Engineering Geology 99 (2008) 147–159

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Geomorphological hazards related to deep dissolution phenomena in the Western Italian Alps: Distribution, assessment and interaction with human activities

W. Alberto [a], M. Giardino [a,*], G. Martinotti [a], D. Tiranti [b]

[a] Earth Sciences Department, University of Torino, Italy
[b] ARPA Piemonte, Area Previsione e Monitoraggio Ambientale, Italy

ARTICLE INFO

Article history:
Accepted 14 November 2007
Available online 21 February 2008

Keywords:
Dissolution
Deep-seated Gravitational Slope Deformation
Quaternary
Western Alps
Italy

ABSTRACT

Deep dissolution affects great part of soluble rocks (e.g. gypsum and anhydrite) of the Western Italian Alps. The related superficial phenomena (sinkholes, gravity-induced processes and a local worsening of geomechanical rock properties) are not limited to typical karsts landscape and cause slope instability also affecting populated sites and infrastructures. The paper aims to describe general characteristic of dissolution phenomena, to interpret their conditioning factors and evolutionary stages and to assess possible hazards due to their superficial effects.

The search for evidences of deep dissolution leads to the selection of representative sites in the central part of the Western Italian Alps (Piemonte and Valle d'Aosta Region). Detailed geological and geomorphological studies have been used to classify the selected sites by type, size and variable state of activity. Very different evolutionary stages of dissolution phenomena have been interpreted by comparison of case-studies: some are early “embryonic”; others are more evolved, up to typical sinkholes, or even remodelled by other phenomena. Some cases show an extreme complexity in the interactions between corrosion phenomena and other geomorphic processes: slope deformations, from one side, and karst, fluvial and glacial phenomena, to the other. A wide range of movement rates on slope instabilities induced by deep dissolution have been estimated by topographic and geomorphic data. Geochemical data on removed rocks by dissolution indicate 0.4 mm/year values for local subsidence. Historical and technical data indicate low frequency of major dissolution-induced collapses, but highlight widespread damages to tunnels, roads and buildings, especially along slopes.

1. Introduction

The underground and superficial effects of dissolution processes affecting soluble rocks (gypsum/anhydrites, limestone, dolomites and marble) are very enhanced, well known and studied especially in those regions (Klimchouk et al., 1996–1997; Gutiérrez et al., 2001; Johnson, 2005) where gypsum rocky masses outcrop. If large carbonate and sulphate rocks masses outcrop, fairly well developed cave systems and a related karst geomorphological landscape can generally be found, such as in the “native” region of the “karst” term, the Carso plateau between Slovenia and North-Eastern Italy. Independent of the presence of a typical karst landscape and of large outcropping soluble rock masses, the karsts evolutionary stages, following base level height changes, can lead to a significant demolishing of the deep rocky masses, by means of accelerated corrosion (Gutiérrez, 2005). Several factors can favour greater water “aggressiveness” towards certain parts of the karstland. Lithology, climate and geomorphology are the key-factors in the control of solution rates: from these follow a series of variables (temperature and precipitation, effective runoff, permeability of soil and rocks, chemical composition of water) able to enhance deep dissolution effects and related superficial phenomena, such as sinkholes, gravity-induced processes and a local worsening of geomechanical rock properties (Johnson, 2005).

In areas characterized by dissolution-related phenomena, man has been living with a dynamic karst environment for centuries or thousand of years, even to extremes such as the town of Calatayud in the Iberian Range (Gutiérrez, 1996, 2005; Gutiérrez-Santolalla et al., 2005); here, the long-term karstification of deep-seated Tertiary gypsum formations caused sin- to post-sedimentary subsidence phenomena affecting at first the Neogene infillings of the Calatayud graben and later the Quaternary alluvial top sediments. The still on-going dissolution phenomena are not only having large superficial “direct” effects on natural and anthropogenic elements, such as fluvial channels and irrigation ditches, roads and buildings: they also cause frequent slope instabilities along the Calatayud scarp.

In the Western Italian Alps, the superficial effects of deep dissolution were rarely dealt with researchers, even if carbonate (especially limestone and dolomite) and sulphate rocks are well represented in the alpine structure. Because of the glacial Pleistocene environmental dynamics in the alpine valleys and their intense post-glacial erosion, the sulphate rocks rarely outcrop, but they can be found at depth along the main tectonic contacts.

* Corresponding author.
E-mail address: marco.giardino@unito.it (M. Giardino).

0013-7952/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.enggeo.2007.11.016

Several evidences of deep dissolution in the Western Italian Alps are presented below. Their geomorphological evidences have been described by type, size and variable state of activity; their evolutionary stages and conditioning factors have been interpreted, based on a combination of local geological, structural and geomorphological features. In a mountain environment whose landforms are rapidly changing the activity of corrosion/dissolution phenomena gives rise to a large series of possible interactions with human activities and structures. Moreover, in such high-relief areas, often the dissolution is followed by slope gravitational processes (landslides and Deep-seated Gravitational Slope Deformations — DSGSD, Dramis and Sorriso-Valvo, 1994). In some cases dissolution can be interpreted as the primary cause of slope instabilities, in others it amplifies their effects (White, 1988). There are different factors conditioning the activity of DSGSD (Bonnard et al., 2004), including geological factors (Varnes et al., 1989), tectonic factors, such as the characteristic and the orientation of the discontinuities (Dramis and Sorriso-Valvo, 1994; Bovis and Evans, 1996; Agliardi et al., 2001), glacial erosion and retreat (Soldati et al., 2004), but only few studies concerning the importance of deep dissolution have been carried out (Wu, 2003).

The evaluation of chemical/physical features (in particular chemical composition and flow) can help in quantitative knowledge of volume removed by underground dissolution; the volume datum can be translated in subsidence ratio, knowing the size of involved area by means of studies on water origin and circulation.

2. Geographical, physical and climatic setting

The Western Alps are located at the boundary between Italy and France. The Italian part of the alpine territory is comprised in the Piemonte and Valle d'Aosta regions.

From a geomorphological point of view, the arch-shaped Western Alps show an asymmetric transversal cross-section: the internal (Italian) flank is shorter and steeper than the external one. In the Piemonte sector the front range shows a very important step from plains (elevation 200÷300 m asl) to the mountain relieves (elevation from 1000 m asl up to 4800 m asl, in the axial sector of the range).

Alpine valleys are carved radially from the Western Po plain; major valley systems (Susa, Lanzo, Sesia, Ossola) are deeply incised in bedrock and their slopes often overcomes 3000 m of relief. The incision of the major alpine valleys can be dated back to the Messinian (Bini et al., 1978) or pre-Pliocene (Staub, 1934): a regressive continental sequence of Middle Pliocene to Lower Pleistocene age ("Villafranchiano" Auct.) lies on top of marine deposits of Pliocene age which filled the terminal part of the valleys (Carraro, 1996). In the Quaternary age, these alpine valleys were repeatedly occupied by wide glaciers. The repeated glacial pulsations modelled the alpine valleys, resulting in the present regional setting. Locally, Holocene gravitational and fluvial/torrential processes deeply modified glacial landforms and deposits, causing widespread instability phenomena (Soldati et al., 2006).

From a geological point of view, deep geophysical investigations in the Western Alps (Roure et al., 1990, 1996; Pfiffner et al., 1997) evidenced a complex double-verging structure. Three main structural sectors (Fig. 1), partly corresponding to paleogeographic realms of the classic alpine literature, have been distinguished:

– An internal sector, belonging to the upper plate of the collisional system ("Southalpine" domain) made by a Hercynian and pre-Hercynian basement with lower continental crust and upper mantle rocks.
– An external sector, belonging to the lower plate of the collisional system ("European" foreland area: Helvetic–Dauphinois domains of literature) made by Hercynian intrusive massifs (e.g. Mont Blanc), Mesozoic sedimentary covers and detrital deposits (flysch).
– An axial sector bounded by two crustal scale discontinuities, corresponding to the Pennidic frontal thrust externally and to the Insubric Front internally (Malusà, 2004). This complex sector is made by Hercynian and pre-Hercynian continental crust rocks, Hercynian metasedimentary covers, oceanic lithosphere sections, cover units from the ocean facing continental edges and orogenic flysch units, including important calcschists units of uncertain paleogeographic and stratigraphic position.

In the Western Alps, at scale of the whole chain, a complex kinematic framework (involving extensional, contractional and strike-slip tectonics) dominates in the internal zones, whereas a coeval contractional kinematics affects the external zones (Malusà, 2004).

Along major tectonic contacts of the Western Alps, several units of carbonate/sulphate rocks are distributed as discontinuous masses, whose geomorphological evidences are enhanced by differential weathering with respect to other massive or schistose metamorphic non-soluble rocks.

Climatic conditions of the Western Alps have a great influence on distribution and intensity of weathering phenomena, differentially affecting soluble and non-soluble rocks. The present-day climatic setting is conditioned by moderate to low oceanic/marine moisture supply; 900 mm of mean annual precipitation indicates a dryer environment with respect to Northern and Eastern Alpine regions. Xeric conditions are concentrated along major valleys and intermontane basins (down to 500 mm/year in the Central Aosta Valley; 700 mm/year in the upper Susa Valley). Average low intensity precipitation is indicated by mean values not exceeding 20 mm/day in the Susa Valley, whose "sublittoral" pluviometric regime shows a summer primary minimum, a fall primary maximum and a spring secondary maximum. This is in contrast with "pre-Alpine" pluviometric regime of surrounding part of the Western Alps showing a winter primary minimum, a spring primary maximum and a fall secondary maximum (Biancotti and Bovo, 1998).

Due to this combination of the geological, geomorphological and climatic conditions, deep dissolution phenomena are concentrated in certain sectors of the central part of the Italian Western Alps (Piemonte and Valle d'Aosta region; Fig. 2). Dissolution sites have different characteristics: geographical location, elevation and position with respect to geomorphological features, relationships to soluble rock masses and land use.

A few locations show enhanced superficial effects due to widespread occurrence of outcropping soluble rocks (e.g. Seguret and Thuras Valley sites), many others have distinctive elements of deep dissolution phenomena without outcropping soluble rocks (e.g. Quart and Villeneuve sites). Most of the dissolution sites have been located and studied due to the occurrence of damaged man-made structures or to the set up of researches and technical investigations for infrastructure projects and town planning.

In this study dissolution sites have been selected in order to be representative at best of the "diversity" of dissolution phenomena, expressed by natural distinctive elements (deep and/or superficial) and in consequence, by "anthropogenic" features. The selected sites (listed in Table 1) are the base for a comparative description of "characterizing factors" of dissolution phenomena.

3. Soluble rocks in the Western Italian Alps

3.1. Distribution

In the Western Italian Alps, soluble lithotypes can be split into two large families; carbonate rocks (limestone and dolostones) and sulphate rocks (gypsum and anhydrites). These have highly differing geo-mechanical and solubility features.

Carbonate rocks create many massifs (Chaberton, Gondran, Rochebrune, Gran Roc, etc). The main examples found along the French–Italian border from the head of the Susa Valley to South (Fig. 2).