Chapter II.10

GYPSUM KARST OF THE BALTIC REPUBLICS

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Introduction

The Baltic Republics of Estonia, Latvia and Lithuania have karst areas developed in both carbonate and gypsiferous rocks. In the north, within the Republic of Estonia, Ordovician and Silurian limestones and dolomites crop out, or are covered by glacial Quaternary sediments. To the south, in Latvia and Lithuania, gypsum karst is actively developing in evaporites of Late Devonian (Frasnian) age (Fig. 1). Although gypsum and mixed sulphate-carbonate karst only occupy small areas in the Baltic countries, they have important engineering and geo-ecological consequences. Due to the rapid dissolution of gypsum, the evolution of gypsum karst causes not only geological hazards such as subsidence, but it also has a highly adverse effect on groundwater quality.

The karst territory of the Baltic states lies along the western side of the area, called the Great Devonian Field that form part of the Russian Plain (Narbutas, 1960). Within southern Latvia and northern Lithuania there is an area, exceeding 1000 sq. km, where mature gypsum karst occurs at the land surface and in the subsurface. This karst area is referred to here as the Gypsum Karst Region of the Baltic States. Here the surface karst forms include sinkholes, karst shafts, land subsidence, lakes and dolines. In Lithuania the maximum density of sinkholes is 200 per sq. km; in Latvia they reach 138 units per sq. km. Caves, enlarged dissolution voids and cavities are uncommon in both areas.

1. Climate, Geology and Hydrogeology

1.1. Climate

The Gypsum Karst Region is located about 100-200 km south-east of the Baltic Sea. It is characterised by a humid and mild climate, transitional between continental and maritime, these are conditions favourable for karst development. In the region the mean annual precipitation varies significantly from 434 mm to 921 mm, with an average of 640mm. The wettest period is in July and August when 6 to 19 per cent of the annual rainfall occurs. The dryest period is in February when snow accounts for 2.5-6 per cent of the annual precipitation. Evapotranspiration in the karst region removes 75 per cent (469 mm of total precipitation) from the surface (Paukstys & Taminskas, 1992). Favourable conditions for high evaporation are created by shallow groundwater levels and the presence of clays and moraine till which form a vadose zone of low permeability. The total dissolved solids (TDS) in the precipitation amount to 11.3 mg/l, half of which (6.1 mg/l)

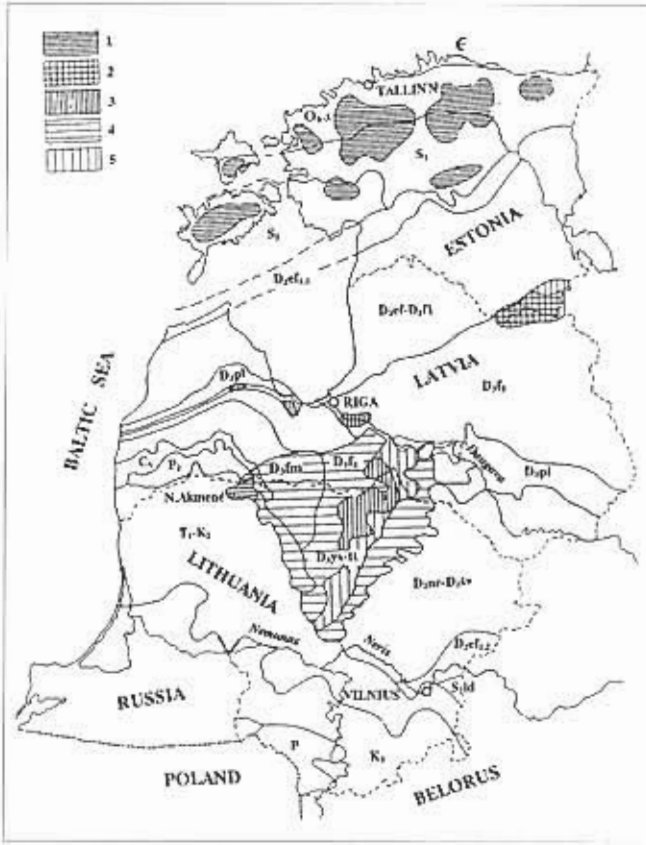

Fig. 1. Karst territories of the Baltic republicks (by V.Narbutas, E.Vodzinskas & U.Heinsalu).
Karst types:
1 = carbonate,
2 = gypsum-carbonate,
3 = active gypsum karst,
4 = old stabilized carbonate karst,
5 = old stabilized gypsum karst

is composed of calcium and sulphate. This precipitation with a pH of 5.4 is highly aggressive to carbonate rocks, but becomes neutral when it infiltrates the soil and reacts with carbonate there (Paukstys, 1996). Mild winters and humid summers characterise the Gypsum Karst Region. The mean average temperatures range from a low of -5°C in January to a high of +15°C in June.

Surplus humidity and a positive balance of precipitation generate surface run-off and streams that recharge the rivers. The mean annual specific discharge of the karst rivers varies from 4.9 to 5.5 l/sec/km^2, but groundwater contributes only about 5 per cent to this total (Paukstys & Taminskas, 1992).

1.2. Geology

In the Baltic States the karstified gypsum and gypsiferous-dolomitic rocks occur at two stratigraphical levels; the Narva Formation of Middle Devonian age and the Tatula and Salaspils Formations of Late Devonian (Frasnian) age. The gypsum in the Narva Formation occurs at a depth of 100 metres or more and karst features are not visible at the surface. However, buried palaeokarst forms are present and these include breccia-filled pipes and carbonatic debris (Narbutas 1979).

The Late Devonian (Frasnian) gypsum sequences occur within the Tatula Formation in Lithuania and the Salaspils Formation in Latvia. The Tatula Formation includes two gypsum layers, the lower one is called the Pasvalys (20m thick) and the upper one the Nemunelis (15m thick). The gypsiferous rocks are underlain by the dolomites and marls of the Pliavinias Formation which in turn are underlain by the thin (2-9m) Jara clays and marls. Below this clay thick sandstones and argillaceous sandstones of the Sventoji and Upninkai Formations occur forming a major aquifer. This aquifer overlies the Narva clay Formation that is the regional aquiclude present at the base of the gypsum karst region. The Late Devonian gypsiferous rocks dip at between 10-15' and 2o to the west. The sequence has been planed off by glacial action and the gypsum crops out as a narrow southwest-trending strip between 12 and 20 km wide (Narbutas, 1979). This strip is mainly covered by thin Quaternary deposits; within this zone modern karst with sinkholes and subsurface cavities is highly developed (Fig.1).

1.3. Hydrogeology

Hydrogeologically, the Gypsum Karst Region forms part of the Baltic Artesian Basin and is located in a zone of active water circulation. Both the Devonian and Quaternary formations are water-bearing and form a single interconnected hydraulic system of aquifers. All the aquifers are being exploited to varying degrees for domestic and industrial use. The Quaternary glacial sands contain mainly fresh calcium bicarbonate water (TDS 0.5 - 0.8 g/l) which is often heavily polluted by nitrogen and organic compounds. The karst aquifer typically has slightly mineralised, but very hard water (TDS 1.5 - 2.4g/l; total hardness up to 35 meq/l). Calcium and sulphate are the main chemical constituents of this water. The aquifer is very vulnerable to pollution and as a result the level of contaminants (nitrogen and organics) often exceeds the maximum allowable concentration for drinking water (Klimas & Paukstys, 1993).

The dolomite aquifer below the gypsum karst rocks usually contains fresh calcium-magnesium bicarbonate water (TDS 0.5 - 0.8g/l; total hardness up to 10meq/l). However, in places due to hydraulic connection with the overlying mineralised karst water, calcium sulphate water (TDS of 1-2g/l) is locally present; some observation wells are also showing traces of pollution.

The lowest aquifer is composed of Middle Devonian sandstones with groundwater of high quality (TDS 0.2 - 0.6g/l; total hardness 5-7meq/l). However, sulphate concentrations locally reach 100mg/l and traces of nitrogen compounds show that this aquifer is locally connected to the upper water-bearing horizons (Paukstys 1996).

2. Karst Forms

Within the active gypsum karst region of Lithuania 8500 sinkholes were counted in an area of 400 km^2. The majority of sinkholes (about 60 per cent) are of oval shape, with the diameters of 10-50 m. The depth of the sinkholes varies from 2 to 12 m, the average being 5 m (Buceviciutë & Marcinkevicius, 1992). The sinkholes are concentrated along the valleys of Mûsa, Levuo, Pyvesa rivers and also along the water divides of these rivers. The density of sinkholes in such areas exceeds 20 per square kilometre; the highest density of sinkholes (200 per km^2) was recorded

in the Karajimiskis geological reserve (Paukstys, 1996).

In Latvia the average density of karst forms in the vicinity of Skaistkalne village is 13 sinkholes per square kilometre, but the highest concentration is 138 per square kilometre. The densities of sinkholes in other parts of Latvia are: Baldone and Adazi -5 sinkholes/km^2, Kemeri-4 sinkholes/km^2, Saulkalne -2 sinkholes/km^2. Sinkholes and collapses were also observed in the vicinity of Riga city, but because they are all now filled with soil their density is not known. In Latvia the some of the sinkholes exceeds 50m in diameter and 10m in depth. Some of the large collapses are of complicated shape with several ponors; they form systems of interconnected holes in the land surface.

In the Gypsum Karst Region, the majority of the collapses are small to medium in size with diameters ranging from 1-2 to 10-15 and depths from 1 to 6 m. Most of holes are dry, but some of them are periodically filled with water. The deeper sinkholes reach unconfined groundwater and sometimes the level of the confined, artesian water; in such cases springs occur, especially along the river valleys. In Lithuania, karst springs occur in the valleys of Levuo river at Pasvalys, next to the Orija river near Berklainiai village and the Apascia river at Draseikiai village. In Latvia karst springs occur along the Iecava and Memele rivers. Some springs are the sources for rivers; the spring that discharges from a shallow sinkhole, with a diameter of 13 m in Likenai village, creates the Smardone stream, a tributary of the Tatula river. Conversely, the 8 km long Pozemis stream disappears underground in a karst fracture. Both in Lithuania and Latvia, some of the large collapses are water filled and form small lakes, some over 10 m deep. Lake Ilgasis ("Long Lake" in Lithuanian) at Kirkilai village is composed of 30 amalgamated sinkholes; it is 1100 m long and 200 m wide (Kilkus 1977). In the Gypsum Karst Region the lakes have mixed recharge both from the precipitation and from the groundwater that commonly gives their water a slight smell of hydrogen sulphide.

Surface karst forms are common, but only one gypsum karst cave is known today in Lithuania. This cave, at the Karajimiskis Geological Reserve was given the status of a geological monument. The cave entrance is at the bottom of a karst hole 9.5 meters deep. The cave comprises of a main cavity, which is partly filled with water and three narrow passages. The height of the main cave is 3.1 m and the total length of the passages is 46 m. The total area of the cave is 42 square metres, with a volume of 28 cubic metres (Laiconas, 1979). The walls and sides of the cave are covered with water-eroded scallops and it is clearly of phreatic origin. However, the cave is now only about half full of water and a solution roof or laugdecke is present just above the summer water level. The cave water is of calcium sulphate type (TDS 1.5-2.2 g/l; total hardness 23-29 meq/l). The groundwater temperature in the cave does not exceed +5°C even in mid summer.

3. Environmental Problems Associated with Gypsum Karst

The main human activities influencing gypsum karst development are groundwater abstraction and agriculture.

The interconnected system of aquifers, both in and around the Gypsum Karst Region, is being exploited for drinking water supplies by dug and drilled wells. Besides the individual wells, two

waterworks in the towns of Birzai and Pasvalys respectively abstract 2000 and 2600 m^3/day of groundwater. As a result of these abstractions, the water level at the Pasvalys waterworks has fallen by 7.5m since 1970. At Birzai the drawdown has been 8m since 1961. Groundwater abstraction boosts gypsum solubility, it also accelerates the removal of dolomite debris from subsurface cavities so that it can be redeposited into other openings or removed by pumping (Paukstys, 1996).

Agriculture also has a strong regional influence on karst development and protection. In common with other parts of Lithuania and Latvia farming is highly developed in the Gypsum Karst Region. The shallow unconfined waters in many of the domestic wells of the region and the karst aquifer are both heavily polluted by nitrogen and organic compounds (Paukstys, 1996).

Resulting from the investigations of the natural and human-induced factors contributing to karst development, a series of protection measures for the Gypsum Karst Region were instigated.

In Lithuania the karst area was divided into two parts; a karst protection zone of 166,000 ha and a zone of active karst development with an area of 27,600 ha. (Paukstys, 1996; Narbutas 1994). Considering the number of sinkholes present per 100 ha, which indicates the vulnerability of the karst terrain, the active karst zone was further subdivided into four land groups. Each land group has a specific level of agricultural restriction imposed upon it, these are:

Land group 1 (up to 20 sinkholes/100 ha) - grain crops should compose at least 50% of arable lands, perennial grass 40% and root crops (potatoes and sugar beet) not more than 10%. Fertilisers are limited to a maximum of 90 kg/ha of nitrogen-potassium-phosphorus (NPtP- active ingredients) and 80 t/ha of manure. Triazinic herbicides and chloroganic insecticides are prohibited.

Land group 2 (20/50 sinkholes/100 ha) - grain crops should compose 43% or arable lands and perennial grass 57%. Root crops (potatoes and sugar beet) are prohibited as are the setting up of new orchards and gardens. Fertilisers are limited to a maximum of 60 kg/ha of NPtP and 60 t/ha of manure.

Land group 3 (50 - 80 sinkholes/100 ha) - Perennial grass and pastures only are allowed. Fertilisers are limited to a maximum of 60kg/ha NPtP. Mineral nitrogen fertilisers are prohibited as are pesticides (except for fungicides).

Land group 4 (80 - 100 sinkholes/100 ha) - only meadows and forests are allowed. All fertilisers and pesticides are prohibited. In all the land groups a 25m radius protection zone is required around each doline. Within this protection zone only grass without fertilisers or pesticides may be grown.

Ecologically sound agricultural plans have been designed for each land group. Thus in Lithuania, the protection of karst water from pollution, and the reduction of human impact on the vulnerable karst area, is now official Government policy. Groundwater abstraction is only allowed from the sandstone aquifer, underlying the karstic one. The planned mining of the Skaistkalne gypsum deposit in Latvia and Rinkunai deposit near Pasvalys (Lithuania) were both cancelled for environmental reasons; these were to avoid dewatering, to protect the water quality and to prevent subsidence.

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