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DEVELOPMENT OF PIETRA MAURA LANDSLIDE AND INTERACTIONS WITH THE MARSICO NUOVO DAM (BASILICATA, ITALY)

ABSTRACT: BENTIVENGA M., PALLADINO G. & CAPUTI A., *Development of Pietra Maura landslide and interactions with the Marsico Nuovo dam (Basilicata, Italy)*. (IT ISSN 0391-9838, 2012).

This paper deals with a big earthflow, known as Pietra Maura landslide, which has an artificial reservoir, formed by an earthfill-rockfill dam, at its toe. The landslide is located immediately north of Marsico Nuovo village along the eastern flank of the high Agri Valley. The geological evolution of the Agri Valley is essentially related to the Pleistocene extensional and strike-slip tectonics, overprinting older Apennine contractional structures. The geological formations recognized in the study area are all related to the Lagonegro Basin domain. They are mostly characterized by abundant clay intervals, sudden lithological variations and diffuse structural complexities.

In the plane view, the Pietra Maura landslide shows a NW-SE-oriented elongated shape with a large depletion zone, a narrow channel and a wide toe which deflect the Agri River. At the moment the activity of the landslide seems to be mostly restricted to the depletion area and, to a lesser extent to the lateral channel streams. In contrast, the resting part is dormant.

In 1983 the construction of the Marsico Nuovo dam led to the provision of water for irrigation purposes. The dam is 68,2 m high and 460 m wide and the reservoir's top height is 786.6 m a.s.l. When completed, in the 1996, it created a basin with a capacity of 7 Mm^3, partially invading the toe of the Pietra Maura landslide. The dam is attested both on clay and limestone deposits that are separated by a steep fault.

The described structural conditions, coupled with the low strength values of the outcropping rocks, are a concern especially if a series of loading/downloading cycles are provided for the water reservoir.

Most of the problems are linked to the presence of water in the toe of the landslide which may greatly reduce the strength values of the outcropping terrains.

The aim of the study is to achieve a better understanding of the stability conditions in the northern area of the Marsico Nuovo dam. It highlights the presence of landslide bodies, which are totally or partially reactivated or susceptible to reactivation such as the Pietra Maura landslide.

KEY WORDS: Pietra Maura landslide, Agri River, Ddam, Basilicata (Italy).

RIASSUNTO: BENTIVENGA M., PALLADINO G. & CAPUTI A., *Sviluppo della frana di Pietra Maura e rapporti con la diga di Marsico Nuovo (Basilicata)*. (IT ISSN 0391-9838, 2012).

In questo lavoro sono stati studiati gli aspetti geologici e geomorfologici di un'area di circa 26 km^2 corrispondente al bacino idrografico del fiume Agri sovrastante la diga di Marsico Nuovo. In particolare, l'obiettivo è stato quello di individuare l'evoluzione della colata di Pietra Maura per capire le implicazioni che questa comporta sulla sottostante diga di Marsico Nuovo. La conoscenza dettagliata del movimento franoso nel tempo ha permesso di dare indicazioni su come operare per stabilizzare l'area e di conseguenza ridurre gli aspetti negativi sull'invaso artificiale. L'alta valle del fiume Agri è un ampio bacino intermontano di natura tettonica, ubicato nell'Appennino lucano, che durante il Quaternario è stato colmato da depositi di natura continentale. L'evoluzione quaternaria dell'alta val d'Agri è stata condizionata da strutture tettoniche pleistoceniche, a cinematismo sia estensionale sia trascorrente, che si sono sovrapposte a quelle compressive mioceniche che hanno portato alla formazione dell'Appennino meridionale. Le formazioni affioranti nell'area di studio sono riferibili al Bacino di Lagonegro, presentano litologie estremamente varie e mostrano un assetto tettonico molto complesso. Le maggiori strutture tettoniche osservate sono riconducibili ai sovrascorrimenti miocenici, che hanno originato la catena appenninica e al sistema di faglie dell'alta val d'Agri. A Pietra Maura è stato osservato il sovrascorrimento della Formazione di Monte Facito su quella dei Galestri che ha determinato il raddoppio delle Unità Lagonegresi. A questa struttura si sovrappone il complesso di faglie trascorrenti ed estensionali ad alto angolo dell'alta valle dell'Agri che mostra orientazioni preferenziali all'incirca N140°-N150° e che genera fasce di taglio, spesso cataclastiche.

Lo studio geomorfologico ha evidenziato numerose frane responsabili dell'evoluzione rapida dei versanti. I risultati portano a ritenere che la diffusa franosità è dovuta al concorso di più fattori destabilizzanti, spesso tra loro interconnessi. Tra i principali si possono citare la natura e l'assetto litostratigrafico delle formazioni affioranti, la presenza di zone di taglio in corrispondenza di strutture tettoniche, terreni con scarse caratteristiche di resistenza, l'acclività dei versanti, corsi d'acqua in erosione e variazione del contenuto d'acqua nel terreno.

La natura prevalentemente argillosa dei terreni affioranti, favorisce in particolare lo sviluppo di colate e frane complesse. Tuttavia, in corrispondenza dei terreni più competenti, sono stati rilevati diversi scivolamenti rotazionali.

Lo studio ha interessato in particolare la colata di Pietra Maura che percorre, da NW a SE, gran parte dell'area rilevata. Questa frana, lunga 4.2 km, presenta una ampia zona di alimentazione che coincide con un'area molto deformata conseguente al raddoppio tettonico delle Unità Lagone-

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gresi. Il canale della colata coincide in parte, lungo il fianco destro, con una importante fascia di taglio riconducibile ad un importante sistema di faglie trascorrente. Il piede della colata di Pietra Maura, che ha deviato ad arco un tratto del corso del fiume Agri, ricade in parte nella zona di inondazione della diga di Marsico Nuovo. Questa condizione, associata alla presenza di numerosi fossi in erosione, potrebbe favorire la riattivazione del movimento franoso e dare luogo a un rapido interrimento nell'invaso.

TERMINI CHIAVE: Frana di Pietra Maura, Fiume Agri, Diga, Basilicata (Italia).

INTRODUCTION

The study of the interaction between landslides and dams is an important issue especially after the Vajont landslide event in 1963 which caused many victims and severe damages (Broili, 1967; Mantovani & Vita-Finzi, 2003; Genevois & Ghirotti, 2005). After this disastrous experience it became clear that the areas located upstream of dams must be studied in detail with the aim of recognizing any instabilities and thus of preventing loss of lives and properties. This kind of study can now be performed by means of an accurate geological and geomorphological field survey supported by more recent methods as well as the multi-temporal analysis aero photographs or satellite images (Zanutta & *alii*, 2006; Bitelli & *alii*, 2009; Ventura & *alii*, 2011).

The aim of this paper is to illustrate a well exposed case study from the High Agri Valley river basin, in the southern Apennine thrust belt, where the toe of a very large earthflow, the Pietra Maura landslide (Grassi & *alii*, 1988), interacts with the Marsico Nuovo dam basin. The presence of an extended and slow earthflow upstream of the water reservoir may represent a serious risk for man-made structures distributed along the landslide and also leads to the hypothesis of a strong decrease in useful volume consequent to the reactivation of the landslide in the near future.

The focus of this study is the detailed geological and geomorphological study of the right side of the Agri river, where the earthflow developed, to achieve a better understanding of the possible evolution of the landslide and its interactions with the Marsico Nuovo dam. The identification of the causes favouring the silting up of the water reservoir and knowledge of the slope evolution will allow us to establish the most suitable solutions to solve or at least mitigate these problems.

The study area lies within the Southern Apennine chain, along the north-eastern edge of the High Agri Valley that is considered a Quaternary tectonic depression conditioned by the activation of Pleistocene tectonic structures (Giano & Schiattarella, 2002; Cello & *alii*, 2003; Maschio & *alii*, 2005). Here a series of argillaceous, easily eroded and landslide prone formations extensively crop out. The poor soil conditions have also deteriorated during the activity of the recent tectonic structures. In fact the study of the stratigraphic and tectonic relationships among the different outcropping formations reveals the presence of several deformational stages which occurred between the Oligocene and the Quaternary periods. These deformation stages have been recognized as being crucial in the creation of profound alterations in the primary relationships among the different geological units.

From the geomorphological study it is clear that the main factors contributing to morphological modifications of the study area are intense fluvial erosion and above all the gravity-driven processes.

The comparison between the geological and geomorphological maps has emphasized that the area mostly affected by landslides, including the Pietra Maura landslide, coincides with some of the most important tectonic structures of the Agri Valley.

METHODS

The work consisted in a detailed analysis of geological and geomorphological features, which has been mainly conducted by means of field surveys and stereoscopic analysis of I.G.M.I (Istituto Geografico Militare Italiano) flight aerial photos allowing a 3-D view of the whole area. This method helped in the detection and mapping of the morphogenetic landforms. From the field survey two very detailed geological and geomorphological maps at 1:10000 scale have been drawn up.

The geological survey was carried out in order to fully understand the stratigraphic organization of the outcropping lithotypes and the tectonic arrangement of the studied High Agri valley sector.

Subsequently the study focused on the spatial distribution of landslides, which are mainly responsible for the slope evolution of the area. Major attention was dedicated to the Pietra Maura landslide (Grassi & *alii*, 1988), a big earthflow developing along the right side of the first segment of the Agri River.

The geomorphological field work was aimed at the detection of possible signs of activity as well as fractures, trenches etc. Also, great importance was given to the ascertainment of the damages suffered by linear structures of anthropogenic origin, such as roads, electricity networks, waterworks and buildings. At the same time, a multi-temporal analysis was performed in order to reconstruct the evolution of the Pietra Maura earthflow and to identify possible future interactions with the Marsico Nuovo artificial lake. This analysis was carried out by using I.G.M.I aerial photos related to 1954/55 (scale 1:33.000), 1992/93 (scale 1:33.000) and 2003 (scale 1:31.000) flights.

GENERAL SETTING

Geological setting

The Val d'Agri basin is a Quaternary, NW-SE oriented tectonic depression, located in the axial portion of the Southern Apennine fold and thrust-belt (Carbone & *alii*, 1991; Monaco & *alii*, 1998; Lentini & *alii*, 2002; Shiner & *alii*, 2004) (fig. 1a, b).

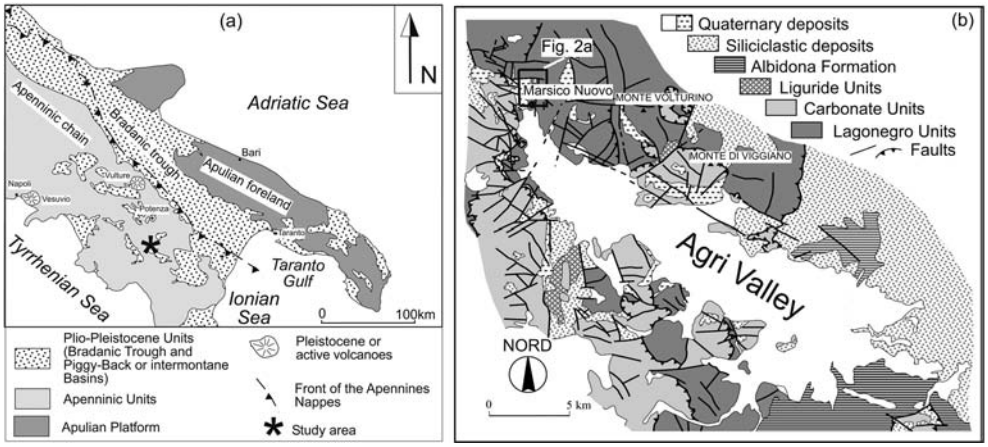

FIG. 1 - Geological sketch map of: a) Southern Italy (Bentivenga & *alii*, 2004); b) High Agri Valley basin (Giano & Schiattarella, 2002).

In the High Agri Valley the Meso-Cenozoic carbonate units belonging to the Campania-Lucania Platform tectonically overthrust coeval pelagic units pertaining to the Lagonegro Basin, through a regional Miocene thrust (Scandone, 1967; Pescatore & *alii*, 1999). The Lagonegro Units, in turn, are affected by a main internal thrust plane (fig. 2a). As a consequence it is possible to distinguish two tectonic units (Scandone, 1967; 1972) identified as Lagonegro I and Lagonegro II. In particular, at Pietra Maura, Il Monte and Mt. Cugnone localities the Triassic basal terms of Lagonegro II, represented by the Monte Facito and Calcari con Selce formations, overthrust the Jurassic-Cretaceous portion of Lagonegro I, represented by the Scisti Silicei and Galestri formations (fig. 2a, b). Contractional tectonics were responsible for the formation of large-scale folds in the Lagonegro terrains, observed at Mt. Lama, Serra di Calvello and Mt. Cugnone (Mazzoli & *alii*, 2001).

The NW-SE-oriented Plio-Quaternary extensional and strike-slip faults (VAFS of Cello & *alii*, 2000), which overprint the Miocene contractional structures and were the origin of the Agri Valley depression, are considered the main factor determining recent basin evolution (Giano & *alii*, 2000). In particular, the main N120°-trending left-lateral strike-slip faults and the associated N90°-N110° trending left-lateral, N30°-trending right-lateral and N130° to N150°-oriented left-lateral transpressive strike-slip faults are responsible for the opening of the Agri Valley and several Quaternary intermountain basins (Colella, 1988; Knott & Turco, 1991; Schiattarella & *alii*, 1994, Schiattarella, 1996; Giano & *alii*, 2000; Cello, 2000; Cello & *alii*, 2000).

The Plio-Quaternary tectonics is evident to the west of the Pietra Maura locality where several fault planes, showing strike-slip and extensional kinematics, have been detected. Large cataclastic zones (from some decimetres to some metres thick) corresponding to fault planes are often recognized. The Pleistocene movements along the border faults are largely registered by the scree deposits, which can be observed folded and uplifted at different heights along the basin margins (Di Niro & Giano, 1995; Ortolani & *alii*, 1992; Giano & *alii*, 2000).

Geographical location and geomorphological features

The study area is located in the south-western part of Basilicata, specifically to the SSW of Potenza. The area extension is about 26 km^2 and coincides with the higher part of the High Agri Valley; in particular it regards the drainage basin above the dam, which was built on the north-western side of Marsico Nuovo village (fig. 3).

Along the borders of the basin there are several reliefs, in particular Mt. Lama (1568 m) and Serra di Calvello (1605 m) on the eastern side, Tempa del Lupo (1317 m) and Il Monte (1420 m) on the northern side, Mt. dell'Arena (1354 m), Pietra Maura (1243 m) and Mt. Cugnone (1035 m) on the western side, while a portion of the Marsico Nuovo village is located on the southern side. The study area is included in the mountain altimetric zone, as it ranges in altitude from 700 to 1600 m a.s.l (fig. 3a, b).

The strong uplift of the Southern Apennines, which took place in the period from late Pliocene to Quaternary, has been recognized as the main determinant of the current morphology, which is dominated by fluvial erosion and gravity-driven processes. Land modelling is also controlled by lithology and the structural setting.

The area is frequently characterized by steep slopes, narrow and deep stream cuts and, in correspondence with tectonic structures and lithological variations, abrupt acclivity changes.

Specifically, higher acclivity is found around the top of Il Monte, Mt. Lama and Serra di Calvello where limestone and cherts crop-out. On the other side, low acclivity values are detected at Mt. Arena, on the east side of Mt. Cugnone and immediately to the north of the Marsico Nuovo village, where clayey terrains are present.

Similarly to slope acclivity, the drainage pattern observed within the High Agri Valley is strongly conditioned by the lithology. The first segment of the Agri river is quite straight except above the artificial lake, in correspondence with the Pietra Maura landslide body. Along the right side, the tributaries of the Agri river are characterized by dendritic patterns, due to the clayey nature of the outcropping formations. Along the left side they mainly develop in

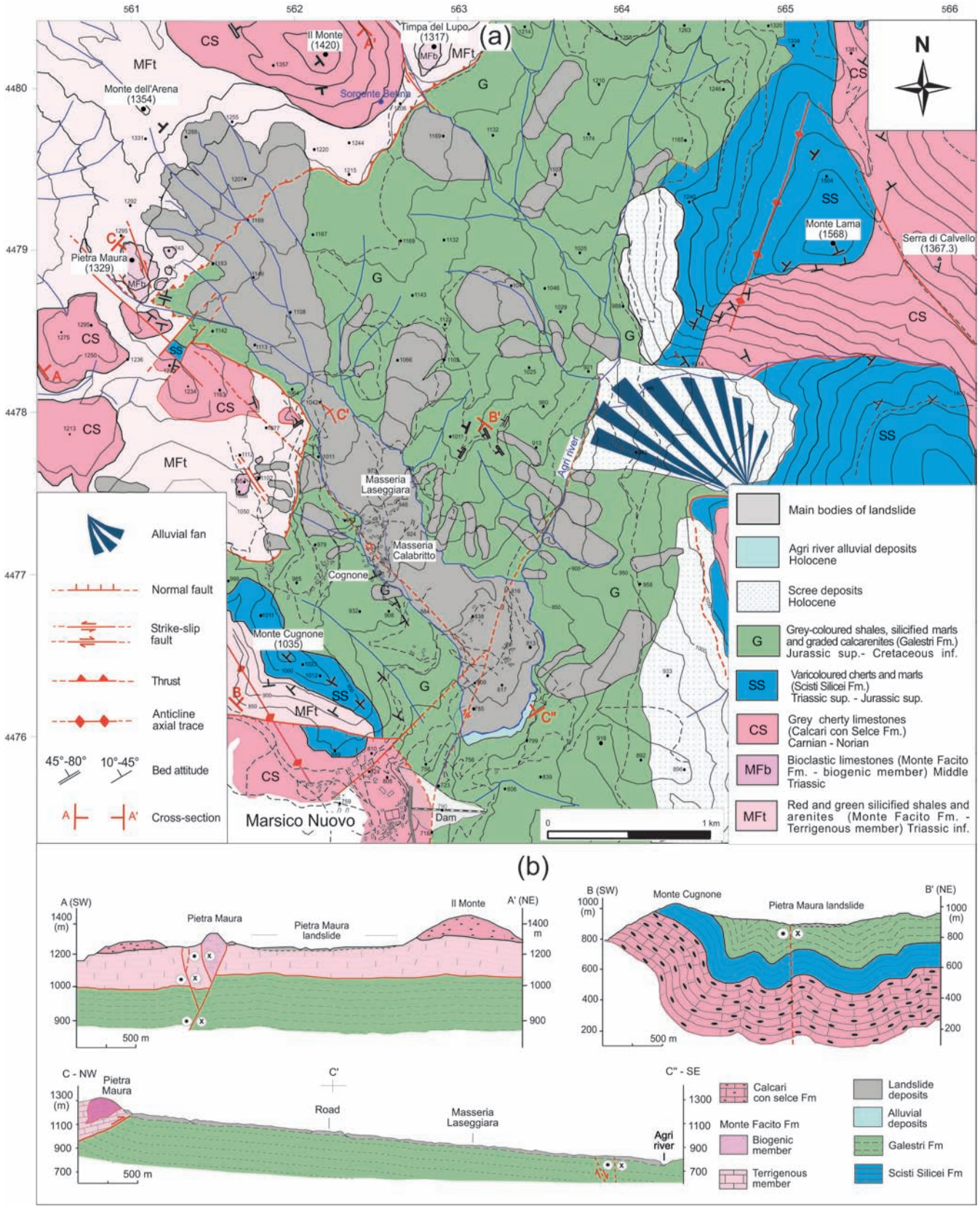

FIG. 2 - a) Detailed geological map; b) Cross-sections.

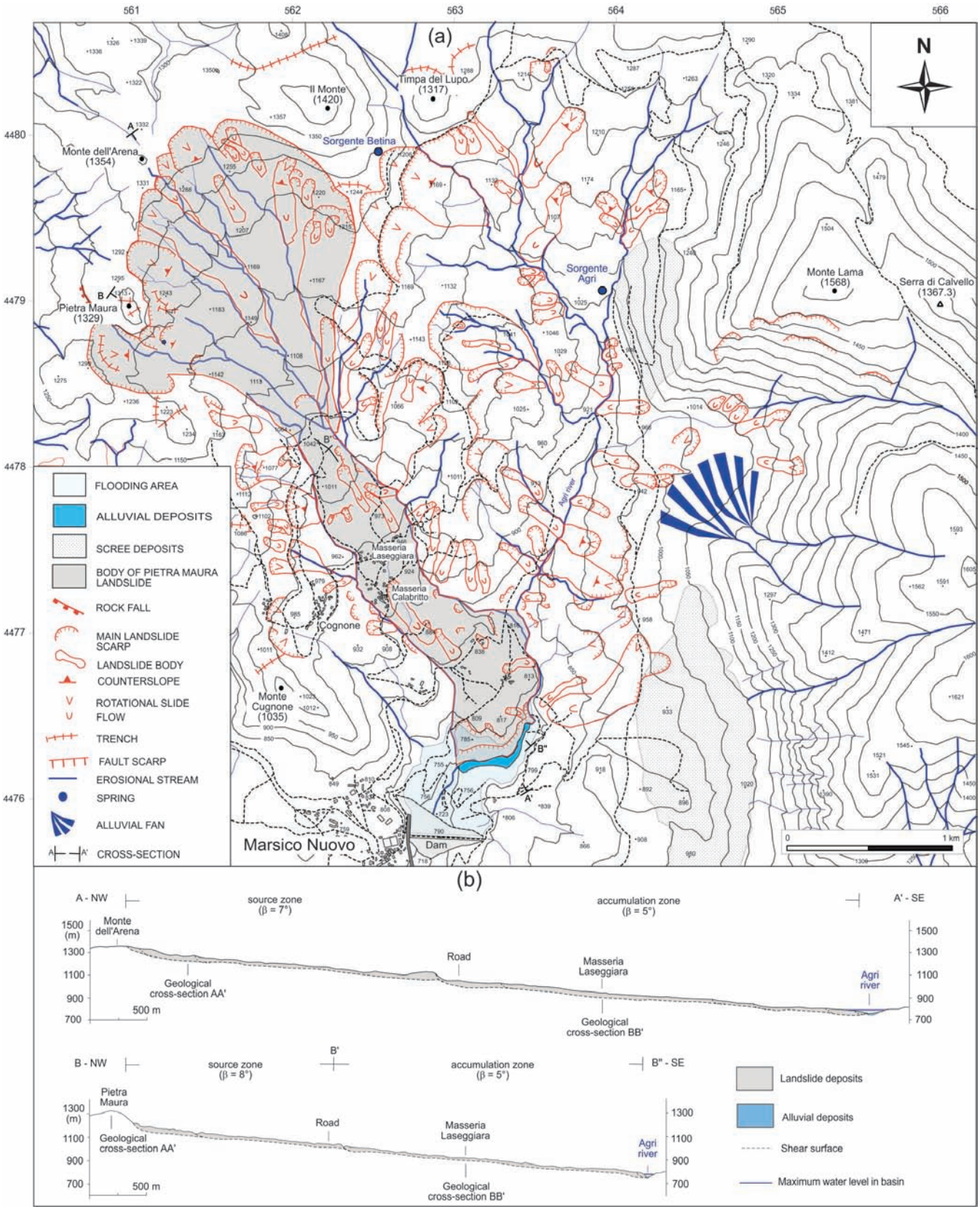

FIG. 3 - a) Geomorphological map; b) Cross-sections.

limestones and cherty rocks and flow almost side by side, before pouring into the Agri river.

In the study area there are some springs that are influenced by seasonal changes. The best conditions for spring formation are documented where there is contact between the clays and limestones.

Landslide movements assume a remarkable importance in the morphological evolution of the reliefs in the study area, because they are part of the main mass transfer phenomena and they cause quick slope alterations.

The geomorphological map of the area (fig. 3a) illustrates the presence of several landslides and their typology (Varnes, 1978, Carrara & *alii*, 1985; Cruden & Varnes, 1996). The earthflows are the most frequent kind of landslide but we can also find falls, topples, rotational slidings and complex landslides, especially rotational slide-earthflows.

Our attention has mainly been focused on a large mass movement, identified as «Pietra Maura landslide».

THE PIETRA MAURA LANDSLIDE

The Pietra Maura landslide (figs. 3, 4) has entirely developed on the right side of Agri river basin and consists of a well-developed earthflow with a large depletion zone and a narrow elongated body. In particular, several smaller and isolated earthflows converging in the Agri river thalweg have given rise to the main landslide body. The landslide is already visible in the photos of 1955 that represent the oldest flight available for this area.

Nevertheless, we do not have data about any activations before 1955.

The landslide is from 230 to 2000 meters wide with an average width of about 900 m. Greater detail shows that the landslide arc-shaped source area achieves its maximum width in correspondence with Mt. dell'Arena, Il Monte and Pietra Maura and has a length of about 4.2 km.

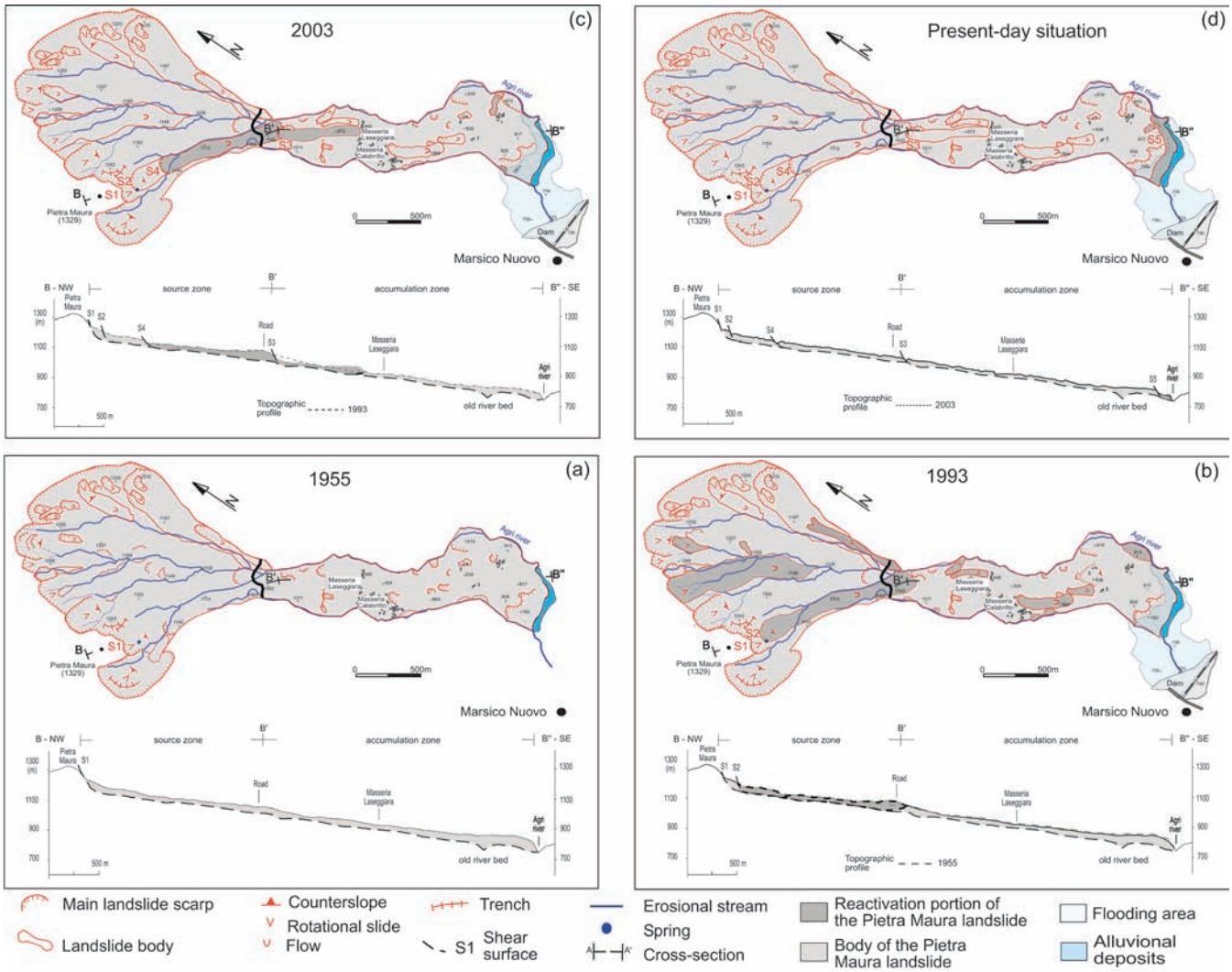

FIG. 4 - Evolutive scheme of the Pietra Maura landslide: a) during 1955, before the construction of the dam; b) in the 1993; c) in the 2003; d) present-day situation.

The maximum toe width measured along the Agri river is about 1 km. The landslide body steepness in the accumulation area is about 5°, while it is about 7-8° in the source area (fig. 3b). The difference in height between the top of the Pietra Maura landslide and the final part of the earthflow body is about 580 m. The size of the damaged area is about 3 km^2 and previous studies (Grassi & *alii*, 1988), dealing with the construction of the Marsico Nuovo dam, show that the average thickness of the main landslide body is about 15 m (fig. 3b). All the terrain involved in the gravitational movement is part of the Monte Facito and Galestri formations, and is entirely of marly - clayey nature. The instability connected to the lithology is clearly evident in the constant movements which occur especially during rainy seasons involving the alimentation and accumulation zones. The comparison between the geological and geomorphological maps (figs. 2, 3) shows that the area occupied by the Pietra Maura landslide strictly coincides with tectonic structures such as thrusts and faults, which created marked morphologies (as well as steep escarpments) and strong internal deformation in the clayey lithologies. Specifically, the Pietra Maura landslide source area strictly coincides with a strongly deformed interval coinciding with the main thrust plane that superposes the two Lagonegro tectonic units. In addition, part of the right side of the Pietra Maura landslide body fits with a tectonic lineament, well recognizable on the field, corresponding to a N140° - N150°-oriented left-lateral strike-slip fault.

Along the landslide crown, it seems that mass movements do not directly involve the reef limestones of the Monte Facito Formation, outcropping in the Pietra Maura locality, as previously indicated (Grassi & *alii*, 1988), even though they are subject to falls and topples in the eastern part as a result of the presence of numerous fractures isolating several blocks.

Typical elements of the Pietra Maura landslide, observed in the depletion area, include numerous water filled depressions, indicating the lack of a well-developed drainage system. A series of strings has been identified in this area located at the contact between Monte Facito limestones and Galestri marls.

The landslide accumulation zone is characterized by an elongated shape, showing a hummocky surface with a fan-shaped final part, which caused the deviation of the Agri River towards the SE. There are two rural areas on the earthflow (Masseria Laseggiara and Masseria Calabritto), which are situated in the middle part of the accumulation zone; in addition, several scattered houses are present in the area of the landslide. Some of these buildings appear deeply cracked (fig. 5a). Landslide activity is also proven by linear structures such as roads, which are severely damaged, as well as an aqueduct and power lines that need constant maintenance (fig. 5b). Hydraulic regimentation interventions, such as drainages, have been detected in the final part of the accumulation area and along the streams which form lateral boundaries to the earthflow body, where there are numerous check-dams, while they are absent in the remaining landslide area.

FIG. 5 - Examples of damages to infrastructures recognized above the Pietra Maura landslide body: a) Cracked building; b) Main road cracked bridge.

MULTI-TEMPORAL ANALYSIS

Multi-temporal analysis allows the detection of all the elements necessary to ascertain the series of events that led to the present morphology in a certain time interval. This analysis was performed by stereoscopic observation of aerial photos obtained in different years. In particular, for the area to the North of Marsico Nuovo, 1954/55, 1992/93 and 2003 I.G.M.I. flights were studied. Field observations were used to deduce the present morphology. The analysis has led to a recognition of the morphological changes which have taken place over the last 50 years and, in particular, the activity and the evolution of the Pietra Maura landslide (fig. 4). Multi-temporal analysis offers an understanding of the morpho-evolutionary series that will probably characterize the studied area in the near future and this could facilitate the choice of the best initiatives to be

undertaken in order to stabilize the area. The stereoscopic analysis performed on 1955 aerial photos reveals that the Pietra Maura landslide was already entirely developed (fig. 4a). At that time the Marsico Nuovo dam had not yet been built. Detailed observation shows that the most active part is represented by the deplation area and, in particular, the north-western portion corresponding to the Pietra Maura relief. Additional small instabilities can be recognized in correspondence with the streams laterally bounding the landslide body (fig. 4a).

The construction of the Marsico Nuovo dam began in the 1980' and was completed in the 1996. The 1993 aerial photos reveal the presence of the dam but the reservoir was empty. Stereoscopic analysis highlight a diffuse reactivation of the higher portion of the Pietra Maura landslide, involving the main road situated north of Masseria Laseggiara village. Other significant reactivations are visible all along the remaining part of the landslide body. Of considerable interest is the reactivation of a part of the toe presumably linked to the erosion of the Agri river (fig. 4b).

In the 2003 aerial photos the Marsico Nuovo dam results as almost full. The stereoscopic analysis shows a series of active landslides that are visible along the middle portion of Pietra Maura landslide. As in 1993, the toe is seen to be still affected by erosion in correspondence with the Agri river (fig. 4c).

At the present time, the Marsico Nuovo dam reservoir is full and a diffuse series of instabilities are visible on the field along the depletion area. However, the main reactivations are visible at the toe of the Pietra Maura landslide corresponding to the right side of the Marsico Nuovo dam reservoir (fig. 4d).

Summarizing, two main considerations arise by the study of multi-temporal analysis:

Firstly, a constant activity in the source area has always been observed. Also the Pietra Maura landslide, in the older aerial photos, shows stronger landslide activity along its boundary streams, which is absent in the more recent photos. It is probable that an improvement in the stability conditions may be obtained by several subsequent hydraulic regimentation interventions.

Secondly, a series of reactivations occurred at the Pietra Maura landslide toe coinciding with the filling of the dam. The latter consideration highlighted the negative role played by the reservoir water on the considered earthflow.

INTERACTION BETWEEN PIETRA MAURA LANDSLIDE AND THE MARSICO NUOVO WATER RESERVOIR

Landslides interacting with dams are a worldwide problem in areas located in active mountain belts where slope instabilities are mostly favoured by gravity induced mechanisms and earthquakes. In the southern Apennines most dams have been built in correspondence with destructured argillaceous terrains which are very prone to landslide activation. As is well known the presence of landslide bodies in the proximity of a dam reservoir can represent a serious risk for the survival of the structures. This risk increases if we consider that the high Agri valley is a very active tectonic depression (Boenzi & *alii*, 2004).

The landslide described in the present case-study is characterized by a series of reactivated bodies converging towards the valley bottom giving rise to a wide toe partially occupying the adjacent the Marsico Nuovo water reservoir (figs. 3, 6).

Even if field observations led as to exclude a totally reactivation of the entire landslide body, potentially dangerous in terms of lives and properties, the presence of continuous reactivations at the toe of the main body may be responsible for a fast silting up of the dam basin. In fact, the main stream suopplying water to the dam reservoir must cross mostly reworked clayey lithologies. Consequently, the continuous linear and areal erosion can lead, in a short period of time, to a drastic reduction of the water reservoir storage capacity.

On the other hand, the stability of the Pietra Maura landslide can be compromised by constant changes in reservoir water level, which cause changes in the neutral pressures in the deeper parts of the landslide body. This could give rise to new reactivations of the whole earthflow.

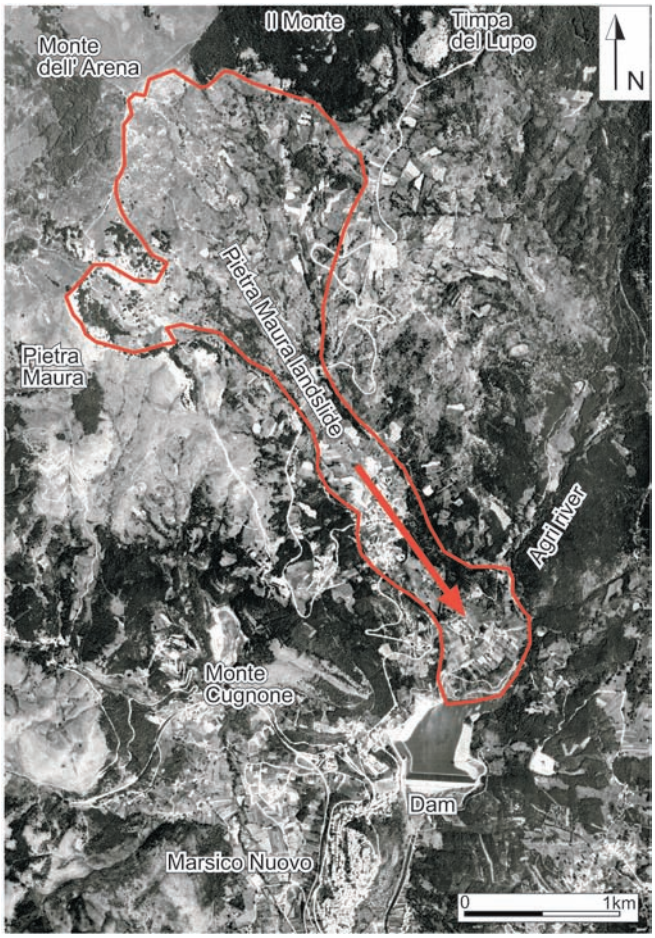

FIG. 6 - Aerial view of the study area. Note as the Marsico Nuovo water basin strictly interacts with the Pietra Maura landslide toe.

DISCUSSION AND CONCLUSIONS

The study performed north of the Marsico Nuovo village led to an improved definition of the morphological evolution of the Pietra Maura earthflow and the interactions with the Marsico Nuovo dam (fig. 7).

The preliminary geological survey showed that the outcropping formations all belong to the Lagonegro Units, which are characterized by the prevalence of clayey lithologies intensely affected by tectonic deformation. In particular, wide shear zones highlighted by cataclasites, were recognized in the study area, influencing the spatial distribution of the Pietra Maura landslide. Thrust and fault planes are particularly evident in the higher part of the study area, especially near the Pietra Maura relief. As a consequence, the main factors contributing to the development of the Pietra Maura landslide are the lithological features, the loss of strength of rock bodies within the shear zones, the presence of rivers eroding the toe of the landslide body, the seasonal increase of rainfalls the autumn-winter periods and the high slope steepness.

The multi-temporal analysis allowed us to trace its evolutionary mechanism. This analysis highlighted the hydrographical network's changes that mostly include deviations of gullies related to the arrival of the landslide body. This can be clearly seen at the toe of the Pietra Maura landslide, which deflects the Agri river just above the Marsico Nuovo water reservoir. In the last few decades, some streams have undergone a remarkable deepening.

This is important for the implications related to the presence of the Marsico Nuovo dam just downstream. The lower part of the landslide body is situated in the floodable area of the water reservoir and this could cause quick silting up of the artificial reservoir and, at the same time, it could cause instability at the landslide toe during the operation of the reservoir. The study of the reactivation mechanisms related to the Pietra Maura earthflow indicates that several works (mainly water regulation) are needed in order to stabilize the landslide area.

The optimization of the water regime and drainage works must cover the whole landslide area in order to avoid often seasonal gravitational movements, over time as they cause instability above the detachment area and overloads downstream. The surface and deep drainages should cover the whole landslide area in order to lower the water table and to reduce the interstitial pressure. These works must be linked to the side streams of the landslide body along which further check-dams must be created. Water drainage works must also involve the Agri river, in order to reduce linear erosion and to avoid the toe erosion of the Pietra Maura landslide body.

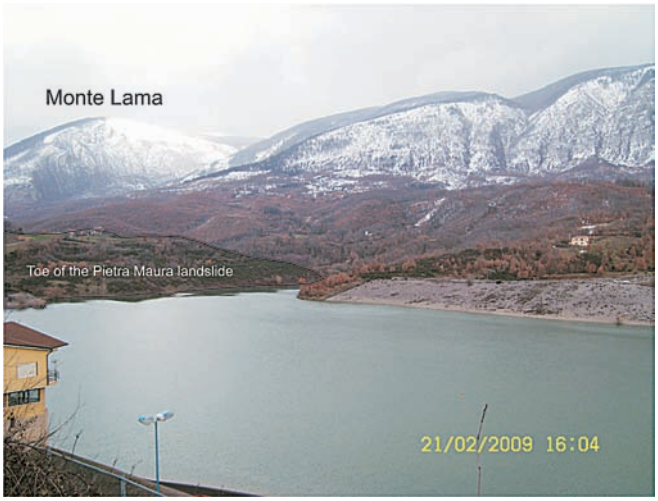

FIG. 7 - View of the Marsico Nuovo water reservoir. On the left, the toe of the Pietra Maura landslide is evidenced.

REFERENCES

BENTIVENGA M., COLTORTI M., PROSSER G. & TAVARNELLI E. (2004) - *A new Interpretation of Terraces in the Taranto Gulf: the Role of Extensional Faulting*. Geomorphology, 60, 383-402.

BITELLI G., GATTA G., LANDUZZI A., VITTUARI L. & ZANUTTA A. (2009) - *La fotogrammetria digitale di archivio per lo studio multitemporale di un'area in frana nelle Prealpi vicentine*. Atti 13ª Conferenza Nazionale ASITA, Bari.

BOENZI F., CAPOLONGO D., CECARO G., D'ANDREA E., GIANO S.I., LAZZARI M. & SCHIATTARELLA M. (2004) - *Evoluzione geomorfologica polifasica e tassi di sollevamento del bordo occidentale dell'Alta Val D'Agri (Appennino meridionale)*. Bollettino della Società Geologica Italiana, 124, 357-372.

BROILI L. (1967) - *New knowledge on the geomorphology of the Vaiont Slide slip surfaces.* Rock Mechanics & Engeneering Geology, Jour. Int. Soc. Rock Mechanics. 5 (1), 38-88.

CARBONE S., CATALANO S., LAZZARI S., LENTINI F. & MONACO C. (1991) - *Presentazione della Carta Geologica del bacino del fiume Agri (Basilicata).* Memorie della Società Geologica Italiana, 47, 129-143.

CARRARA A., D'ELIA B. & SEMENZA E. (1985) - *Classificazione e nomenclatura dei fenomeni franosi.* Geologia Applicata e Idrogeologia, 20, 223-243.

CELLO G. (2000) - *A quantitative structural approach to the study of active fault zones in the Appennines (Peninsular Italy)*. Journal of Geodynamics, 29, 265-292.

CELLO G., GAMBINI R., MAZZOLI S., READ A., TONDI E. & ZUCCONI V. (2000) - *Fault zone characteristics and scaling proprieties of the Val d'Agri Fault System (Southern Appennines, Italy)*. Journal of Geodynamics, 29, 293-307.

CELLO G., TONDI E., MICARELLI L. & MATTIONI L. (2003) - *Active tectonics and earthquake sources in the epicentral area of the 1857 Basilicata earthquake(southern Italy)*. Journal of Geodynamics, 36, 37-50.

COLELLA A. (1988) - *Pliocene-Holocene fan deltas and braid deltas in the Crati basin: a consequences of varying tectonic condictions.* In: Nemec W. & Steel R.J. (eds.), «Fan deltas: Sedimentology and Tectonic setting». Blackie, Glasgow and London, 50-74.

CRUDEN D.M. & VARNES D.J. (1996) - *Landslide types and processes.* In: Turner A.K. & Shuster R.L. (eds.), «Landslides: Investigation and Mitigation». Transp Res Board, Spec Rep 247, 36-75.

DI NIRO A. & GIANO S.I. (1995) - *Evoluzione geomorfologica del bordo orientale dell'Alta Val D'Agri (Basilicata).* Studi Geologici Camerti, 1995/2, 207-218.

GENEVOIS R. & GHIROTTI M. (2005) - *The 1963 Vajont Landslide*. Giornale di Geologia Applicata, 1, 41-52.

GIANO S.I. & SCHIATTARELLA M. (2002) - *Geomorfologia e Neotettonica dell'alta Val d'Agri. Guida all'escursione geomorfologia dall'Val d'Agri a Matera*. Assemblea AIGeo, Potenza, 22-34.

GIANO S.I., MASCHIO L., ALESSIO M., FERRANTI L., IMPROTA S. & SCHIATTARELLA M. (2000) - *Radiocarbon dating of faulting in the Agri high valley, southern Italy*. Journal of Geodynamics, 29, 371-386.

GRASSI D., MERENDA L. & SDAO F. (1988) - *Esempi di fenomeni gravitativi di diverso tipo nell'Appennino Campano-Lucano*. Memorie della Società Geologica Italiana, 41, 897-904.

HUTCHINSON J.N (1988) - *Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology.* Proc. of the Fifth Intern. Symp. on Landslides, Losanna, A.A. Balkema ed.

KNOTT S.D. & TURCO E. (1991) - *Late Cenozoic kinematics of the Calabrian arc, Southern Italy.* Tectonics, 10, 1164-1172.

LENTINI F., CARBONE S., DI STEFANO A. & GUARNIERI P. (2002) - *Tectonic evolution of the lucanian Southern Apennines: Stratigraphical and structural constraints*. Journal of Geodynamics, 34, 141-158.

MANTOVANI F. & VITA-FINZI C. (2003) - *Neotectonics of the Vajont dam site*. Geomorphology, 54, 33-37.

MASCHIO L., FERRANTI L. & BURRATO P. (2005) - *Active extension in Val d'Agri area, southern Apennines, Italy: implications for the geometry of the seismogenic belt.* Geophysical Journal International, 162 (2), 591-609.

MAZZOLI S., BARKAM S., CELLO G., GAMBINI R., MATTIONI L., SHINER P. & TONDI E. (2001) - *Reconstruction of continental margin architecture deformed by the contraction of the Lagonegro basin, Southern Appennines, Italy.* Journal of the Geological Society, London, 158, 309-319.

MONACO C., TORTORICI L. & PALTRINIERI W. (1998) - *Structural evolution of the lucanian Apennines, southern Italy*. Journal of Structural Geology, 20, 617-638.

ORTOLANI F., PAGLIUCA S., PEPE E., SHIATTARELLA M. & TOCCARELLI R.M. (1992) - *Active tectonics in the Southern Appennines: relationships between cover geometries and basements structure. A hypothesis for a geodynamic model.* IGCP No. 276, Newsletter, 5, 413-419.

PESCATORE T., RENDA P., SCHIATTARELLA M. & TRAMUTOLI M. (1999) - *Stratigraphic and structural relationships between Meso-Cenozoic Lagonegro basin and coeval carbonate platforms in southern Apennines, Italy*. Tectonophysics, 315, 269-286.

SCANDONE P. (1967) - *Studi di geologia lucana: la serie calcareo-silico-marnosa e i suoi rapporti con l'Appennino calcareo*. Bollettino della Società dei Naturalisti in Napoli 76, 1-175.

SCANDONE P. (1972) - *Studi della geologia lucana: Carta dei terreni della serie calcareo-silico-marnosa e note illustrative.* Istituto di Geologia dell'Università di Napoli.

SCHIATTARELLA M., TORRENTE M. & RUSSO F. (1994) - *Analisi strutturale ed osservazioni morfostratigrafiche nel bacino del Mercure (confine Calabro-Lucano).* Il Quaternario, 7, 613-626.

SCHIATTARELLA M. (1996) - *Tettonica della Catena del Pollino (Confine Calabro-Lucano).* Memorie della Società Geologica Italiana, 51, 543-566.

SHINER P., BECCACINI A. & MAZZOLI S. (2004) - *Thin-skinned versus thick-skinned structural models for Apulian carbonate reservoirs: constraints from the Val d'Agri Fields.* Marine and Petroleum Geology, Vol. 21, 805-827.

VARNES D.J. (1978) - *Slope movement types and processes*. In: Schuster R.L. & Krizek R.J. (ed.), «Landslides, analysis and control». Transportation research board sp. rep. no. 176, Natural Academy of Sciences, 11-33.

VENTURA G., VILARDO G., TERRANOVA C. & BELLUCCI SESSA E. (2001) - *Tracking and evolution of complex active landslides by multi-temporal airborne LiDAR data: The Montaguto landslide (Southern Italy).* Remote Sensing Environment, in press.

ZANUTTA A., BALDI P., BITELLI G., CARDINALI M. & CARRARA A. (2006) - *Qualitative and quantitative photogrammetric tecniques for multi-temporal landslide analysis.* Annals of Geophysics, 49, 1067-1080.

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