGal
Height of measurement	H = 0.920 ± 0.001 m
Vertical gravity gradient	δg/δh = —298 ± 2 μGal/m
GRAVITY VALUE AT THE GROUND	**g = 980 104 268 ± 3 μGal**

ABSOLUTE GRAVITY VALUES AT SATELLITE STATIONS

MLZ-g1

Entry to the Town-hall. On the right side of the principal entry. On the marble threshold of the first door. On the right corner.

g = 980 104 154 ± 8 μGal

Table 7 — Vulcano (Aeolian Island)

ABSOLUTE GRAVITY STATION VLC-g0

Church of Vulcano Piano. Inside the first room of the sacristy. At the right side of the church.

Lat.=38°22'42" Long.=14°59'00" h=417 m

Date	22-23 June 1990
Average atmospheric pressure	P=975 mbar
Gravity measured value	g_H=980 029 362±2 μGal
Height of measurement	H=0.964±0.001 m
Vertical gravity gradient	δg/δh=—343±2 μGal/m
GRAVITY VALUE AT THE GROUND	**g=980 029 693±3 μGal**

ABSOLUTE GRAVITY VALUES AT SATELLITE STATIONS

VLC-g1

Church of Vulcano Piano. On the marble threshold, in the left corner.

g=980 029 784±4 μGal

Table 8 — Centuripe

ABSOLUTE GRAVITY STATION CNT-g0

Scuola Media Statale "G. Verga". In the second room of the underground floor. In front of the staircase. At the centre between the external and internal walls, and between the two windows on the left.

Lat.=37°37'19" Long.=14°44'30" h=750 m

Date	16-17 October 1991
Average atmospheric pressure	P=943 mbar
Gravity measured value	g_H=979 822 784±1 μGal
Height of measurement	H=0.934±0.001 m
Vertical gravity gradient	δg/δh=—325±2 μGal/m
GRAVITY VALUE AT THE GROUND	**g=979 823 087±3 μGal**

ABSOLUTE GRAVITY VALUES AT SATELLITE STATIONS

CNT-g1

Scuola Media Statale "G. Verga". On the threshold of the principal gate. Between the two blocks in iron.

g=979 822 472±5 μGal (6/1992)

g=979 822 470±9 μGal (10/1992)

CNT-g2

Chiesa Madre of Centuripe. On the marble threshold at the right side entry. On the left corner.

g=979 812 173±4 μGal (6/1992)

Table 9 — Etna.

ABSOLUTE GRAVITY STATION ETN-g0

Osservatorio Astrofisico di Catania. Stazione Stellare di Serra La Nave (Mt. Etna). Inside the garage of the guest-room. At the center between the two central pillars.

Lat. = 37°41'52" Long. = 14°58'21" h = 1750 m

Date	11-12 October 1991
Average atmospheric pressure	P=834 mbar
Gravity measured value	g_H=979 641 686±4 μGal
Height of measurement	H=0.918±0.001 m
Vertical gravity gradient	δg/δh=—299±6 μGal/m
GRAVITY VALUE AT THE GROUND	**g=979 641 961±7 μGal**
Date	15 October 1992
Average atmospheric pressure	P=821 mbar
Gravity measured value	g_H=979 641 687±2 μGal
Height of measurement	H=0.918±0.001 m
GRAVITY VALUE AT THE GROUND	**g=979 641 962±6 μGal**

ABSOLUTE GRAVITY VALUES AT SATELLITE STATIONS

ETN-g1

Osservatorio Astrofisico di Catania. Stazione Stellare di Serra La Nave (Mt. Etna). At the beginning of the road to the guest-room and the cupolas (telescope dome). The station is situated beyond the barrier close to the guardian's house and is on the right, at the center of the top of the pillar in concrete used for the installation (forced centering) of geodetic instrumentation. It is just in front of the generator's cabin.

g=979 640 858±8 μGal (6/1992)

g=979 640 859±8 μGal (10/1992)

destruction of the main station. The gravity differences between the satellite stations and the absolute main station were measured using the feed-back system of the LCR 136-D meter. The monographs of the main absolute and satellite stations are given in Figs. 2 and 3. The corresponding gravity values are also given in Tables 1-9.

ABSOLUTE GRAVIMETRY AT MT. ETNA

After a two year period of quiescence, on December 14th 1991, a new eruption of Mt. Etna began. The eruption was preceded by strong gravity variations with increases of up to 400 μGal between June 1990 and June 1991 at stations on the summit of Mt. Etna (Rymer et al., 1993). Because height changes were too small, a mass redistribution in the underground has been postulated to account for the gravity increase. Two surveys carried out during the eruption, in April and June 1992, revealed gravity increases relative to October 1991. Gravity data are expressed relative to the reference station at Rifugio Sapienza (1910 a.s.l.) (Rymer et al., 1993). On October 1991, two absolute gravity stations were established in the area, namely, at the Osservatorio Astrofisico di Serra La Nave (Mt. Etna), and in Centuripe, about 30 km away, located in a very different geological setting. The local reference station of Rifugio Sapienza was linked to the absolute station of the Osservatorio Astrofisico.

The absolute measurement of the gravity acceleration was repeated, on October 1992, at the Osservatorio Astrofisico after the paroxysmal phase of the eruption. Again, the link bet-

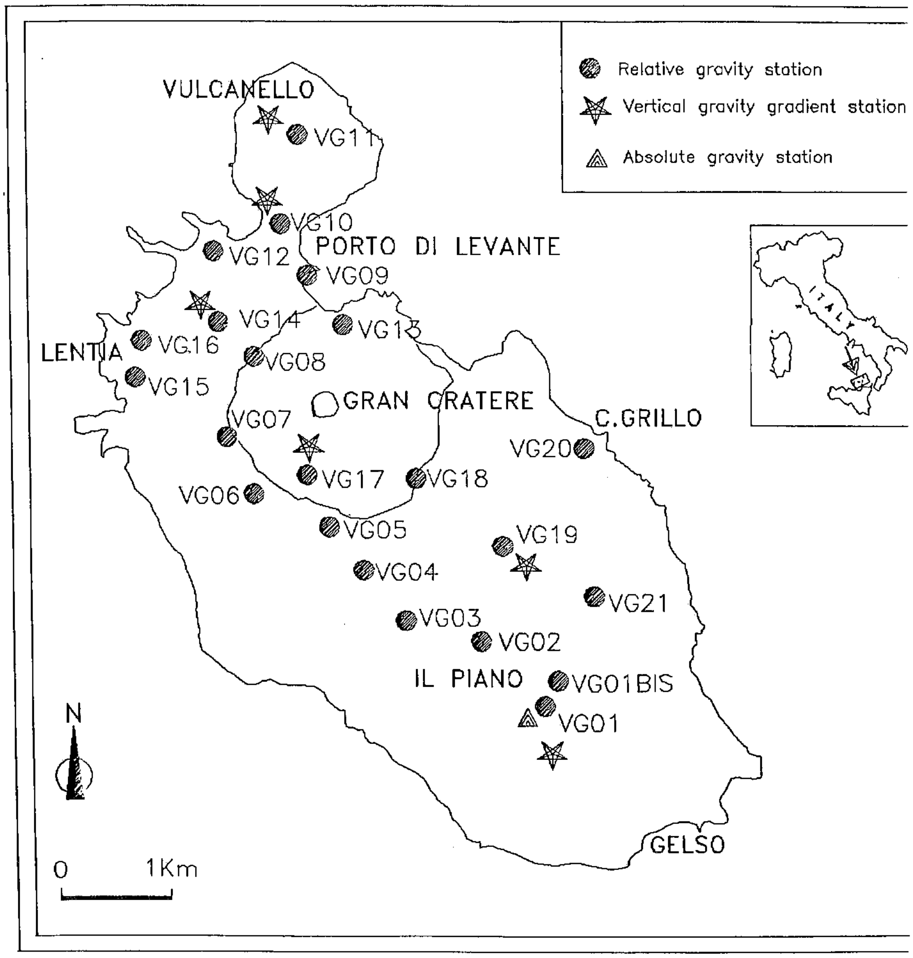


Fig. 4 — Gravity and gradiometric networks on Vulcano (Aeolian Islands).

ween the Osservatorio and Rifugio Sapienza was repeated. The results obtained agree well with the previous ones (Table 9), showing that no gravity change occurred at the site during the 1991-1992 euption. Therefore, the gravity increases observed on the summit of Mt. Etna since October 1991 can be ascribed to mass movements at shallow depth.

GRADIOMETRIC OBSERVATIONS ON VULCANO ISLAND

In 1991, a program of periodic FAG measurements was started on the island of Vulcano (Fig. 4), where significant gravity changes have been observed since 1982. The program is aimed at better detecting changes in the gravity field produced by sources at shallow depth. In fact, the gravity change field in the area appears to be a combined effect of local variations superimposed on a regional trend that affects the whole Aeolian archipelago. The long term regional variation appears to be related to a deep source; the local gravity variations on Vulcano completely swamp the regional changes in the short term. However, the long term variation on Vulcano can be observed on the temporal trend of the average gravity variation; the latter shows a positive temporal gradient of about 1 μGal/year. The short term gravity changes on Vulcano are poorly correlated with ground movements, and are generally observed in the area

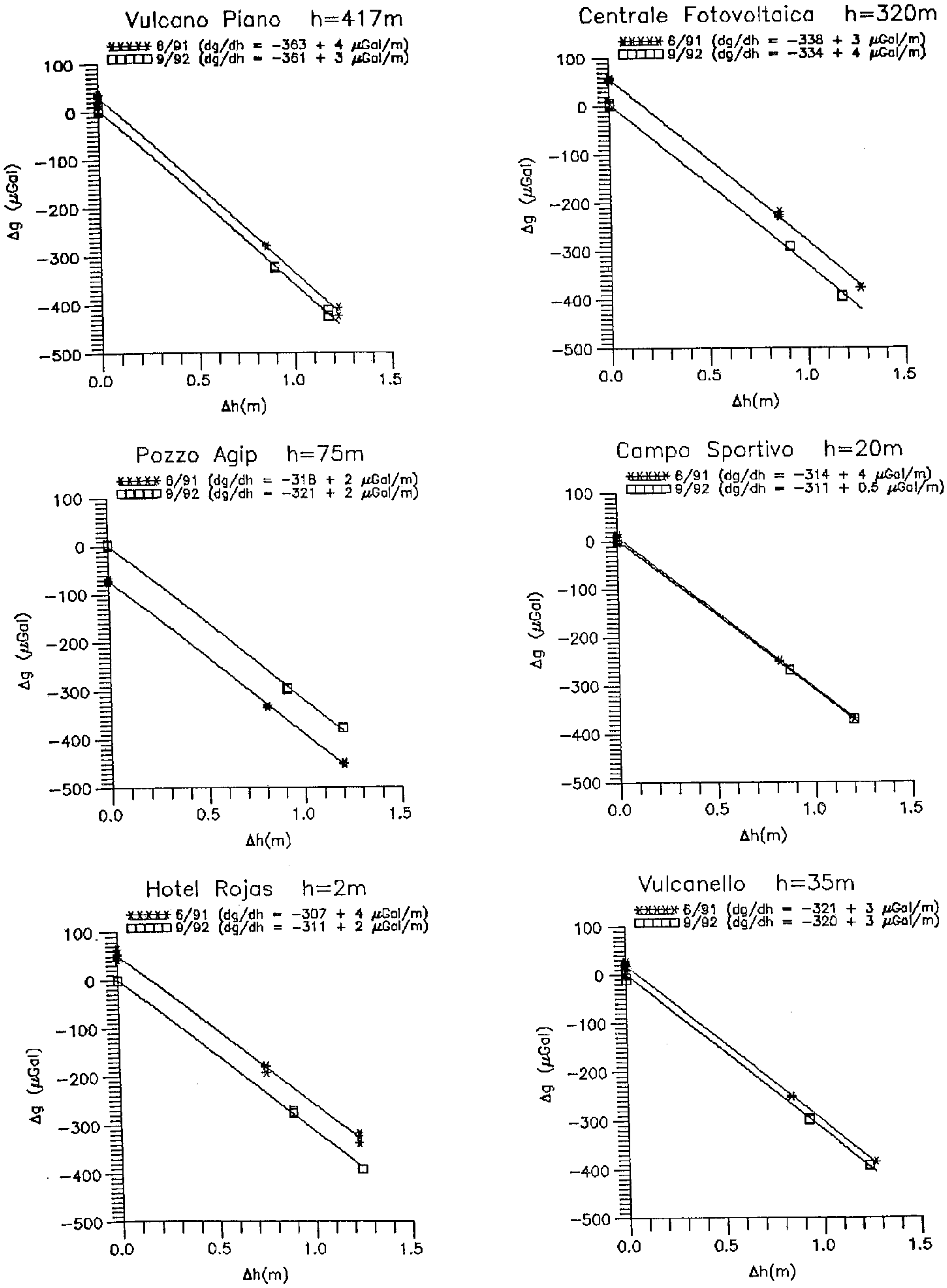


Fig. 5 — Vertical gravity gradients through the linear correlation Δg—Δh at each gradiometric station on Vulcano.

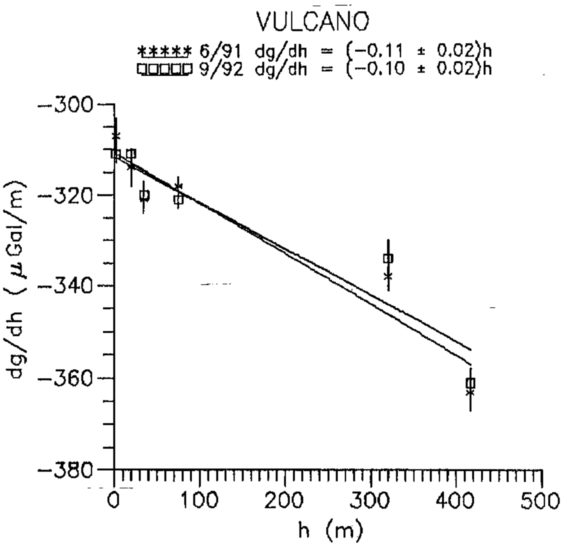


Fig. 6 — Correlation between the vertical gravity gradient and the station elevation.

of the isthmus (Porto) and at the base of the Gran Cratere. The localized nature of the gravity changes, their relatively rapid extension to different parts of the island, and their independance of changes in ground level, suggest that fluid migration at shallow levels may be the cause. The migrating fluids may belong in part to an active geothermal system, and in part to a hydrological system which controls the local level of the water table (Berrino et al., 1988b; Berrino and Corrado, 1991).

Six gradiometric stations have been established close to benchmarks of the high precision gravity net (Berrino and d'Errico, 1993); the map of the gradiometric and gravity stations is given in Fig. 4. The gradiometric sites were chosen in flat areas to minimize the effects of local terrain morphology. Two surveys were carried out, respectively in June 1991 and in September 1992, at same time as the gravity surveys; the results are shown in Fig. 5 and in Table 10. The FAG ranges from −310 μGal/m, at sea level, to −362 μGal/m at the height of about 400 m, with an average value on the island of −327 μGal/m. The different values of FAG are mainly due to the effect of elevation, as also shown in Fig. 6, where the trends of FAG versus height are represented separately for the two surveys.

The results of the gradiometric observations show that during the period June 1991 - September 1992 no significant changes in the mass distribution occurred at shallow depth, as also shown by the results of the gravity measurements.

Moreover, the definition of the FAG areal distribution on the island permits a more reali-

Table 10 — Vulcano island.

STATION	h (m)	dg/dh (μGal/m*) 6/1991	9/1992	Weighted mean
Vulcano Istmo (VG 10)	2	307±4	311±2	310±2
Campo Sportivo (VG 14)	20	314±4	311±0.5	311±3
Vulcanello (VG 11)	35	321±3	320±3	321±2
Pozzo Agip (VG 17)	75	318±2	321±2	320±1
Centr. Fotovoltaica (VG 19)	320	338±3	334±4	336±2
Vulcano Piano (VG 01)	417	363±4	361±3	362±2

*1μGal/m=10^{-8} sec^{-2} in the SI-System.

stic computation of gravity anomalies due to mass changes in the underground.

CONCLUSIONS

A net of absolute gravity stations has been created on the active volcanoes of Southern Italy, and in "stable" areas as reference. The values of g have been obtained with an error of a few μGal, between 3 to 7 μGal. The gradiometric observations also carried out are affected by errors ranging from 0.5 to 4 μGal/m. The measurements taken on Mt. Etna constrain to a shallow depth the source of the gravity changes observed since October 1991 at the summit of the volcano. The gradiometric data collected on the island of Vulcano define the areal pattern of the FAG, and also evidence the absence of changes in the shallow mass distribution. In June and September 1993 the absolute gravity stations on Pantelleria have been completed (Berrino, 1993b).

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REFERENCES

Alasia F., Cannizzo L., Cerutti G. and Marson I.; 1982: *Absolute gravity acceleration measurements: experiences with a transportable gravimeter.* Metrologia, **18**, 221-229.

Alessio G., Esposito E., Gorini A., Luongo G. and Porfino S.; 1990: Identification of seismogenic areas in the southern Apennines, Italy. Annali di Geofisica, **36**, 227-235.

Becker M., Bernard B., Boulanger Y., Corrado G., Faller J., Fried J., Groten E., Hanada H., Lindner K., Meurers B., Peter G., Roder R., Ruess D., Timmen L., Toro B., Tsuruta S. and Zurn W.; 1990: *Relative Gravity Measurements at the 3rd International Comparison of Absolute Gravimeters.* In: Bureau Gravimetrique International, Bull. d'Information, n. 67, December, pp. 152-160.

Berrino G.; 1992: *Absolute gravity observations at Centuripe and Serra La Nave (Mt. Etna) stations.* Tech. Rep. Science Plan "Volcanic deformation and tidal gravity effect on Mt. Etna", Project n. SC1*-CT91-0700 (TSTS), June.

Berrino G.; 1993a: *Gravity changes induced by height-mass variations at Campi Flegrei caldera.* Journ. Volcanol. Geoth. Res., in press.

Berrino G.; 1993b: *Precise gravity observations at the island of Pantelleria.* Acta Vulcanologica, in press.

Berrino G., Cannizzo L., Cerutti G. and Corrado G.; 1988a: *Nuove misure assolute di gravità nell'Italia meridionale.* In: Proc. 7° Annual Meeting of Gruppo Nazionale di Geofisica della Terra Solida, Esagrafica, Roma, pp. 949-958.

Berrino G., Coppa U., De Natale G. and Pingue F.; 1993: *Recent geophysical investigation at Somma-Vesuvius volcanic complex.* Journ. Volcanol. Geoth. Res., **58**, 239-262.

Berrino G. and Corrado G.; 1991: *Gravity changes and volcanic dynamics.* Cahiers du Centre Europeen de Geodinamique et de Seismologie, **4**, 305-323.

Berrino G., Corrado G. and Luongo G.; 1988b: *Gravity changes and dynamics of the Aeolian Islands.* Rendiconti Soc. Ital. Mineral. Petrog., **43**, 935-946.

Berrino G., Corrado G., Luongo G. and Toro B.; 1984: *Ground deformation and gravity changes accompanying the 1982 Pozzuoli uplift.* Bull. Volcanol., **47**, 187-200.

Berrino G. and d'Errico V.; 1990: *Rete gravimetrica di precisione all'isola di Pantelleria.* Internal report Osservatorio Vesuviano - National Group for Volcanology CNR, August.

Berrino G. and d'Errico V.; 1993: *Gravity and gradiometric observations.* Acta Vulcanologica, section on "Data related to eruptive activity, unrest phenomena and other observations on the italian active volcanoes - 1991. Stromboli and Vulcano", **3**, 295-298.

Berrino G., Rymer H., Brown G.C. and Corrado G.; 1991: *Gravity-height correlations for unrest at calderas.* Journ. Volcanol. Geoth. Res., **53**, 11-26.

Budetta G., Grimaldi M. and Luongo G.; 1988: *Variazioni temporali di gravità all'Etna (1986-1988).* Boll. National Group of Volcanology, 107-117.

Gantar C. and Morelli C.; 1959: *Sulla base gravimetrica nazionale Bologna-Ferrara e sulle variazioni nel tempo del fattore strumentale dei gravimetri Worden.* Boll. Geof. Teor. e Appl., **1**.

Harrison J.C. and Sato T.; 1984: *Implementation of Electro-static Feedback with a LaCoste & Romberg Gravity.* Journ. Geoph. Res., **89**, 7957-7961.

Morelli C.; 1952: *Primo contributo per una rete gravimetrica fondamentale in Italia.* Annali di Geofisica, **5**.

Rymer H., Murray J.B., Brown G.C., Ferrucci F. and McGuire W.J.; 1993: *Mechanisms of magma eruption and emplacement at Mt. Etna between 1989 and 1992.* Nature, **361**, 439-441.

Sanderson T.J.O., Berrino G., Corrado G. and Grimaldi M.; 1983: *Ground deformation and gravity changes accompanying the March 1981 eruption of Mount Etna.* Journ. Volcanol. Geoth. Res., **16**, 299-315.

Torge W.; 1989: *Gravimetry.* De Gruyter Ed., Berliner-New York, 465 pp.