# Cover Collapse Sinkhole Risk in the Cagliari province (Sardinia, Italy): location, genesis and forecasting

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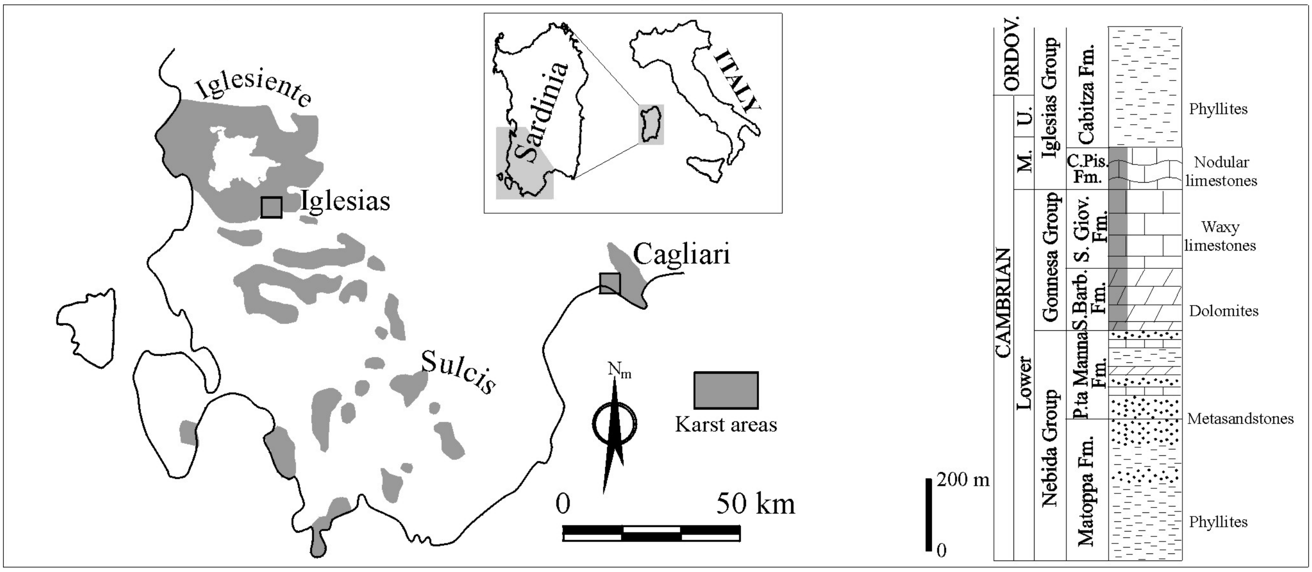
## ABSTRACT
During the last 10 years many cases of karst collapse have been reported in the western part of the province of Cagliari (Sardinia, Italy). A historical study of these phenomena has pointed out several areas in which these hazards have frequently occurred and where the risks of cover collapse sinkhole formation seems to be much higher. Direct and indirect surveys have enabled to formulate a hypothesis for the genesis of most of these hazards, leading to a forecasting method for their formation and their location. This study tries to explain the genesis of these cover collapse sinkholes, to define their most probable location and can help local planners to avoid hazards due to these phenomena in the future.

## RIASSUNTO
Negli ultimi 10 anni diversi casi di subsidenza carsica sono stati riportati nella parte occidentale della provincia di Cagliari (Sardegna, Italia). Uno studio storico di questi fenomeni ha portato a definire le aree in cui questi dissesti si sono verificati con maggiore incidenza e dove, quindi, esiste un rischio maggiore per la formazione di queste doline di crollo. Studi diretti ed indiretti hanno consentito di formulare una ipotesi di formazione per la maggior parte di questi crolli, portando anche ad un modello di previsione per la formazione e la localizzazione di questi dissesti. Questo studio cerca di spiegare la genesi di queste doline di crollo, di definire la loro più probabile localizzazione e può aiutare gli amministratori a prevenire che questi dissesti avvengano nel futuro.

## INTRODUCTION
In the past years the Western part of the Cagliari Province has been afflicted by cover collapse sinkholes, especially during the rainy periods. These phenomena normally don't cause serious damage, due to the fact that they occur in scarcely dense populated areas, but could damage some important infrastructures such as railways, roads and buildings with significant economical impact. The study of these hazards leads to a better understanding of the phenomenon, and can help local planners avoiding disasters in the future.

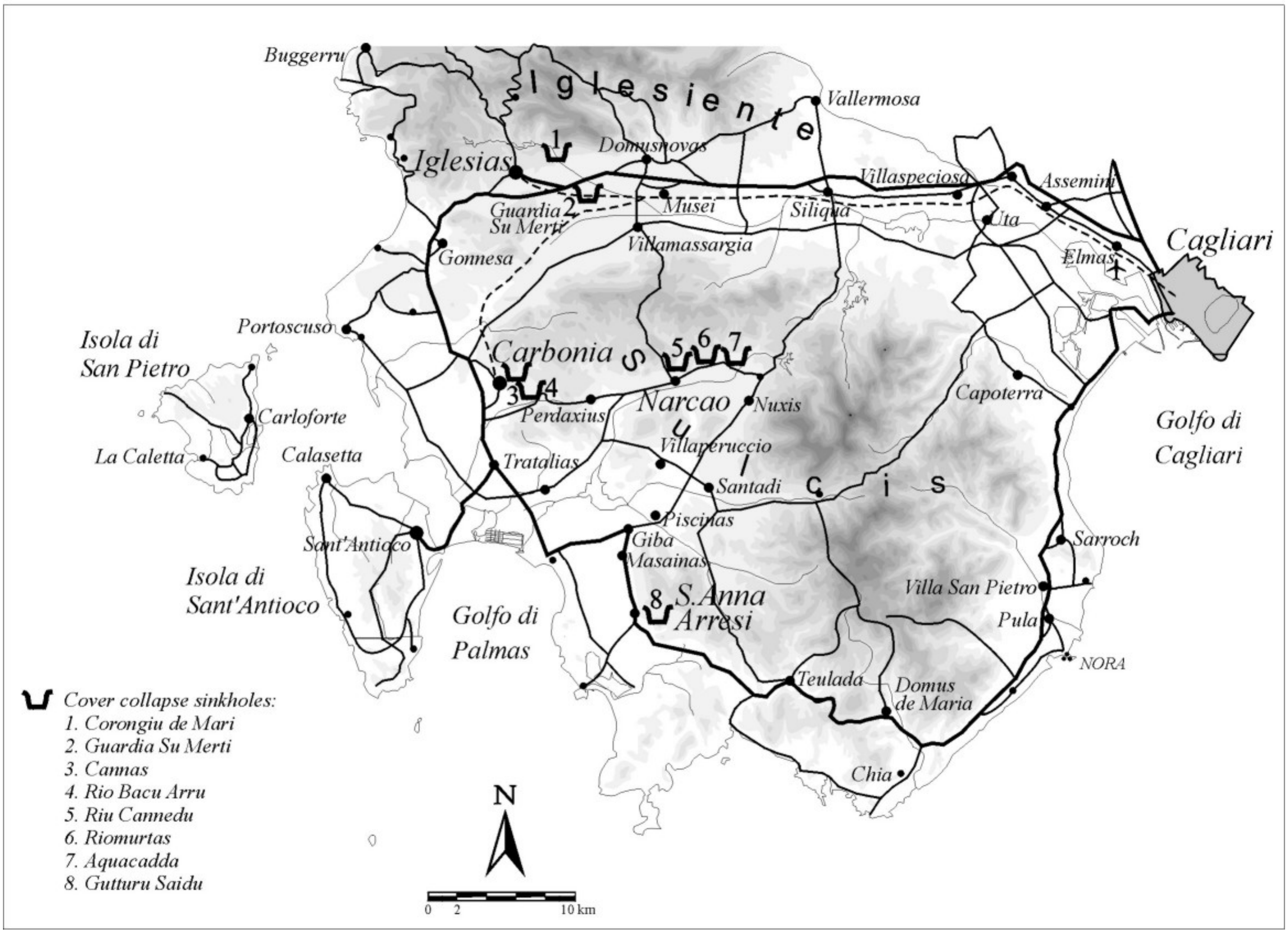
## REGIONAL GEOLOGY
The Western part of Cagliari province is characterised by lithologies covering a lapse of time going from Palaeozoic to Quaternary: among these Palaeozoic sequences are the most interesting. This sedimentary succession starts with the monotonous siltitic and arenaceous sediments of the Bithia Formation (Precambrian?) followed by a thick sequence of Cambrian rocks (CIVITA et al. 1983).
From a stratigraphic point of view this Cambrian succession is divided in three major Groups: Nebida Group, Gonnesa Group and Iglesias Group (Figure 1) (BECHSTADT & BONI, 1996).
The Nebida Group (Lower Cambrian) is composed of delta and coastal sediments and is divided in two Formations: the Matoppa Formation (sandstones and shales) and the Punta Manna Formation (oolithic limestones and calcareous sandstones followed by sandstones with carbonatic fossiliferous lenses and strata).
The Gonnesa Group (Lower-Middle Cambrian) is characterised by typically carbonatic deep-sea sediments and is divided in two Formations according to the trilobite content: the Santa Barbara Formation (mainly dolomitised rocks) and the San Giovanni

Figure 1 - Schematic geological section of the Cambrian-Ordovician sequence and karst areas of the western province of Cagliari



Formation (intensely karstified waxy limestones).

Figure 2 - Cover collapse sinkholes in Cagliari province




The Iglesias Group (Middle Cambrian-Lower Ordovician) is divided in two Formations: the Campo Pisano Formation, constituted of nodular limestones, followed by a thick succession of shales of the Cabitza Formation.
The Cambrian carbonatic rocks contain deposits of galena, sphalerite, pyrite, barite of sedimentary genesis, intensely exploited since prehistory with emphasis during Pisan occupation and in the past 150 years. These carbonatic rocks have been involved in several karstic cycles since Ordovician, and constitute the most important aquifer of the region, confined by the impervious sandstones at the bottom and by the slates at the top.
After a long period of continentality and an important tectonic phase (*Fase Sarda*) the Sea returns to occupy this area with the deposition of the Ordovician conglomerates (*Puddinga*), followed by Silurian and Devonian sediments. After the Hercynian orogenesis a long continental period starts in the region (Carboniferous-Middle Trias), only shortly interrupted in Middle-Triassic and in Paleocene-Eocene times.

## COVER COLLAPSE SINKHOLE DEVELOPMENT

### LOCATION

The cover collapse sinkholes have occurred in different regions of Cagliari province. Among these the most sensible areas for sinkhole development are Corongiu de Mari and Guardia su Merti (Iglesias), Riu Cannedu, Riomurtas and Acquacadda (Narcao), Rio Cannas and Rio Bacu Arru (Carbonia), and Gutturu Saidu (Sant'Anna Arresi) (Figure 2).

### DESCRIPTION

Close to Iglesias, at Corongiu de Mari, several collapses occurred on the bottom of the sediment filled valley of Riu Arrali in the mid 90's, after an intense rainy period. These sinkholes had a diameter of approximately 1 meter and had depths of up to 3 meters. No limestone could be seen on the bottom of these pits that were entirely contained in the fluviatile deposits (Photo 2).
Near Guardia Su Merti, close to the railway, in the winter of 1999 an impressive cover collapse sinkhole formed in the continental Cixerri deposits. Its width was 15 meters for a depth of 16, but no limestone could be found on the bottom (Photo 1). Close by, at only 40 meters away, in a much older and tinier collapse, Cambrian limestone is almost outcropping.
Near Narcao, along the course of the Rio Cannedu several collapses have formed during the past ten years, especially after periods of heavy rainfall. Two among these is correlated to a subterranean cave, while the other two major sinkholes are prevalently imbedded in a sedimentary cover and reach the underneath limestone at depths of respectively 2 and 3 meters.
Near the village of Riomurtas instead collapses occur since more than ten years. In a wide depression on the contact between Cambrian phyllites and limestones many cover collapse sinkholes have formed and are continuously forming especially after rainy periods. In one of these a temporary river disappears.
Close to Acquacadda, in the mining area of Sa Marchesa, also nearby a little natural channel, other sinkholes have generated, most of these in fluviatile deposits. Close by a minor collapse shows dolomite rock at shallow depth.
Along the valleys of Rio Cannas and Rio Baccu Arru (Carbonia) several cover collapse sinkholes hosted in recent sediments have formed and are continuously filled with waste and detrital

material. One of these depressions had dimensions of more than 400 cubic

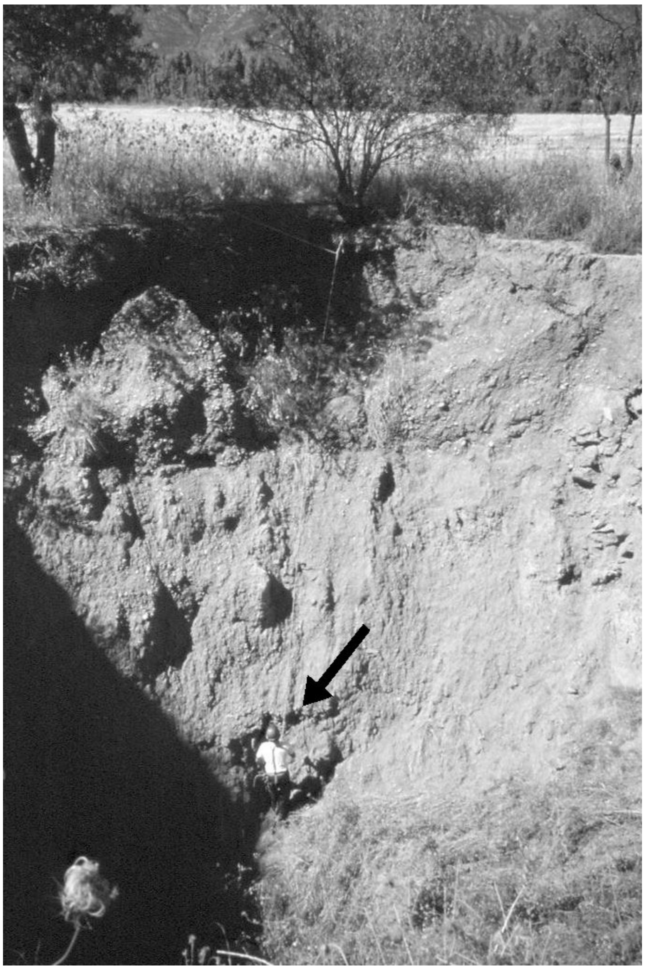


Photo 1: The Guardia Su Merti Cover collapse sinkhole

meters, while the other reached approximately 150 and 60 cubic meters. In neither of both limestone is outcropping, even though, considering the geological context and the vicinity of Cambrian carbonatic rocks, its depth should be relatively shallow. Both have formed during wintertime, respectively in December and in March 1996.

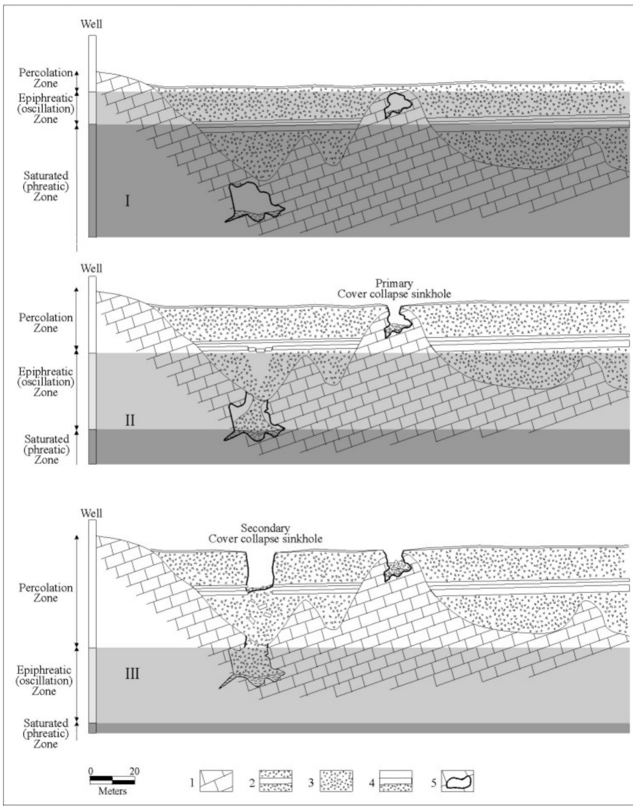
Near Sant'Anna Arresi, in the beginning of the 90's subsidence phenomena have started to appear at less than a km of the village, along the road that brings to Gutturu Saidu. In 1996, after heavy rains, part of the road was devoured by a great collapse and many families were completely isolated for some weeks. These cover collapse sinkholes are correlated to the Cambrian dolomitic limestones that outcrop along the road and are surely present at shallow depth underneath the alluvial plain.

**GENESIS**

The study of the cover collapse sinkholes in the province of Cagliari has enabled the analysis of their spatial and temporal distribution and to relate these data with the local geological and structural situation.

Most of the cover collapse sinkholes observed in the epikarstic zone are of secondary origin and only few are related to primary collapse. The genesis of these last can be explained by the collapsing of the roof of a karstic void (cave) in the upper part of a karst aquifer (epikarstic zone) (Figure 3). Natural collapsing caused by dissolution of limestone is extremely difficult to observe in a Man's time frame. The most common cover collapse sinkholes are related to the transport of sediment in existing major karren and/or karstic tunnels and are generally triggered by the oscillation of the water table and only occasionally by the collapse of a karstic void at greater depth. The downward movement of sediments into the epikarstic zone is termed ravelling (BECK 1988).

Figura 3 - Schematic example of formation of cover collapse sinkhole (Guardia Su Merti, Iglesias): 1. Cambrian limestones; 2. Hard sandstones (Cixerri Formation, Oligocene); 3. Loose sediments (Cixerri Form., Oligocene)); 4. Quaternary deposits (Holocene); 5. Karstic voids.




In general, cover collapse sinkhole formation is enhanced by four major factors: the decreasing of buoyant support of water, the increasing of the gradient of water velocity (and thus ravelling), the water-level fluctuations and the induced recharge of the aquifer.

It is quite clear that these factors, and thus the major part of the hazards, are correlated to human activities, especially to extensive pumping of aquifers and to modification of natural water runoff patterns (construction of channels, deviation of water flows, etc.) (DREW & HÖTZL 1999).

In fact, many of the sinkholes have developed close to pumping stations (Riomurtas, Cannas, Gutturu Saidu, Corongiu de Mari, Guardia Su Merti) or not far from metallic mines in which pumping of water was performed to enable cultivation of lead-zinc ores (Aquacadda, Mont'Ega-Riu Cannedu).

The installation of pumping boreholes in fact, create a forced circulation of subterranean water and solid transport, causing the ravelling and thus enlarging existing voids in loose sediments, especially above karst aquifers. This emptying of the voids, together with the lowering of the phreatic level, enhance ravelling and subterranean collapsing and during this process, in particular if the embedding sediment is dry and more solid, an air-bubble can be formed above the void. By further ravelling and collapsing of this air-bubble, generally during wet periods, a cover collapse sinkhole suddenly appears on the surface. In these sinkholes the karstic origin is never really clear, because no carbonatic rocks crop out (Figure 3). In the case in which the sinkhole forms by gradual lowering at the land surface it is termed a "raveling sinkhole" (WHITE et al. 1995).

The effective collapsing of a sediment package covering a void depends on different factors: the weight of the covering soil and its physical characteristics, the depth of the roof of the void and its width (JIANYI & JIAN 1987).

Photo 2 - Cover collapse sinkhole at Corongiu de Mari

If the void is deeper than 10 meters collapse will only occur if its dimension is large or after many years of ravelling. Anyhow, most of the sinkholes are deep less than 5 meters, with a presumable depth of the carbonatic substrate (thus the voids) of less than 10 meters.

But in cases where collapsing should normally not occur in natural conditions, hazard is caused especially by oscillation of the water table. In fact, the movement of water in an alluvial aquifer causes solid transport and therefore the modification of soil structure, diminuishing the solidity of the entire sedimentary cover. The withdrawal of the water table by itself, due to extensive pumping, would not have great consequences, if not in the case in which heavy rains cause the fluctuation of its level in the vertical range between roof of the void and covering sediments. These movements of water generate subterranean solid transport and loss of cohesion in the soil, causing collapse. These phenomena are not the result of sudden and extraordinary events (heavy rains), but reflect a long-during state of water level oscillation and thus subterranean erosion, causing collapse even several years after the beginning of pumping.

## FORECASTING

Most cases of cover collapse sinkhole formation are related to human activities, especially exploitation of subsurface and subterranean aquifers, and occur in covered karst regions. The historical analysis of these phenomena together with the geological knowledge of the Iglesiente-Sulcis area allow to determine the most probable areas where cover subsidence sinkholes can occur in the future. Most of these areas are described in this work.

Cover collapse sinkholes form in areas of high infiltration rates, where downward erosion of covering sediment into pre-existing karstic voids is enhanced. This means that collapses prevalently occur in low areas (valleys and low plains) covering the epikarstic zone, often close to little streams where concentrated water flows during heavy rains. The presence of pumping stations or drainage systems can trigger collapsing, while high construction density enhances concentrated infiltration and turbulent flow.

## FINAL CONSIDERATIONS

Cover collapse sinkholes have formed in several parts of Southwest Sardinia in the past ten years and seem always related to well determined climatic conditions and confined to specific geological and morphological situations. Most of the cover collapse sinkholes studied in this work have been triggered by human activities, especially water table lowering by the exploitation of the karstic aquifer or by mining activities.

Construction and settlement should be avoided in the areas that already have been interested by collapsing phenomena in order to prevent human losses and material damage in the future.

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## REFERENCES

BECHSTADT, T. & M. BONI 1996. Sedimentological, stratigraphical and ore deposits field guide of the autochtonous Cambro-Ordovician of South western Sardinia. *Mem. Descr. Carta Geol. Ital.* 48: 1-390.

BECK, B. F. 1988. Environmental and engineering effects of sinkhloes--the processes behind the problems. *Proc. 21st Congress Internat. Assoc. Hydrogeol., Karst Hydrogeology and Karst environment Protection, 10-15 oct. 1988, Guilin, China*: 17-29.

CIVITA, M.; COCOZZA, T.; FORTI, P.; PERNA, G.; TURI, B. 1983. Idrogeologia del bacino minerario dell'Iglesiente (Sardegna sud occidentale). *Mem. Ist. Naz. Spel*., S.2, v.2: 137 p.

DREW, D.; HÖTZL, H. (Eds.) 1999. *Karst Hydrogeology and Human Activities. Impacts, Consequences and Implications*. Balkema, Rotterdam, 322 p.

JIANYI, T; JIAN, C. 1987. Preliminary study of karst collapse. Forecast method. *Endins*, 13: 99-104.

WHITE, W.B.; CULVER, D.C.; HERMAN, J.S.; KANE, T.C.; MYLROIE, J.E. 1995. Karst Lands. *American Scientist*, 83: 450-459.