Chapter II.4

GYPSUM KARST OF FRANCE

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Many small and scattered areas of gypsum karst are present in France. They occur in the plains and plateaux (Paris, Lorraine, Provence) as well as in the mountains, especially the Alps (Fig. 1). Typical gypsum karst landforms are well developed and widespread, but underground cavities are scarce, despite much exploration and the apparent existence of subsurface waterflow. The Alps and Provence contain the largest karstic areas.

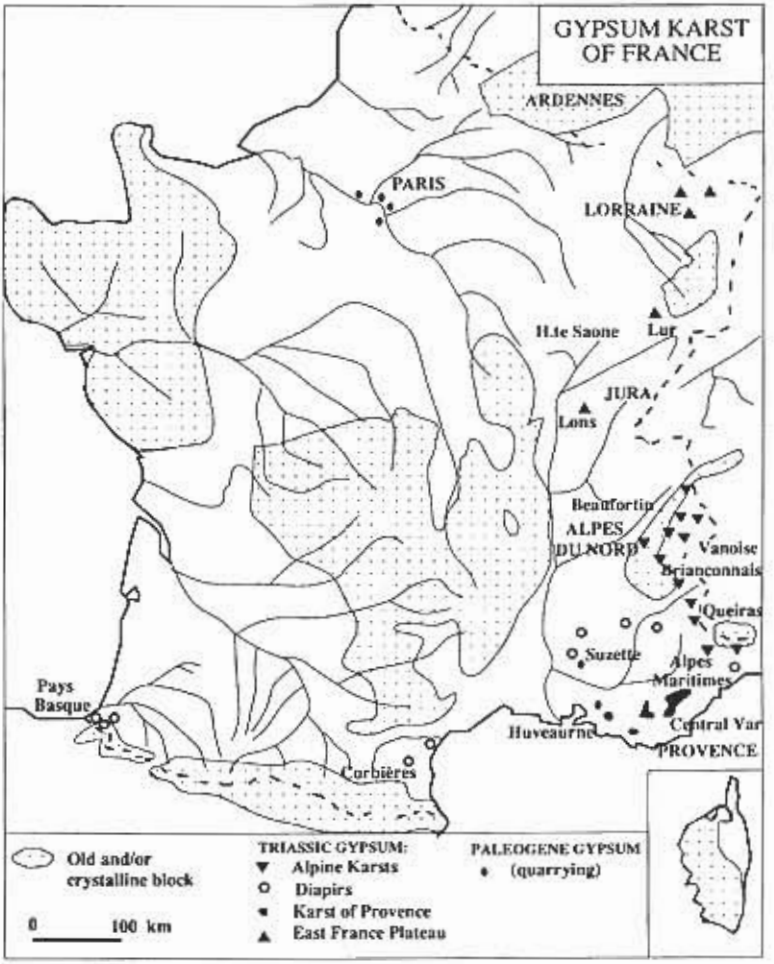

Fig. 1. Gypsum karst in France (After Karstologia 25, 1995).

Table

Significant gypsum caves in France

Name	Valley	District	Altitude (m)	Length (m)	Depth (m)
Gébroulaz	Tarentaise	Les Allues	2630	375	-50
Champ Bernard	Tarentaise	Granier	1200	525	-46
Sourcedes Poux	Tarentaise	St Bon	1700	110	0
Sourcedes Planes	Tarentaise	Pralognan	1650	210	10
Les 14 chapeaux	Maurienne	Bramans	1275	130	-
La Balme du Chatel	Maurienne	Sollières	1330	405	-35
Tunnel Col du Galibier	Maurienne	Valloire	2556	300	0

1. Gypsum karst in the northern Alps

A large number of small gypsum areas, mainly less than 10km^2, are scattered throughout the French Alps, mainly in the eastern part of the northern Alps. The total area of Alpine gypsum karst is estimated to be almost 400km^2, concentrated in the districts of Savoie and near Briancon. The highest point is Roc du Soufre (2,940m) in the upper Vallon du Fruit, near the Gebroulaz Glacier (Méribel, Savoie). Figure 2 shows the location of these areas. Gypsum formed by the hydration of Alpine Triassic anhydrite crops out at the surface in many places; the gypsum is commonly fine-grained and forms thick beds of white rock. The thickness of gypsum varies from one to fifty metres, but most of the rock is poorly exposed. Three main lithological facies are identified: 1) saccharoidal (sugar-like) gypsum, 2) pure thin-bedded gypsum and, 3) a mixed variety with layers of gypsum dolomite and cellular dolomite ("cargneules"). Discontinuous and linear outcrops of gypsum/anhydrite lie along the fronts of the Alpine thrust sheets and on the basement blocks (Beaufortin).

In high mountain environments (generally above 2,000m) the main gypsum karst areas are represented by a superficial karstic landscape with doline fields, karren and depressions.

In the lower mountains and valleys, gypsum karst is commonly covered by surface deposits of glacial, fluvial or colluvial origin. These areas have landforms including large dolines, closed depressions and ponds. Generally, the dolines are tens of metres in diameter, but the largest depressions, such as Mone and Saulces near Mont Blanc de Pralognan (2,677m) are 300-400m long, 100-200m wide and 30-40m deep. There are three sinkholes and resurgences at Combe de la Nova, Gebroulaz and Vallon des Avals de Courchevel. A most important landform is the small poljé, 1km long, that forms the Valoire depression near Mont-Cenis. The road tunnel of Galibier (2,556m) shows that the high gypsum karst is drained in a diffuse way, a result of its porosity and degree of fracturing. However, no important caves have been discovered by speleologists, just some located close to the surface.

These landforms can be related to the very recent de-glaciation morphogenesis, which began some 16,000 years ago, but which was more recent in the upper Alpine valleys.

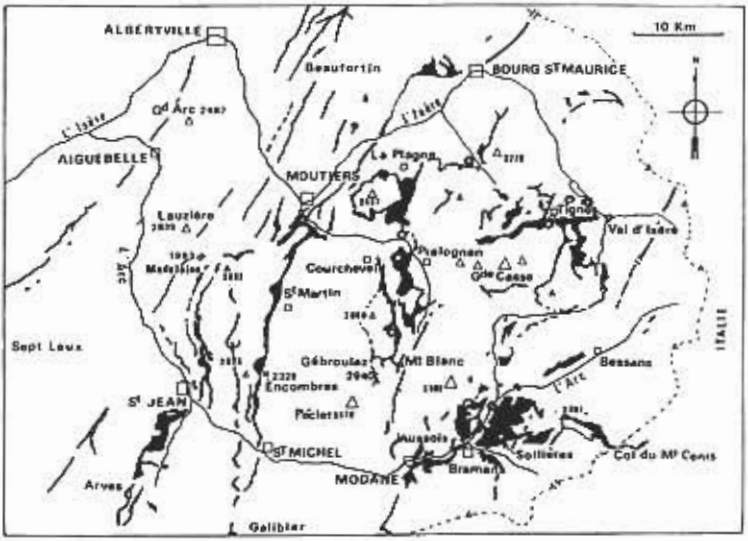

Fig. 2. Gypsum karst in the Northern Alps (black areas) and important springs (white stars).

The climate is temperate in the valleys and cold in the high mountains, where the 0oC mean annual air temperature isotherm occurs at 2,400m. The annual precipitation is moderate, ranging from 800mm in the valleys to 1,200-1,500mm on the summits. The mean annual run-off is estimated to be 1,000mm/year at 2,500m, where the snow cover lasts from October until June. Underground water flow is thought to be significant only in a few areas, such as Tignes and Gebroulaz. In the gypsum mountain areas two broad kinds of flow have been identified:

1) Sub-surface and temporary flow, active during the summer.

2) An extensive permanent and slow deep flow through both the gypsum and anhydrite layers.

The latter flow type feeds perennial karstic springs in the lower parts of the valleys of Daille de Val d'Isère (mean discharge 300L/s and mean mineralization >1,000ms/cm), Gouille de Tignes and Sources de la vallée des Avals. High mineralization and a constant flow demonstrate the existence of a local aquifer with considerable storage. High flow occurs in late spring and early summer when the snow is actively melting. In the high mountains (above 2,000m) the mean total karstic denudation is estimated to be 1mm/year. This increases to 4mm on the bare gypsum outcrops at 2,500m and up to 6mm/year in the artificial and well-drained lacustrine area of Mont Cenis. Chardon (1996) has suggested a scheme involving dissolution for the formation and geomorphological evolution of gypsum domes.

2. Gypsum karst in Provence

In Provence there is a large surface area of gypsum karst, but karstic dissolution phenomena are scattered and random. The Triassic gypsum layers occur at two levels: 1) as gypsum lenses within clay layers of Keuper facies and, 2) as gypsum with halite in the middle Triassic strata beneath the Muschelkalk layer. These deposits were deformed by the Pyreneo-Provenceal (Eocene) tectonic movements and have developed disharmonic folds both at the bases of the thrust planes and in diapiric domes.

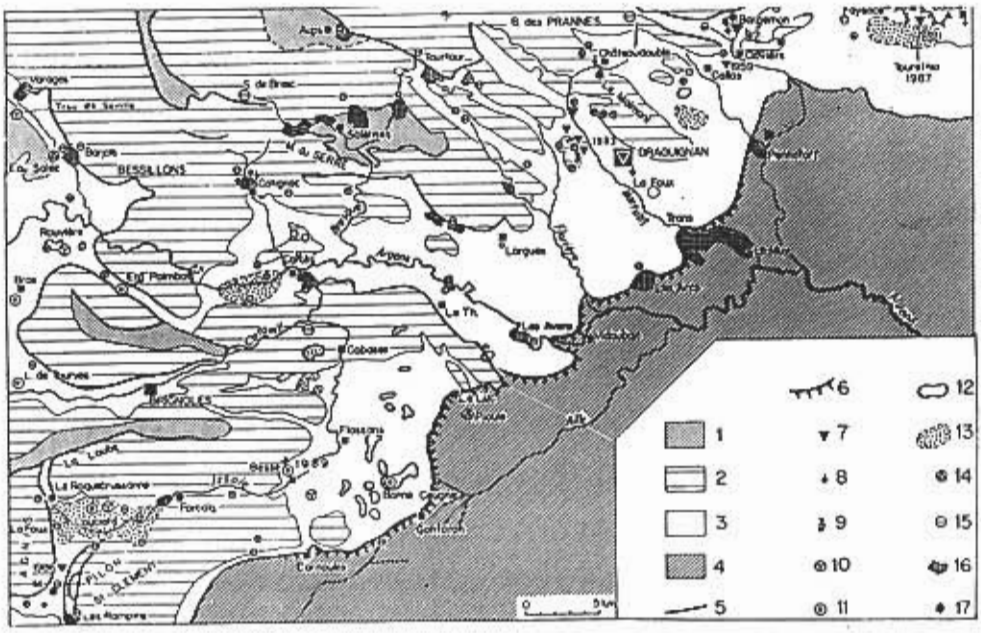

Fig. 3. Karst phenomena and landslides in gypsum karst of the Middle Var (Provence). 1 = late Cretaceous and Cenozoic basins, 2 = Jurassic limestone plateaux, 3 = Triassic, 4 = Permian depressions, 5 = main tectonic scarp, 6 = cuesta, 7 = funnel or "clape", 8 = collapse, 9 = landslide, 10 = doline, 11 = karst lake, 12 = uvala, 13 = filled polje, 14 = sulphate spring, 15 = other springs, 16 = travertines, 17 = old gypsum quarry.

At the centre of the Var district, a multi-bedded gypsum aquifer is fed by water leaking down from the overlying karstified Jurassic limestones; in the Issole valley various karstic ponds and lakes are related to this hydrological phenomenon. Many springs hereabouts have sulphate and chloride waters, such as La Foux de Roquebrussane in the Nartuby valley, which is the main spring feeding the ponds and lakes. It has the following characteristics: mean discharge 0,9m^3/s, mean ionic composition (in meq./L): Ca^{2+} =20.6; Mg^{2+} =2.8; SO_4^{2-} =15.1; Cl^- and Na^+ =13; the total solute load = 27,265m^3/year. This active chemical corrosion is responsible for the development of numerous superficial karstic landforms.

No important caves have been noted around here, but from time to time superficial collapse pits suddenly appear, due to breakdown of underground cavities. They include the "clapes" (funnels) in the Naturby valley, just above Draguignan; of these "La Nouvelle Clape" formed in 1983 and "Le Trou de Bargemon" (about 40,000m^3 in volume) formed during August of 1992. Ponds or lakes (Grand Lucien, Besse) are located on the anticlinal structures of the Muschelkalk limestones, they are situated in collapse sinkholes formed by the dissolution of the underlying gypsum beds. Some of the flat-floored dolines have a thick colluvial cover along their slopes and small poljes such as Marais de Gavoty, with siliceous deposits, can be interpreted as having had a long evolution, possibly since the Late Miocene.

3. Other important areas of Triassic gypsum

Some large karst landforms are known in the Alpes Maritimes, North of Nice. These include the enormous sinkhole of Beuil-Valberg and the 200m-long cave of Source des Isles in Lantosque. The massive Roquebilliere landslide, which occurred here in 1926, has also been attributed to gypsum dissolution after heavy rain.

In the Western Pyrénées, karst depressions are connected with Triassic gypsum that occurs in diapiric structures, the most conspicuous is Bassin de Sare in the Basque country.

In the eastern part of France, Loraine and Franche-Comté, there are many landforms resulting from collapse, including funnels, pit holes and sinkholes or "mardelles", which occur commonly in the forest areas. However, La "Font de Lure" in Haute Savoie is a sinkhole pond in the central part of the town.

Tertiary gypsum beds (Palaeocene and Ludien) are well-known in the central part of the Paris sedimentary basin; at Forèt de Montmorency they are up to 30m thick. Hereabouts many natural caves have been encountered in both ancient and modern mines. The old gypsum quarries of Vaulours and Béthemont-en-Forét lead to a 350m-long cave network called Denis Parisis. The surface karst landscape above the gypsum is dotted by numerous collapse sinkholes, of which the best example is Chanteloup-les-Vignes.

4. Environmental and geotechnical problems

Numerous natural hazards and risks have been associated with gypsum karst processes and landforms. These processes can be accelerated by climatic variations and human impact, including amongst others, dam construction and water abstraction.

Many collapse phenomena have allowed the delineation of potentially dangerous areas in Provence. These include the centre of Draguignan, districts of Bargemon, Callian and Abbaye du Thoronet, plus Roquevaire, where the old gypsum quarries are now deserted. In the Paris district many events, reported as "fontis" or breakdowns, have occurred in Meudon, Aubervilliers, Montreuil, Chanteloup and Porte de la Chapelle. The same phenomena have been noticed in the Alps at Grand-Coeur and Aussois.

Landslides, torrential floods and mud flows are also more common where gypsum crops out, especially in the Alps: Tarentaise (Pralognan, Moutiers); Maurienne (Modane, Val Cenis); Alpes Maritimes, Beaufortin (Aréches).

These natural hazards are allowed for by geotechnical mapping and prediction. Z.E.R.M.O.S. maps and "Cartes et Plans de Prévision des Risques Naturels" (P.E.R.) have been compiled for many of the potentially dangerous zones. In the Paris Basin the collapse risk is increased by over pumping water from the underlying aquifers. In the Alps, where there is a lack of surface water flow, the contamination of drinking water supplied from springs is a serious problem for some important tourist centres and ski-resorts, such as La Plagne, Tignes and La Norma. Human activity has caused a severe increase in the rate of karstic denudation, slope gullying, landslides and the sudden formation of subsidence pits. Many problems have been caused by civil engineering projects, including the construction of roads, artificial ski paths and artificial tunnels, which have

destroyed the natural morphological balance of the landscape in areas such as Val Fréjus, La Plagne, Tignes, Galibier and Modane.

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