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LANDSLIDE AND FLOOD HAZARD FROM THE LAGO SIRINO, BASILICATA, ITALY

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ABSTRACT

The Sirino lake or Lago Sirino in Basilicata, Italy, is possibly a disaster waiting to happen, in some ways similar to the situation at Vaiont in the months and years leading up to the landslide there in October, 1963, with both precursor movements and expert opinion dismissed and not acted upon.

The lake is retained in a basin, which is entirely contained within a fault-bounded and displaced block of Jurassic-age rocks, thought to be Schisti Selice. The lake is fed by precipitation on the adjacent mountainside (Monte Sirino), which rises to approximately 2000 m a.s.l. A significant proportion of the precipitation is snow melt. The natural dam retaining the lake moves from time to time, creating fissures down which some of the lake disappears. Lake water level is usually maintained by spring via a stream, and this water also infiltrates the rock mass, and later issues downslope in a series of copious springs that feed a further series of streams. These downslope streams are exploited for water supply and irrigation. This lake is approximately circular in plan with a diameter of about 200 m, and a maximum depth of about 12m. The maximum lake level is controlled by an overflow weir and discharge tunnel.

Downslope of the natural dam and the lake which it impounds, there are numerous small settlements, and at a distance of 2.5 km and some 370-400 m lower in elevation, there is the town of Nemoli which has over 1600 inhabitants. Any breach of the natural dam would lead to a flood down the natural channel to Nemoli and beyond. While the town centre is not directly threatened, there are numerous houses on the edge of the town that are. Around the rim of the lake, which despite its potential for mayhem, is rather attractive, is an array of houses, hotels, restaurants and bars, as the local community relies on the existence of the lake and its considerable visual attractions for a lively tourist business.

This paper describes the geological setting of the lake, with some accounts of past movements and water losses, but in the absence of detailed subsurface investigations, the short description that follows is mainly geomorphological in character and no further prognosis of the behaviour of this system is possible.

Key words: *lake, sinkholes, springs, seepage erosion, landslides, flood hazard*

INTRODUCTION

Landslides and floods are endemic throughout Europe, but the Italian peninsula is particularly susceptible due to its climate, geology and tectonic setting. It is widely recognised that severe consequences are associated with landslides that release the contents of natural lakes or artificial reservoirs, the latter including those that retain mine waste with a high water content.

While the most well-known and catastrophic example of modern times of the release of water from a reservoir is, of course, the example of the Vaiont dam (which retained a storage reservoir for the Piave hydroelectric scheme) and the mountain landslide that pushed much of the reservoir contents over the dam without breaching it, other examples, even in Italy have occurred. For example, the 1972 collapse of an earth embankment retaining tailings from a fluorite mine in the Val di Stava caused significant loss of life and material damage.

Historically, lakes retained behind valley-blocking landslides have overtopped and eroded the natural dam away, for example the landslide at Borta (Cavallin & Martinis, 1974), and so a number of such landslide dams have been provided with control works to enable the normal river discharge to flow safely over the dam. A modern example is the Val Pola landslide, and historical examples is at Alleghe (De Biasio *et alii*, 2000). Other seiches causing dam overtopping include the case of the reservoir at Fedaia, caused by a landslide of ice and debris from the Marmolada Glacier. As at Vaiont, the dam survived the event. Schuster (1983) describes numerous examples of landslide dams; Schuster (2000) describes many instances of dams built on landslides. The head drop across a landslide dam is commonly utilised for hydroelectric generation, with examples in the Dolomites (Venetian Pre Alps) given by Coppola & Bromhead (2008).

Natural lakes sometimes release large volumes of water. This is common in the case of glacial lakes, which may be dammed by ice or moraine. In October 1994, a partial collapse of a moraine along the edge of the Luggye Lake in the Bhutan Himalaya released a glacial outburst flood (Nayar, 2009) that swept away a farming community with their livestock, crops, and homes. The death toll of 21 would have been much higher in a more densely populated region.

Occasionally, lakes are impounded in the hollows of an existing landslide. A major example is given by Hancox & Perrin (1994): their example of the Green Lake landslide exhibits several of the phenomena above: it slid into an existing lake, it also formed a landslide dam, and a lake also formed on top of the 26 km^3 of landslide deposits. Landslide ponds or lakes are at risk of being released through movements of the landslide, particularly where such movements open up pathways via joints and fissures in the landslide mass. The Lago Sirino is believed to be one such lake.

It is believed that the lake has formed on top of a landslide that occurred at the end of the last ice age, or the end of the Würm, between about 11,000 and 9,000 years ago. In such landslides, the masses are structurally chaotic, and even today are currently in a state of limiting equilibrium, as a result of post-glacial changes in slope morphology caused by river and other erosion. They have one or more shear surfaces often at depths greater than 40 m from ground level and their longitudinal profiles sometimes extend kilometres from their source. Commonplace movements are slow and of small displacement, but significant reactivation leads to a devastating collapse of the slope. Most affected are towns and urban areas on the summits of the mountains, but settlements below the source area are at risk of being overwhelmed.

In southern Italy, there are few high-altitude lakes, largely because of climatic factors, and this the risks of sudden emptying of such lakes are not widely experienced, in contrast to the processes of vulcanism, earthquakes and landslides which are regularly experienced. However, springs are common at mid slope, especially in the area under consideration, and the hydrogeology at Sirino has produced a series of clean, clear spings of potable water that provides a feed for the lake.

LOCATION AND GEOLOGY

The Lago Sirino or Sirino Lake (Fig. 1) is a small lake located at the foot of the western slope of Mount Sirino but at an altitude of 783 m above sea level, and below the lake the hillside continues to slope steeply. The lake and the settlements that surround it are part of the Lucanian Apennines National Park.

According to Scandone (1972), the lake lies in a small basin excavated in glacial debris deposits composed of purplish red silt-clay mixed with calcareous

Fig. 1 - Location map of the Italian Peninsula, indicating the Basilicata Regio in the south together with the location of the Lago Sirino and the town of Nemoli

and siliceous breccias which rest on the Lagonegro siliceous shale unit. The western side of M. Sirino is composed of Mesozoic and Cenozoic soils of different paleogeographic domains structurally affected by the Apennine tectonic phase I (Pliocene). The soils belong to the oldest unit (Lagonegro) (Scandone, 1967, 1973), from the oldest to the most recent we have (see Fig. 2. which shows the structural geology):

- Monte Facito Formation - Lower-middle Triassic (MF);
- Limestone with flint - Upper Triassic (CS);
- Siliceous shale - Upper Triassic - Upper Jurassic (SS);
- Flysch Galestrino - Upper Jurassic - Lower Cretaceous (G).

(Letters in this list are a key to the structural geology map).

The most recent rocks outcropping on the site belong to the Liguride unit and are represented by part of the Crete Nere (CN) Formation which is Cretaceous - Middle Eocene (Banardi *et alii*, 1988).

All these units are strongly tectonized, often unstructured with clastic fragments e.g. the siliceous shale (SS) and flysch Galestrino (G).

The phase of compression in the genesis of the Apennines (Doglioni *et alii*, 1996; Patacca & Scandone, 2001), is still causing shear deformations along strike-slip faults with the oldest oriented NE-SW and along NW-SE thrust faults (Coppola, 1993).

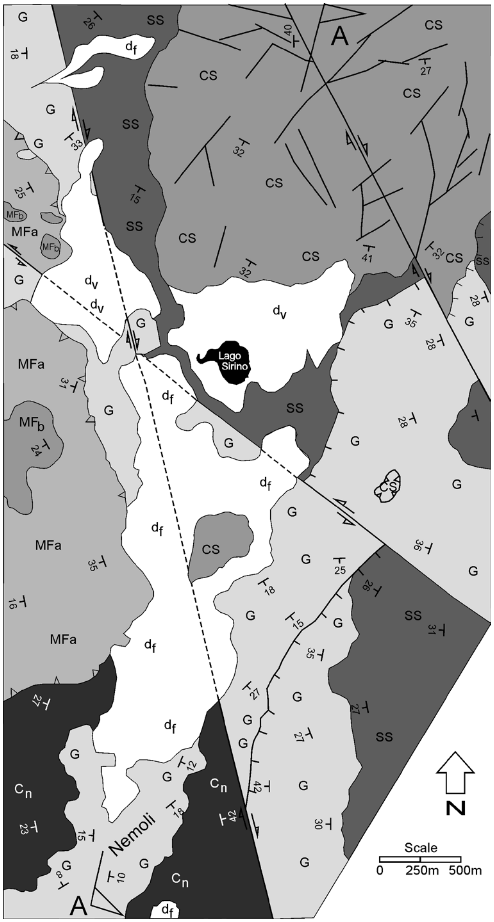

Fig. 2 - Structural-geological map of the area around Lago Sirino and the town of Nemoli. Line of section Marked AA with arrows showing view direction Legend: ***Solid lines****: large displacement transcurrent fault associated with the recent stress field, with arrows showing left or right lateral movement.* ***Dashed line****: position of fault not apparent at surface. Tags denote normal fault, Vee tags denote overthrust.fault. Dip angles shown conventionally*

ORIGINS OF THE LAKE

It is widely and perhaps correctly believed that the lake is a natural feature, although one that has been somewhat landscaped into today's form. It is fed by a series of springs, the discharge from which flows into the lake via a small channel which enlarges into a sort of canal before entering the lake at about its deepest point. For this paper, the Authors have also adopted the conventional explanation that the lake is a natural feature.

Local folklore has a fanciful (and religious) explanation for the origins of the lake, in which the lake formed as divine retribution for peasants working in their farms instead of attending church. An interesting point about the myth is that it is unequivocal that there was a time when the lake did not exist. The south eastern end of the lake is dammed by a very small ridge, along which the main road through the settlement passes, and on which there are two crossroads. This ridge separates the lake from the head of a Vee-shaped and therefore stream-cut valley, down which the overflow spillway channel runs, and the overflow from the lake passes underneath the road in a small tunnel. Some distance down the valley, small springs emerge, which are used inter alia to feed a fish farm. Given that the width of the road and the two intersections are modern constructs, the original ridge must have been smaller still, in which case it is tempting to ascribe the whole lake to an unrecorded damming of the course of a stream at some time in the past. Moreover, the

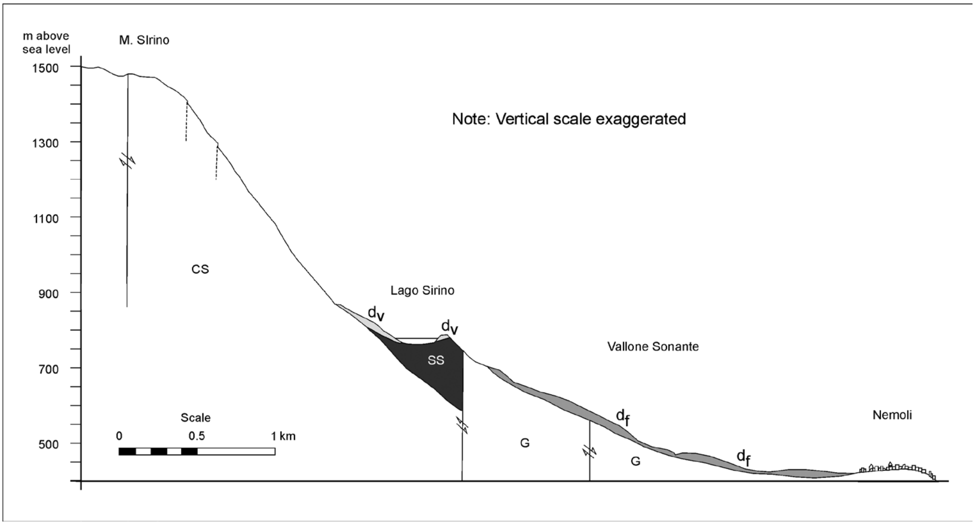

Fig. 3 - Cross section AA: M. Sirino - Lago Sirino - Nemoli

spring-fed stream that enters the lake turns by more than 90° at a very imposing ridge that also supports the road at the northern end of the lake.

This issue could be resolved by putting a borehole in the road, or perhaps sampling the lake-bottom sediments. However, even if this speculation were to be proved true, then the situation regarding hazard would remain unchanged, although the lake would lose its status as a natural feature. One of the Authors (EB) is convinced that the lake is at least in part man-made, and if in the UK, would be covered by the Reservoirs Safety Act of 1975 (the latest in a series of laws starting in 1930) which would certainly cover it as Lago Sirino's volume is significantly greater than the 25,000 m^3 qualifying volume.

HAZARD SITUATION

The principal perceived hazard is that the reservoir contents could be released, travelling down one of the two main ravines in the general direction of the town of Nemoli. The lake elevation is c 783 m asl, and the town, which is about 2.5 km distant, lies at about 421m asl (Fig. 3). As the plan of the lake is roughly elliptical, with a length (NW-SE) of 325 m and width (NE-SW) of about 260 m, and its maximum depth is around 12 m in the central part, on average, therefore, the lake when full contains 1,014,000 m^3 of water or less. It undergoes large variations of the water table during the year due to the imbalance between the influx, from a set of local springs. These springs are located in the debris slope just upstream of the reservoir and to the NNW. Water exits the lake through a variety of processes including evaporation, seepage, some outflow through a tunnel and spillway at very high water levels, and more worryingly water losses through occasional ephemeral sinkholes (Fig. 4) that for centuries have opened and subsequently closed in the bottom of the lake. When a sinkhole opens, the lake level falls rapidly. These sinkholes form due to tension in the rock mass, and are an indication of the precarious state of stability of the whole slope. An example of one of these sinkholes was reported to have occurred on the 24th July 2011 (Lovoi, 2011), although in the photograph accompanying that article this sinkhole occurred above lake level in the bank. More serious is the case where they occur in the bed of the lake, and evidence of such submerged sinkholes was seen by the Authors in July 2012.

Three other springs are situated downslope of the lake in the direction of a left-lateral NW-SE strike-slip fault which skirts the southern limit of the lake consists of siliceous shales of the formation of red siliceous shales. They are perennial (or continuous) springs with flow rates that are fairly constant over time, although when one of the sinkholes opens in the lake floor, the discharge from the springs increases correspondingly. Discharge from the springs is collected and used for water supply purposes down valley: at one time the discharge from these springs also drove a water mill.

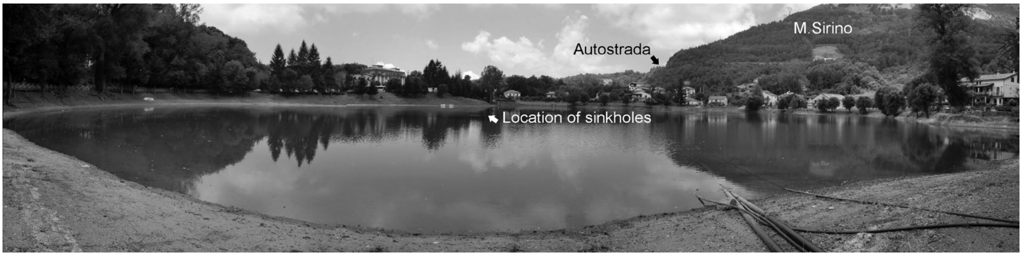

Fig. 4 - Composite photo panorama of the lake viewed from the SW (in vicinity of overflow structure). Pipes in foreground are used to feed a fish farm

SEEPAGE EROSION

The mechanism of seepage erosion has been reviewed usefully by Crosta & Di Prisco (1999), who observe that instabilities induced by seepage erosion have been reported in a wide variety of geological settings and in a range of different geomaterials. This runs counter to the commonly-held (but incorrect) belief that seepage erosion is a phenomenon solely of loose coarse silts and fine sands, although these materials are of course, highly susceptible. Hence there is no guarantee that the rock types beneath the Lago Sirino are not susceptible, At Lago Sirino, the problem of seepage erosion is compounded by the postulated movements of the landslide block, and the opening of sinkholes and associated passages through the rock mass that have the potential to greatly accelerate the process under the pertinent conditions. Moreover, where exposed in a road cutting immediately south of the lake, and therefore at a lower elevation, the rocks are observed to be strongly jointed and fissured, with fissure flow likely to dominate the permeability of the rock mass. Any seepage erosion induced increase in flow could mobilize the landslide debris in the slopes below the Lago Sirino and above Nemoli.

It is fortunate that the precipitation catchment of the lake is small, and that it is fed mainly from springs with generally constant discharge, and the maximum lake level is held by the outlet works so that the low embankment at the SE corner of the lake cannot be overtopped, and that the hydraulic gradients will not therefore be surcharged by an unexpected rise in water levels in the lake.

LANDSLIDE MOVEMENTS ABOVE NEMOLI

In the mapping (Fig. 2) landslide deposits are denoted in a light colour, and these include both currently active landslides (d_f) and ancient slope deposits (d_v). Many landslides in historic times have affected the slope in the vicinity of the reservoir as described by Carrara *et alii* (1985) that affected the source and at the same time, the North marginal part of the lake.

Apart from some very small slides NNW of the lake, the main landslide is mapped as extending into the town of Nemoli at its toe, and extending upslope in two (or possibly three) separate source areas comparatively close to the lake. Indeed, the two main head zones are situated in valley features that appear to be associated with the lake, and in the case of the westernmost head, to within some tens of metres of the lake. This landslide system has a history of movement, especially in the area of its NW part, where within the last decade, shearing movements of around 15 m were experienced. In the spring of 2005, the hilly area adjacent to the W side of the lake has been involved in a massive translational movement cutting the municipal roadway, carrying it downstream and isolating the farms to the west of the lake.

Specific slope instability risks to the lake from this landslide system (marked on Fig. 2 as the main slide area, and labelled d_f) are the potential for it to move such that it:

(a) unloads the toe of the slope holding up the lake, or
(b) chokes off the lower springs, permitting piezometric heads in the slope to rise.

In both cases, destabilization of the landslide debris short of outright collapse could increase the frequency of sinkhole occurrences in the lake basin. The shape of this deposit of landslide debris indicates in general terms the fall line for landsliding, pointing in the direction of the town centre.

PRECURSOR MOVEMENTS

Perhaps more worrying is the thought that the wide range of deformation types could be a series of precursor movements for a much larger failure. These events are, of course, self-evident after the event, but they are rarely identified *a priori*. When specifically sought out by instrumentation or remote observation, it is found that precursor movements are related to pre-failure ground strains (Kalaugher *et alii*, 2000) in materials that have different stress-strain characteristics and different degrees of mobilization of their shear strength. Particularly as failure is approached, these differences in strain lead to differential movements, and in some cases, to the release of minor failures, or at the very least to cracking and fissuring of the ground.

While under constant conditions, the frequency of precursor events increases as a large failure develops (Fukuzono, 1990), in a landscape that experiences seismicity, a single shaking event can instantly cause collapse if the stability reserve is small.

CONCLUSIONS

The Lago Sirino is an unusual feature in Basilicata, and exhibits many of the signs indicative of both local and overall instability. The geological setting is one that provides little security against instability and consequently engenders little confidence in the mind of the experienced professional applied geologist. It merits proper investigation and careful treatment as a potentially hazardous landscape feature.

As there have been a suite of minor instabilities to date, the case of the Lago Sirino must be taken as having possibly already indicated the probability of a future large-scale failure by this range of precursor events.

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