Geogr. Fis. Dinam. Quat.
33 (2010), 187-192, 5 figg.

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GENESIS AND GEOMORPHOLOGICAL EVOLUTION OF DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATIONS: AN EXAMPLE OF DATING IN WESTERN SICILY

ABSTRACT: MONTELEONE S., SABATINO M. & BAMBINA A., *Genesis and geomorphological evolution of deep-seated gravitational slope deformations: an example of dating in Western Sicily*. (IT ISSN 0391-9838, 2010).

The study area lies in the westernmost part of the Sicani Mountain range where a superposition of SE-trending, stacked, geological bodies crops out. this structure is the result of transpressive tectonic phases of Miocene and Lower Pliocene age. The neo-autochthon outcrops are made up of clay-marly deposits of the Middle-Upper Pliocene, and of calcarenites of Pleistocene age.

The extensional Quaternary tectonic phases later dissected and dismembered the original structure, thus involving the calcarenites that show clear, mainly NE-SW oriented dislocations.

Such calcarenites, which have a total thickness of about 80 metres, overlap the Belice marly-arenaceous formation. This determined favourable conditions for Deep-seated Gravitational Slope Deformations (DSGD), which affected the western plateau of St. Margherita Belice causing deep landslides. The trigger agent of these landslides has been correlated with the seismic activity that has affected this area since ancient times.

The Deep-seated Gravitational Slope Deformations considered here have peculiar geomorphologic characteristics such as disjointed blocks, scarps, landslides and areas with double ridges. On top of the tilted bodies, wide trenches are frequently observed, whereas the base of the collapsed masses sometimes shows no real area of accumulation. As a result of the partial rotation of the masses involved in the collapse, the calcarenitic blocks show counter-tilting, and in some cases are covered by «talus»-type deposits of uneven thickness.

These deformations can currently be considered inactive. The discovery of an archaeological site of late-Roman and Byzantine age (VII-VIII centuries AD) has proved that the landsliding activity has been inactive since before the area was inhabited by humans. However, the dislocation of rocky tombs belonging to the middle Bronze Thapsos culture (XV-XIII century BC) suggests that these landslides occurred after the necropolis was built. Data from an archaeological study of the earthquakes involving the city of Selinunte, located just south of the study area, has allowed us to date the onset of the above-mentioned instability.

KEY WORDS: Neotectonics, DSGD, Western Sicily.

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RIASSUNTO: MONTELEONE S., SABATINO M. & BAMBINA A., *Genesi ed evoluzione geomorfologica di D.G.P.V.: un esempio di datazione nella Sicilia Occidentale*. (IT ISSN 0391-9838, 2010).

L'area oggetto della presente nota ricade nel settore più occidentale dei Monti Sicani dove è possibile riscontrare una sovrapposizione di corpi geologici impilati e vergenti verso i quadranti meridionali, quali conseguenza delle fasi tettoniche traspressive riferibili al Miocene e al Pliocene inferiore. In quest'area il neoautoctono è rappresentato dai depositi di natura argillo-marnosa del Pliocene medio-superiore appartenenti alla Fm. Marnoso-arenacea del Belice e dalle calcareniti del Pleistocene. Le crisi tettoniche quaternarie di tipo distensivo hanno ulteriormente sezionato e smembrato l'originario edificio strutturale, coinvolgendo anche le calcareniti che manifestano evidenti dislocazioni orientate, principalmente, NE-SW.

La sovrapposizione delle calcareniti, il cui spessore complessivo si aggira intorno agli 80 metri, sulla porzione a comportamento duttile della Formazione Marnoso-arenacea del Belice determina condizioni favorevoli per una evoluzione geomorfologica del settore occidentale del pianoro di S. Margherita Belice per frane profonde del tipo DGPV. Il loro innesco va correlato con l'attività sismica che ha interessato l'area fin dai tempi più remoti.

Le Deformazioni Gravitative Profonde di Versante prese qui in esame hanno caratteristiche geomorfologiche peculiari; si osservano blocchi disarticolati, gradini, terrazzi di frana ed aree con doppie creste. Al coronamento dei corpi *tiltati* si osservano quasi sempre ampie trincee, mentre alla base delle masse collassate può non essere presente una vera e propria zona di accumulo. Per effetto della parziale rotazione delle masse coinvolte nel dissesto, i blocchi calcarenitici presentano una immersione verso monte e in alcuni casi risultano ricoperti da uno spessore variabile di depositi tipo talus.

Tali deformazioni possono essere considerate attualmente inattive; il ritrovamento di un sito archeologico di età tardo-romana e bizantina del VII-VIII secolo d.C. porta a dedurre che lo stato di attività dell'intero corpo franoso debba essere stato quiescente già prima della realizzazione dell'insediamento stesso. La dislocazione, invece, di tombe rupestri assegnate alla cultura del medio Bronzo di Thapsos (XV-XIII secolo a.C.) porta a considerare tali fenomeni franosi comunque successivi alla realizzazione della necropoli stessa. L'utilizzo dei dati derivanti da un approccio archeologico ai terremoti che hanno coinvolto la città di Selinunte, ubicata poco più a sud dell'area su cui insistono i fenomeni franosi analizzati, ha permesso, infine, di datare l'innesco della instabilità stessa.

TERMINI CHIAVE: Neotettonica, DGPV, Sicilia Occidentale.

INTRODUCTION

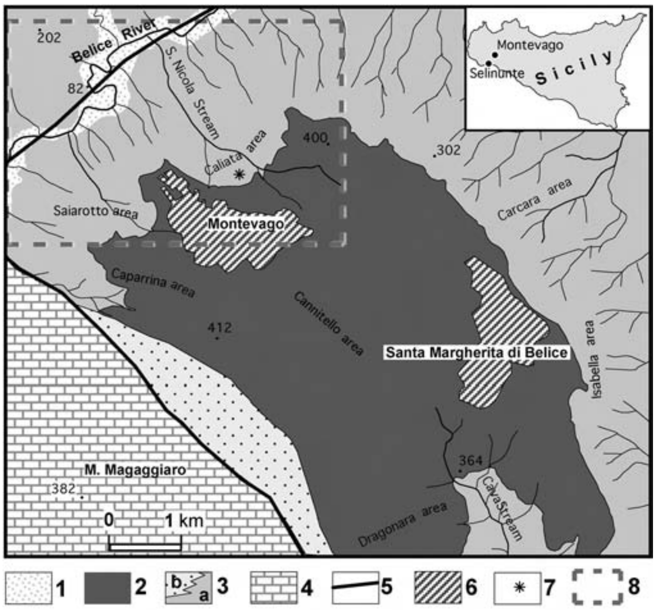
The geomorphological characteristics of slopes involved in Deep-seated Gravitational Slope Deformations (DSGD) have been the object of study for many years. The deformation mechanisms that characterize these landslides are particularly affected by the stratigraphic-structural and tectonic sequences that can trigger them even in normally stable situations.

In depth discussions have defined Deep-seated Gravitational Slope Deformations as «the deformation of a mass for which it is not necessary to postulate the presence of a defined deformation surface» (Dramis & Sorriso Valvo, 1994).

Several authors have studied these phenomena, and they have all tackled the problems of defining the their characteristic morphological elements (Agnesi & *alii*, 1978; Dramis, 1984; Forcella & Orombelli, 1984), and of identifying the geological-structural conditions that are a prerequisite for their occurrence (Agliardi & *alii*, 2001; Di Luzio & *alii*, 2004).

In this paper we describe the results of a detailed geological-structural and geomorphological survey effected on the north-west slope of the S. Margherita Belice (AG) plateau. This was performed with the aim of ascertaining what the prerequisite conditions and triggering factors were that caused the landslides involving the Caliata and Saiarotto areas.

The results show that there are some atypical aspects to these landslides when compared with the classical models of DSGD.



1- Alluvial deposits (Upper Pleistocene - Recent); **2-** Calcarenites (Middle-Lower Pleistocene); **3-** Marly-arenaceous formation of the Belice (Middle-Upper Pliocene): a) clays and marly clays passing upward to b) biocalcarenites; **4** - Calcilutites and marly limestones (Jurassic-Upper Cretaceous); **5** - Fault; **6** - Town site; **7-** Byzantine archaeological site (VII-VIII century AD); **8** - Study area.

FIG. 1 - Geological-structural scheme in the Montevago (AG) area (from Monteleone & *alii*, 2006 - modified).

REGIONAL SETTING

The study area is represented by the western sector of the Sicani Mountain range and is characterised by outcrops of carbonate, clay-marly, clay-sandy and calcarenitic rocks of Jurassic through Pleistocene age (Ruggieri & Torre, 1974; Catalano & D'Argenio, 1978; Mascle, 1979; Di Stefano & Vitale, 1992; Monteleone & *alii*, 2006). Holocene alluvial and marsh deposits are present at the bottoms of the valleys of the main streams, while along the hilly slopes there are terraced alluvial deposits belonging to the Upper Pleistocene-Holocene and to recent accumulations from landslides (fig. 1).

The tectonic phases of Miocene age that took place in this area of the Sicani Mountains generated a structure formed by the overlap of different stratigraphical-structural units that face the southern quadrants. Such arrangement was further modified by the infra-Messinian and Lower Pleistocene transpressive-type tectonics that generated structures having an E-W and NW-SE direction, respectively, sometimes with remarkable displacements(Catalano & *alii*, 1982). The extensional tectonic phases of Pleistocene age sequentially dissected the structure, whose dislocations are mainly NE-SW oriented (Monteleone & Pipitone, 1991).

In particular, the geomorphological structure is characterised by wide valleys with gentle slopes. Here the outcrops mainly consist of clay and clay-marly rocks. Where the slopes are steep, carbonate and calcarenitic rocks crop out. Areas with gentle to sublevel slopes can be found on the calcarenitic substrata of the St. Margherita Belice plateau belonging to the Wide Upper Terrace (WUT) (Ruggieri & Unti, 1977). The WUT develops at an altitude of about 400 m asl and dates back to 700 ka. This means that it has undergone an uplifting rate of about 0.6 mm/y. This is evidence of neotectonic activity in this part of western Sicily.

The diffusion of prevalent pelitic substrata, mainly the marly clays of Medium-Upper Pleistocene age, helped the development of extensive alteration layers, which are frequently involved in surface landslides of the soil-slip type.

Some of the significant morpho-evolutive processes that delineate and model the landscape are gravity-driven. They may be active or quiescent and may be classified as flows, flow-slips and deep landslides of the DSGD type.

Processes caused by the action of canalised waters are equally intense. This is especially true along the tributaries of the Belice River, and where the soil erodes at a different rate, due to different degrees of erodibility.

THE CALIATA AND SAIAROTTO AREAS

A series of evident morphological irregularities in the north-western sector of the calcarenitic plateau of St. Margherita Belice, near the Caliata area, are related to deep gravitational movements; these movements also involve the Saiarotto area (fig. 2). Evidence of Deep-seated Gravitational Slope Deformations are recognizable in both cases. In fact, in these areas it is possible to distinguish disjointed blocks, more or less prominent scarps, wide landslide terraces, double ridged areas and trenches. Owing to such movement, the calcarenitic blocks underwent a counter tilt of up to 40°. In some cases, these blocks are covered by colluvial deposits of variable thickness. On the top of the tilted bodies, wide trenches frequently appear, while the toe of the collapsed mass in the Caliata area lacks real accumulation (Monteleone & *alii*, 2006).

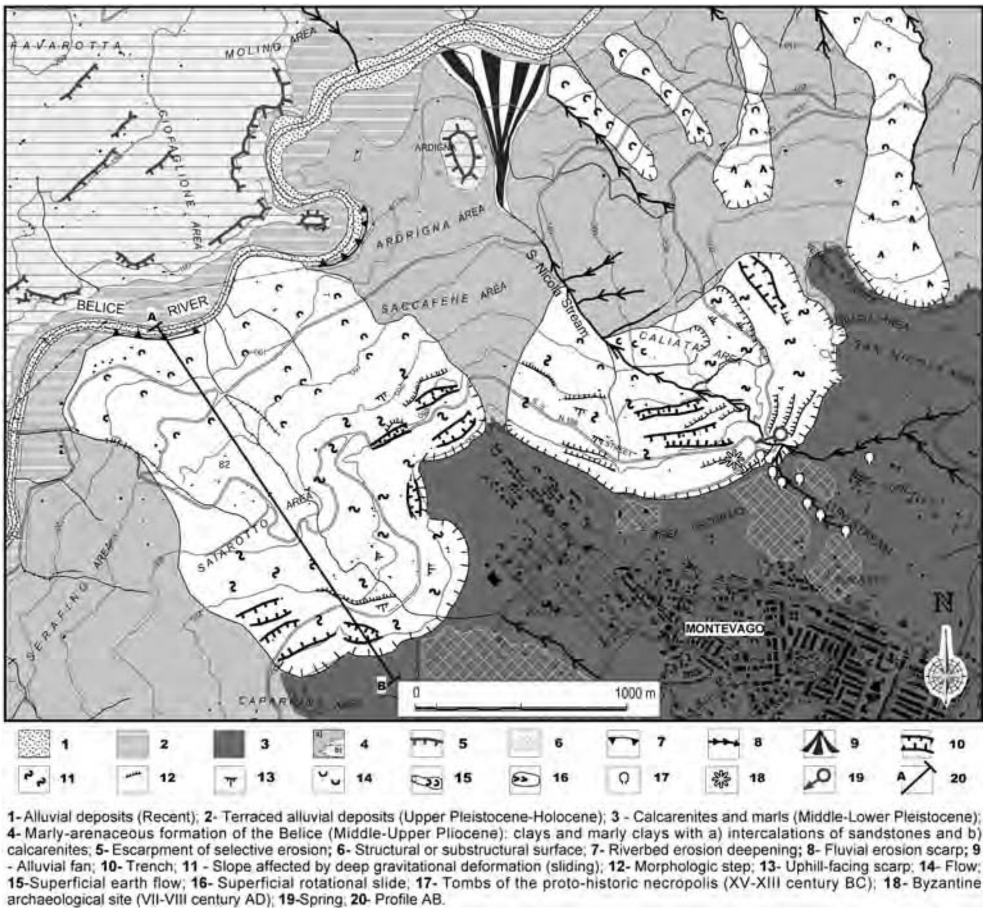


FIG. 2 - Geomorphological map of the study area.

The characteristics of this kind of landslide have been described by many authors who suggested that they are DSGD when the deformation is influenced by factors relative to the mechanical properties of the outcrops. In this study case the outcrop can reach 100 meters, and therefore can be considered as «large landslide».

On the contrary the Saiarotto area instability, which expands for about 2 km with an average thickness 80-100 meters, is a classic example of rotational landslide that evolves in a flow type slide (Sorriso-Valvo, 1984; Sorriso-Valvo & Tansi, 1996). The latter reaches the floodplain of the Belice river, diverting its course towards the right bank (fig. 3).

The rotational slip has produced wide depressions at the foot of these scarps, which have a sublevel pattern due to artificial levelling due to an anthropic action. In general the development of DGSD is very slow, but the presence of scarps, trenches and other forms demonstrate an acceleration in the deformation speed (Dramis, 1984).

These phenomena have not shown any sign of activity since the VII century AD. This is evident from the fact

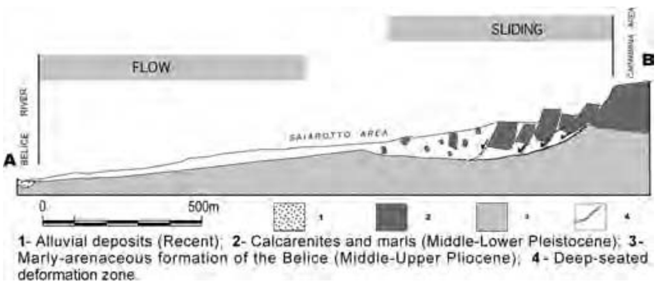


FIG. 3 - Interpretative scheme of the landslide of the Saiarotto area.

that it was chosen as a housing site during the Late-Roman and Byzantine periods (fig. 4). The choice of this site as a residential settlement was undoubtedly made on the presence of a spring, which has a flow of about 5 l/s that reaches the surface through the large disjointed blocks of the landslide.

The present-day form of the main scarp was obtained following the reshaping of its edges caused by the collapse or upset of more or less imposing blocks that were mainly linked to the structural, geomorphological and geotechnical features of the calcarenites and to the seismicity of the area. This involved their retreat at the expense of the overlying plateau.

The main detaching scarp of the deformation of the Caliata area is interrupted by the S. Nicola-Luni stream. This stream deeply carves the biocalcarenites in the lower medium portion of the slope, allowing the outcropping of the marly clay plastic substratum of the marly-arenaceous Belice Formation (Agnesi & Monteleone, 1990).

FIG. 4 - Byzantine acropolis in the Caliata area (VII-VIII century AD).

ANALYSIS OF THE CAUSES OF INSTABILITY

As in the case of geomorphological processes, DSGD are controlled both by geodynamic factors and by structural ones. From time to time these factors determine favorable conditions that trigger these gravitational deformations (Dramis, 1984). The hearth tremors could, for an example, cause an acceleration perpendicular to the slope and trigger or reactivate DSGD. This has often occurred in various areas in Italy (Govi, 1977; Cantalamessa & *alii*, 1981; Cotecchia, 1981).

The factors that triggered these mass landslides, which involved both the Caliata and Saiarotto areas, are to be found: a) in the particular stratigraphical-structural sequence of the substrata, i. e. in the overlapping of lithologies with rigid behaviour on a plastic one, and b) in the geodynamic context in which the area itself is situated.

The high degree of seismicity in the area of the Belice River basin is well known (Monteleone & *alii*, 2009). In fact, the intense tectonic Quaternary uplift associated with these elements, has produced an incision of the fluvial systems, which in this sector of western Sicily, has determined a remarkable increase in the energy of the relief.

To date such instability, we compared the archaeological data with those of historical seismicity. This has enabled us not only to date the onset of these large landslides but also to infer the phases of their evolution.

In particular, archaeological studies carried out in the Caliata area have unearthed, alongside the calcarenitic riverbanks of the S. Nicola-Luni stream, a proto-historic necropolis containing about forty rock tombs belonging to the Sicani period (Castellana, 1990). On the basis of research carried out on the overlying plateau, these tombs (fig. 5) can be dated back to the Thapsos Culture (XV-XIII century BC) of the middle Bronze Age (Castellana, 1990).

The spatial continuity of the tombs is abruptly interrupted just at the main scarp of the Caliata area instability. Here, some of the tombs are no longer in their original

FIG. 5 - Proto-historical necropolis in Luni stream (XV-XIII century BC).

position. This can be clearly seen in the dislocated blocks, which have been rotated and shifted several tens of meters downstream by the landslide. Therefore, the slope instability must be related to a period subsequent to the construction of the necropolis, and certainly after the XIII century BC.

Moreover, another archaeological site is located in correspondence with the sublevel areas, which originated after the collapse of the calcarenitic blocks. Two periods of habitation can be discerned here: one is the Late-Roman and Byzantine period and the other is the Islamic period (Castellana, 1990).

These remains show that the entire landslide had been quiescent since before the establishment of the oldest inhabited settlement (VII-VIII century AD). The Byzantine site is still in its original position, furthermore no disturbed elements in the archaeological stratification, such as evidence of movement or tilting, were found during the excavations. Therefore, we can assume that since then, there has been no significant landslide reactivation, except for localized ones involving regolite, collapse and overturns in the scarp area.

It is therefore possible to ascertain the period in which the deformations affecting the north-western sector of the St. Margherita Belice calcarenitic plateau evolved. In fact, it must have happened between the XIII century BC and the VII century AD.

To better define the kinematics and evolution of these deformations, we have tried to identify the seismic events that triggered the instability during this time interval.

MAIN SEISMIC EVENTS IN WESTERN SICILY

Virgil, in book III of the Aeneid wrote: «*below this mass (Mount Etna) lies the body of the superb Enceladus, and when by pain and laxity he turns over or sighing pants, the mountain and the whole Trinacria shakes*». Apart the epic works of many ancient poets, both Greek and Latin, that draws inspiration from the violent telluric movements that have taken place in Sicily since ancient times, it is sufficient to examine a geological map to get an idea of the intense tectonic activity, both ancient and recent, that has characterised the region. Considering that studies on historical seismicity are useful to better understand the role played by earthquakes in the evolution of ancient civilisations, in our study area we use a similar approach to provide useful information on the particular geomorphological phenomena which are closely related to strong seismic events.

Thanks to instrumental seismology, two seismic events of high intensity are known to have occurred in western Sicily. The first, which had a magnitude of 5.0 (May 1957), hit the areas of St. Margherita Belice, Sambuca di Sicilia, Caltabellotta, Sciacca, Menfi, Montevago, Salaparuta and Gibellina (Monteleone & *alii*, 2000). The second, which had a magnitude of 6.0, hit the Belice Valley in January 1968, killing more than 400 people. It completely destroyed the towns of Gibellina, Poggioreale, Salaparuta, and Montevago, as well as causing heavy damage to several neighbouring towns (Monteleone & *alii*, 2000). Furthermore, there are numerous reports that recount earthquakes that occurred in historical times. In fact, in 1259 an earthquake hit the town of Trapani, while another, which occurred in 1593, involved a large part of western Sicily. In May 1727, an earthquake, followed by numerous strong aftershocks, hit Palermo, Partanna, St. Ninfa, St. Margherita Belice, Villafranca Sicula and Agrigento (Boschi & *alii*, 1997). No other previous information is available.

Since the early years of the 20th century new information on earthquakes has been provided by archaeo-seismology, a discipline based on the assumption that archaeological sources can be particularly useful through the analysis of evidence of destructive events such as earthquakes.

However, it should be emphasised that these two methods (instrumental seismology and archaeo-seismology) are based on two conceptually different time scales: while the written records may refer to the exact moment when the event occurred, the archaeological dating of an event rarely refers to a specific period of time, but more often refers to decades or even centuries.

An archaeo-seismological survey was performed in the area of Selinunte, a Greek colony founded around the first half of the VII century BC. It was destroyed by the Carthaginians in 409 BC and finally abandoned in 250 BC following the Roman conquest. The site was again inhabited by Byzantines during the Middle Ages (Molinari, 1995).

Selinunte was hit by two strong earthquakes in a time-span of several centuries. The first occurred around the IV-III century BC, whereas the second certainly occurred in the Post-Byzantine age and is dated between the VI and the XIII centuries AD (Guidoboni & *alii*, 2002).

The two earthquakes presumably originated from different faults, which were probably located in the open sea, south of the ancient city. Recently (Guidoboni, 2007), the second earthquake has been dated between the VIII and the XII centuries AD.

In the light of these reports, we can hypothesise that the deformations affecting the north-western sector of the St. Margherita Belice plateau were triggered between the IV and III centuries BC, when an earthquake also destroyed the town of Selinunte. The other earthquake documented by archaeological evidence, which occurred between the VIII and the XII centuries AD, seems not to have remobilized the original landslide. This is demonstrated by the absence of disturbance in the archaeological remains of the Caliata area, which is true for both the site of Late-Roman and Byzantine age and for the Islamic site.

CONCLUSIONS

The presence of particular litho-stratigraphic and geological-structural arrangements are certainly responsible for the evolution of the north-western slopes of the St. Margherita Belice plateau. This massive gravitational phenomena can be classified as a Deep-seated Gravitational Slope Deformation. Such movements are favoured by the stratigraphic overlap of Pleistocene calcarenitic rocks onto the underlying plastic lithologies of the Medium-Upper Pliocene.

If this configuration can be considered as predisposing to such an evolution of the slopes, the element that caused it must be linked to the high seismicity of the study area. In fact, the numerous violent earthquakes that have occurred here since ancient times are witness to this, as is the increase in the energy of the relief, which is a consequence of the Quaternary tectonic uplift and the morphometric conditions of the slopes involved in the enormous landslides we surveyed.

These bodies appear to be undergoing an inactive phase: a quiescence that was reached in the VII century AD. In fact activity is limited to modest phenomena of collapse along the main scarps of the landslide and on its surface. Both the archaeological evidence present in the Caliata area and the archaeo-seismology studies carried out in Selinunte were important to the dating of the start and the end of the movements. In particular, the archaeological data allowed us to place the evolution of these landslides in the period between the XIII century BC and the VII century AD. The archaeological approach allowed us to identify the disastrous earthquake that in the IV-III centuries BC, destroyed the town of Selinunte as well as the landslide trigger. The absence of disturbing elements in the plane-altimetrical disposition of the archaeological site of Caliata helped us to realize that the earthquakes that have since struck the area have not caused a resumption of movement. We can therefore state that the area has been inactive and has found long-lasting stability since before the VII century AD.

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(Ms. received 30 April 2010; accepted 30 October 2010)