

# Potential rockfalls induced by bioclastesis phenomena: the role of roots in fracture evolution

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**ABSTRACT:** This work focuses on the role of roots in the propagation of fracture in calcarenitic rocks that may generate rockfalls. Here a study is presented on the geometry of the fractures in calcarenitic rock levels of the east flank of the ravine of Matera as consequence of the action of fig roots. The study shows that a number of fractures, some of them are very recent, which are modifying the flanks, damaging the archaeological heritage and precluding access to the ravine may be attributed to bioclastesis due to the action of fig roots. Therefore, identifying the open fractures and their potential triggers is important for planning a strategy of preservation of this peculiar landscape.

**Keywords:** Bioclastesis; Rockfalls; Fractures; fig roots

## 1 INTRODUCTION

In the rupestrian environment the uncontrolled growth of native vegetation plays an increasing role in conditioning slope evolution: the roots of shrubs and trees—primarily the fig plants (*Ficus carica*)—penetrate along planes of weakness and discontinuity, exerting mechanical pressure that widens fractures and progressively reduces the cohesion of rock blocks. This phenomenon, known as *bioclastesis*, acts as a predisposing and, in some cases, triggering factor in rockfall processes. The present study analyzes the impact of bioclastesis, with particular reference to fracture propagation and a specific case of incipient collapse observed along the eastern flank of the Ravina of Matera. This phenomenon, although particularly evident and of large scale, can be considered representative of other, less conspicuous but potentially critical situations.

The *ravines* of Murge Plateau represent peculiar deep-incision landforms of polygenic origin, where the interaction between tectonic factors and erosional processes has shaped a unique landscape. The main configuration of these valley forms is closely connected to structural lineaments (faults and extensional fractures), along which Quaternary tectonic activity favored the opening and subsequent evolution of deep incisions (Doglioni, 2019). Once the structural framework was established, morphology was progressively reshaped by hydro-erosive processes: concentrated runoff and ephemeral torrential flows carved into the Plio-Pleistocene calcarenitic deposits, which unconformably overlie the Mesozoic limestones of the Apulian Platform, giving the *ravines* their characteristic geomorphological architecture.

The slopes, steep and inherently unstable, host a remarkable rock-hewn heritage of exceptional historical and archaeological value, with settlements and religious sites inhabited since the Neolithic and enriched with evidence from the medieval period. However, the stability of these contexts is today threatened by both natural and anthropogenic processes that accelerate their degradation.

The study focused on the Bioclastesis phenomena as an agent of the geomorphological evolution and was carried out through an integrated approach employing on-site survey and high-resolution geomatic techniques, UAV-based photogrammetric surveys and terrestrial laser scanning (TLS), capable of providing a detailed geometric characterization of fractures and instability patterns. The results offer an innovative contribution to understanding degradation mechanisms and to the planning of conservation and risk mitigation measures.

## 2 GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The Ravina of Matera is part of the geological framework of the Apulian foreland, located along the southwestern margin of the Murge Plateau, where its transitions toward the Bradanic Trough domain, a foredeep basin that developed in response to the Apennine orogeny. Structurally, the area is characterized by an arrangement of uplifted and fractured blocks, resulting from the compressional and subsequent extensional tectonic phases that affected the foreland during the Quaternary (Doglioni et al., 1994; Doglioni & Simeone, 2019). The ravines, deep and often complexly articulated incisions, generally follow a predominant NNW–SSE orientation

and are controlled by extensional fault systems and fracture networks that initiated and guided the subsequent valley incision processes.

From a stratigraphic point of view, the slopes of the Gravina exhibit the typical succession of the Murge margin. At the base crop out the Altamura Limestones (Upper Cretaceous), massive and well-cemented lithotypes forming the carbonate basement of the Apulian Platform. Overlying these, in transgressive contact, are the Plio-Pleistocene Calcareni di Gravina Formation, composed of weakly cemented calcareous sands with interbedded coarse or loose levels (Cherubini et al., 1996). The contact surface between the limestones and calcarenites is marked by a distinct stratigraphic hiatus, reflecting the interruption of sedimentation and the subsequent infilling of the Bradanic foredeep basin.

Geomorphologically, the Ravina of Matera presents as a narrow, deeply incised valley, locally exceeding 100 m in depth. The steep, often sub-vertical slopes display a complex combination of structural and erosional features, including morphological terraces, collapse scarps, artificial cavities, and subvertical fractures. Its evolution has been primarily driven by Quaternary uplift processes, which promoted incision by ephemeral watercourses responsible for the progressive headward erosion of the upper calcarenitic levels and the deepening of the valley. This morphological configuration—closely linked to the geological–structural setting and the weak cementation of the calcarenites—makes the slopes particularly susceptible to gravitational instability phenomena, further intensified by anthropogenic and biological factors.

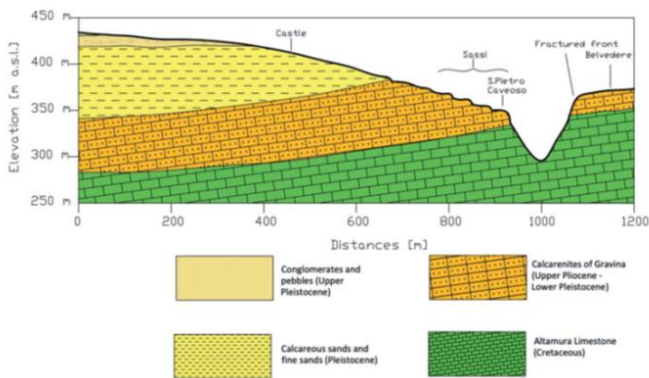


Figure 1. Simplified cross section of the Ravina of Matera (After Doglioni, 2019)

### 3 BIOCLASTESIS AND ROLE OF ROOT

Bioclastesis refers to the set of fracturing and rock degradation processes induced by biological activity, playing a particularly significant role in contexts characterized by poorly cemented lithotypes and pre-existing structural discontinuities, such as the Plio-Pleistocene Gravina calcareous Sandstones (calcareni) Formation. These materials, weakly cohesive and stratigraphically resting unconformably upon the Cretaceous

limestones of the Apulian Platform (Doglioni & Simone, 2019), are especially vulnerable to root penetration and biochemical weathering processes—an effect further enhanced by the intense erosional dynamics still active in the area. Among the various mechanisms involved, the most well-known and widely documented in the literature is root wedging—the wedge-like action exerted by roots penetrating pre-existing fractures and discontinuities, progressively widening them and predisposing rock blocks to gravitational detachment (Pawlik et al., 2016; Viles, 2022). This biomechanical process operates in close connection with other factors, including moisture retention within fissures, microbial activity, and the secretion of organic acids by the rhizosphere, all of which accelerate mineral dissolution and the weakening of discontinuity surfaces (Finlay et al., 2020; Mustoe, 2018).

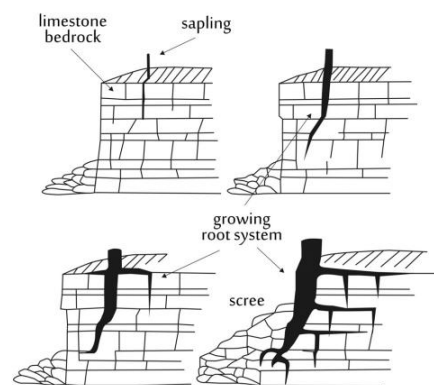


Figure 2. Rock cliff development under biomechanical impact of growing tree roots (Pawlik et al., 2016)

An emblematic case in Mediterranean landscapes is represented by the fig tree (*Ficus carica*), a species capable of colonizing vertical rock faces with long and robust roots that exploit lines of weakness within the calcarenitic mass to propagate fractures and trigger localized detachments. The literature reports that species with aggressive root architectures are able to exert pressures exceeding several MPa during growth—values comparable to or even higher than the tensile strength of soft rocks (Pawlik, 2013; Nie et al., 2017).

Evidence collected by Gabet & Mudd (2010) indicates that root-induced fracturing processes can act in a manner similar to physical thermal fatigue phenomena, generating a network of critical fractures that slowly evolve until causing macroscopic rupture. The radial growth of roots within fissures, exerting pressures on the order of 1–2 MPa (Coutts, 1983; Denny, 1988), is particularly critical in low-cohesion materials, where tensile strength generally ranges between 0.5 and 2 MPa (Bonomo, Leucci & Masini, 2017). For this case history, the Gravina calcarenites, the rock formation in which the phenomenon occurred, are characterized by mechanical strength values that vary widely depending on the degree of cementation. The tensile strength value, according to Lupo et al. (2019), tends to

be between 0.5 and 1.5 MPa, which is perfectly consistent with the data in the literature that provide evidence of this phenomenon.

The phenomenon of bioclastesis is today further amplified by the abandonment of traditional agricultural practices (terracing, rock-cut cultivation) and pastoral activities, which in the past contributed to controlling the spread of spontaneous vegetation. The lack of maintenance has led to an increase in spontaneous root colonization along the slopes, thereby enhancing the biological contribution to instability processes.

#### 4 INVESTIGATIONS AND PRELIMINARY RESULTS

From a methodological point of view, the understanding of bioclastesis processes can be strongly supported by high-resolution investigation tools. In this regard, the use of 3D geomatic techniques (UAV photogrammetry, Structure-from-Motion, terrestrial laser scanning) is becoming a fundamental approach for documenting fracture propagation, measuring millimetric block displacements, and monitoring the evolution of rupture surfaces over time (Westoby et al., 2018; Di Luccio et al., 2023) (Figure 3).

The critical analysis of multitemporal point clouds helps to discriminate deformations related to purely geomechanical factors from those induced by biological processes, thereby improving the understanding of the contribution of bioclastesis phenomena to the development of instability mechanisms. A remarkable case in this sense concerns a large potential instability phenomenon detected along a slope on the right flank of the Ravine of Matera.

To document the ongoing processes, an aerial photogrammetric survey using UAV and terrestrial laser scanner acquisitions were carried out, producing a point cloud of 54 million points with a resolution of 6 mm. This approach made it possible to reconstruct in detail the geometry of a long fracture (approximately 15–20 m), strongly inclined and with a significant aperture, whose presence was detected unexpectedly and suddenly, and which has been attributed to the pressure exerted by the roots of fig trees (Figure 4). The survey carried out with the laser scanner made it possible to reconstruct the orientation of the fracture (Figure 4), but there are no indication of the exact direction of the root, which, being located inside the rock mass, cannot survived (Figure 4). However, it is certain that the roots follow the plane of rupture, even in several directions, but all contained within the plane of rupture.

The observations seem to indicate that the fracture represents the evolution of small pre-existing discontinuities related to slope decompression, which have been enlarged, giving rise to a single fracture progressively widened by root action. The presence of various types of collapses is well documented along the entire slope, and

the study of this case provides evidence that, in this type of instability phenomenon, bioclastesis processes can play a particularly significant role

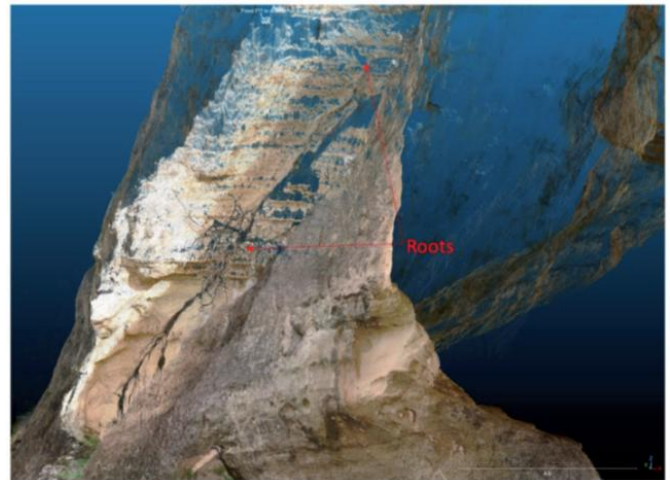


Figure 3. High-resolution 3D point cloud of the eastern wall of the Ravina of Matera, obtained through UAV photogrammetric survey



Figure 4. Fig tree affecting the calcarenitic fracture

#### 5 DISCUSSION AND CONCLUSIONS

This study highlighted how bioclastesis processes constitute a determining factor in the morphological evolution and stability of the rock slopes of the Murgian *gravine*, particularly in lithological contexts characterized by weakly cemented calcarenites.

Bioclastesis represents a progressive degradation factor of rock slopes, whose impact on geotechnical safety and on the preservation of the rock-hewn heritage is still largely underestimated. Although the role of roots in the superficial stability of soils has not been widely investigated in the literature, their destabilizing effects on lithified substrates, particularly on weakly cemented rocks such as the Plio-Pleistocene calcarenites, deserve specific consideration. From an engineering and civil protection perspective, the presence of shrub or tree vegetation on rock faces represents a vulnerability factor that must be carefully assessed. Roots penetrating joints or along the margins of anthropogenic cavities can, over time, reduce the structural stability of blocks and promote the localized collapse of portions of the rock face.

In historical rock-hewn systems, such as those of the *Ravine* of Matera or Salento cliffs, these phenomena represent a combined risk to public safety and the conservation of cultural heritage.

The combined analysis of geomorphological data, field observations, and high-resolution three-dimensional surveys has made it possible to recognize the active role of tree and shrub roots in fracture propagation, loss of material cohesion, and triggering of gravitational instability processes. The biomechanical action of roots adds to biochemical and hydroclimatic processes, creating a synergy among alteration, moisture, and dissolution of carbonate binders that accelerates substrate degradation. This interaction manifests itself especially in anthropized rock-hewn environments, where the abandonment of maintenance practices and the proliferation of invasive plant species increase the vulnerability of slopes and underground cavities.

From a methodological point of view, the integration of 3D geomatic surveys (UAV photogrammetry, terrestrial LiDAR) with geomechanical investigations and laboratory tests on lithological samples has proven to be an essential tool for the quantitative characterization of bioclastesis. Multitemporal point clouds make it possible to detect fracture aperture with millimetric precision and to correlate deformation with the presence and development of roots, thus providing a solid basis for the numerical modeling of instability processes.

The implications of these results are significant not only for geological risk assessment but also for the conservation of rock-hewn heritage and land management planning. It is therefore necessary that the biological component be integrated into slope stability analysis models and monitoring protocols, recognizing bioclastesis as an active geotechnical factor.

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