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LIMESTONE PAVEMENTS IN GREAT BRITAIN AND THE ROLE OF SOIL COVER IN THEIR EVOLUTION

VLOGA PRSTI PRI RAZVOJU ŠKRAPLJIŠČ V VELIKI BRITANIJI

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Aniko Zseni & Helen Goldie & Ilona Bárány-Kevei: Limestone pavements in Great Britain and the role of soil cover in their evolution

The goal of the research was to verify the connection between the solutional power of soil and the shape of rocky features in limestone. Soil samples from runnels, grikes, foot of pavements, top of limestone, grass patches and dolines were collected on limestone pavement areas of North England and examined for the pH and carbonate content. The results of the measurements proved that the soils with lower pH are related to deeper solution features and that proximity to limestone causes a higher soil-pH.
Key words: karst, limestone pavements, weathering, soil, North England.

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Aniko Zseni & Helen Goldie & Ilona Bárány-Kevei: Vloga prsti pri razvoju škrapljišč v Veliki Britaniji

Članek obravnava povezavo med korozivno močjo prsti in skalnimi oblikami v apnencu. V ta namen so vzorcem iz različnih škrapljišč, drugih oblik kraškega površja in vrtač v Severni Angliji, določili pH in delež karbonatov. Rezultati meritev so potrdili, da so oblike pod kislo prstjo globlje in da prisotnost apnenca močno zvišuje pH prsti.
Ključne besede: kras, škrapljišča, preperevanje, prst, severna Anglija.

INTRODUCTION

To understand the evolution of different karstic features, especially types of karren, the investigation of soils on karst landforms is very important. There are some interesting questions e.g.: are there any connections between solutional power of soil (so pH and carbonate content) and the depth, smoothness, and roundness of limestone forms; and has the proximity to limestone an effect on the soils? To answer these questions soil samples were collected on limestone pavement areas of North England.

Limestone pavement is a type of karrenfeld, where areas of bare rock are dissected by opened joints and karren forms. It is dominated by patterns of clints and grikes so that they appear like artificial paving. Other microforms are runnels of various types and small depressions, pits, pans, kamenitzas, grooves, troughs and cavities.

Grikes (or Kluftkarren) are fissures, joint or fault guided, which have been opened by solution. Blocks isolated between them are termed clints (Flachkarren). The area and shape of clint tops is directly dependent upon the frequency and pattern of grikes, and therefore upon the degree of fissuring. Most clint tops seem to fall between 1-10 m^2 in area. (*FORD, D. - WILLIAMS, P.* 1989.) Microforms, e.g. runnels of various types and small depressions, pits, pans, kamenitzas, grooves, troughs and cavities can be found on the clint top. Runnels have been formed by flowing water or under a soil and vegetation cover. Small cup or saucer-shaped depressions (kamenitzas), often partly filled with water can be seen on the limestone outcrops. If they remain damp for any length of time, algae, moss and peaty soil, and later higher vegetation accumulates in them. They become enlarged both by solution from the

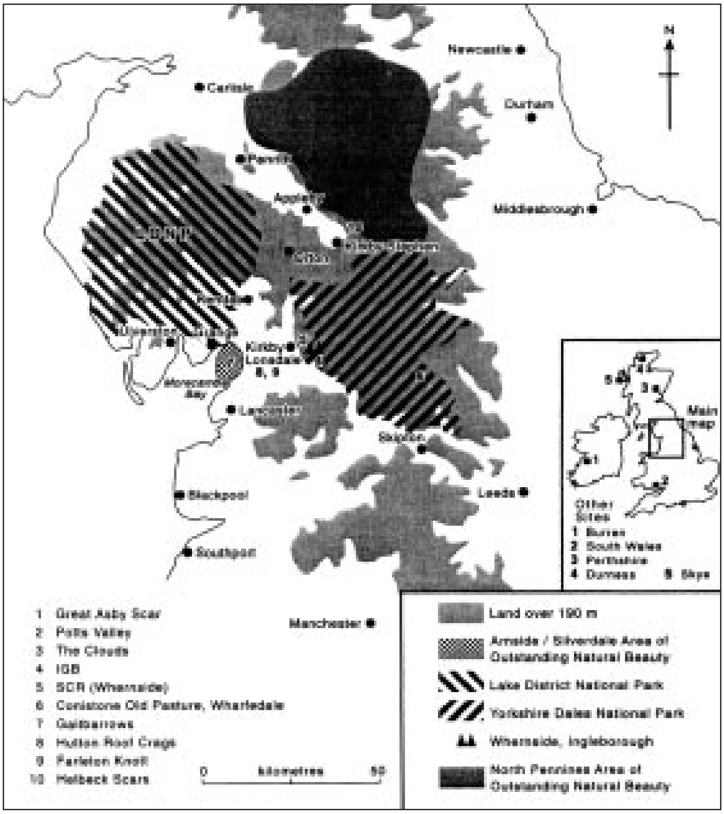

Fig. 1: Limestone pavement areas in Great Britain.

water, and by the action of the vegetation which smoothes their walls (*SWEETING, M. M.* 1966.).

Grikes, runnels and microdepressions are solution features, clints are residuals. They evolve as the grike pattern develops and they are finally consumed as grikes and runnels enlarge. Not all clints weather in the same way, some spall off flakes, others break down into rubble.

The largest outcrops of limestone pavement in the British Isles are in Burren (County Clare, western Ireland, Eire), and in the North Pennines in the counties of North Yorkshire, Cumbria and Lancashire (England). Small outcrops of limestone pavement occur in Derbyshire, Southern Wales and Northern Wales. All sites are on Carboniferous Limestone. There are small limestone pavement outcrops in Scotland, on Dalradian limestone in Perthshire and on Cambrian limestone on Skye and in the Durness area of Sutherland (Fig. 1) (*GOLDIE, H.S. - COX, N.J.* 2000).

THE ROLE OF SOIL COVER IN THE EVOLUTION OF KARREN FORMS

If it is needed to describe briefly the difference between forms which occur under a soil and which developed in open-air conditions, it can be said that angular forms are produced directly by the dissolving power of rain, while rounded forms have formed under a soil or peat cover (*BÖGLI, A.* 1960).

Features, which developed in open-air conditions, are fretted and sharp, having been subjected to much more selective corrosion. On bare rock surfaces rapid run off occurs on sloping surfaces, whereas on flat surfaces or in basins water will be resident on the surface much longer. It can be said that a soil free surface suffers only episodic dissolution events under the action of rainwater. However, in addition rainwater has considerably less dissolution potential than acid soil water. Thus, under conditions of rapid, transient flow, where water depths are limited, only those constituents of the rock will be removed, which are rapidly soluble. Forms will be related to dissolution kinetics and the overall chemical reactions will be rate limited. (*TRUDGILL, S.* 1985, *FORD, D. - LUNDBERG, H.* 1987). On bare surfaces three major types of karren are formed: rillenkarren (on steeper slopes, packed channels commencing at crest of slope, 1-3 cm wide, sharp-edged); trittkarren (on slopes of low angle, smooth surfaces with small steps); and kamenitzas (solution basins). (*TRUDGILL, S.* 1985). In summary, selective solution produces deep grikes and runnels and a rough, pitted surface.

The role of a soil cover in limestone pavement evolution depends on the pH of soil. In general, calcareous soils with high pH (pH of 7 to 9, where calcium carbonate content is higher than 10 %) protect the underlying limestone almost completely from erosion, because water becomes saturated with bicarbonate on passing through the soil profile (*TRUDGILL, S.* 1985). So the soil water arriving at soil-bedrock interface is incapable of dissolving the bedrock. (*WILLIAMS, P.W.* 1966, *TRUDGILL, S.* 1985). The existence of preserved glacial surfaces under drift and soils must be related to the fact that the covers are calcareous. So there is a relationship between soil characteristics, especially pH and calcium carbonate content and a rate of bedrock erosion (*SWEETING, M.M.* 1966, *TRUDGILL, S.* 1986).

If the percolating water is not saturated, then solution will take place. Under acid soil limestone is extensively weathered. Erosion of limestone is most severe beneath deposits supporting acid vegetation and with a pH between 4 and 7 and a calcium carbonate content of 0 to 1 %. (*TRUDGILL, S.* 1985). The extensive weathering under acid soils lead to the formation of solutionally opened joints, and soil often washed down into the dissolved large grikes. This can result in the lowering of the soil surface down the developing cleft, possibly also with soil loss into near surface cave systems. But the surface wash induced by the felling of trees by man in order to utilise the calcareous soils for pasture also cause erosion. So many limestone pavements could be postglacially covered more extensively with drifts and soils (*TRUDGILL, S.* 1985). The presence of smoothly eroded surfaces in many pavement areas supports this hypothesis.

Under drift and soils surfaces can be attacked from many directions, so smooth, rounded, runnelled and pinnacled forms may be found frequently with etched surfaces and comparatively shallow incision of the bedrock. Subsoil attack on tabular blocks from three sides may give rise to a pinnacle form. Arcuate and cuspate forms also occur under acid soils.

Soil moisture distribution, drainage rates, soil texture, soil depth, water-flow rates, slope, vegetation, and the nature of the limestone will all have a strong influence on the distribution of subsoil solutional erosion and resulting landforms.

The degree of erosion is greater under deeper soils, which may reflect the increase in soil air carbon dioxide values with greater depth. There seems to be an overall decrease in erosion beneath soils on steep slopes compared with those on flat or gently sloping ground. Soils on the steeper upslope sites tend to be thinner - the top of the soil profile is often truncated - with a higher rate of downslope removal of material than those on flat ground (*TRUDGILL, S.* 1985). Hypothetically, a light textured soil should enhance leaching with a concomitant decrease in pH and increase in erosion, but other effects mask this effect. The nature of the limestone is important in determining the rate of its erosion beneath a soil. Hard, massive limestones do not break down easily and the soils above them tend to be easily leached. More friable rocks fragment more easily and become incorporated in the soil, making it less acid. Softer rocks typically support a calcareous flora, while hard limestones may support a calcifuge vegetation, which has the effect of increasing the erosion rate. (*TRUDGILL, S.* 1985).

Time is a factor that has great importance in determining whether or not soil characteristics will tend to encourage weathering or protect the rock beneath it (*TRUDGILL, S.* 1985).

The vegetation of limestone pavements has varied in post-glacial time. The peat deposits that occur on many hills of Northern England contain tree remains. Within the last 80 years much juniper scrub has disappeared from areas in the Ingleborough district and in the Morecambe Bay area. Sheep grazing also indicate human occupation, which has damages the young vegetation, especially trees. Ancient enclosures also had an influence. If the surface layers of the clints are removed, the pavements are changed in their nature and may diminish in areas as well. (*SWEETING, M.M.* 1966, *GOLDIE, H.S.* 1986).

SAMPLING AND MEASURING

60 soil samples were collected from limestone pavement areas of North England (Fig. 1). These pavements are well examined and have been described by several researchers (*GOLDIE, H.S.* 1981, 1986, 1995, 1996 a, b, *SWEETING, M.M.* 1966, *ROSE, L. - VINCENT, P.* 1986 a, b, c, *VINCENT, P.* 1995, *WILLIAMS, P.W.* 1966). Our samples are from runnels, grikes, foot of pavements, top of limestone, grass patches and dolines, so different solutional and tectonical features of limestone. Due to the soil being deeper in grass patches and dolines in these cases usually two

samples were collected from one soil profile, as the characteristics of the soil changed. The abbreviations for the samples, which came from different areas, are the followings:

- Farleton Knott: parts of it: Newbiggin Crags (NBC samples), Farleton Fell (FF)
- Hutton Roof Crags (HRC and UBP samples)
- Gaitbarrows (GBS)
- Great Asby Scar (GAS and ASC samples)
- The Clouds (TCL)
- Conistone Old Pasture (COP)

The aim of the investigations is to clear up the following: are there any connections between present solutional power of soil (so pH and carbonate content) and the depth, smoothness, and roundness of limestone forms(and whether the proximity to limestone has an effect on the soil pH and carbonate content.

During the examination the pH was measured in distilled water and in 1 M KCl solution by digital pH-meter. The soil: water ratio is 1:2,5 (6 g soil and 15 cm^3 water or KCl solution). The pH(H_2O) shows actual soil reaction, while pH(KCl) gives information about potential soil reaction. The ΔpH (=pH(H_2O) - pH(KCl)) of soils was calculated as well. The ΔpH value gives us an important information about the acidification tendency of soils: if the value is about 1 or more, than the soil tends to acidify. Scheibler-calcimeter was used to determine the carbonate content of soils.

RESULTS

Soil samples are grouped according to whether they came from a flat limestone surface, a shallow runnel (depths of a few cm) or a deeper runnel, to investigate the role of the soil pH and carbonate content in the solution of limestone (Fig. 2). The pH values of the 3 soils from flat surfaces (HRC1, ASC2, COP1) are between 6,91-7,8. The carbonate content of one soil is 6 %, but it is below 0,5 % in the case of the two other soil samples. The ΔpH is not too high (0,51-0,63). The pH values of the soil samples, which came from shallow runnels (HRC8, UBP1, GAS7, GAS8, ASC3, and ASC5) are about 6,06-7,67. The pH of UBP1 and ASC3 is higher than 7, and they have very high (42 % and 11,5 %) carbonate content as well. The carbonate content of the other soils is less than 0,5 %. In the soils, which have lower pH (the pH is near 6), the ΔpH is high, around 1. The pH values of the soils of the deep runnels (NBC1, HRC7, HRC10, UBP6, GAS3, ASC4, ASC6, ASC7, COP2) are always less than 7 (4,33-6,93). The lowest pH values are in this latter category when comparing these 3 groups of soils. The carbonate content is usually 0 %, except in a few cases, but it is always below 0,8 %. (*ZSENI, A. - KEVEINÉ BÁRÁNY, I.*, 2000.)

The results of the measurements verify that the soils with lower pH are related to deeper solution features, not surprisingly as their solvent power is greater than that of the soils with higher pH.

The appearance of the limestone surface can vary in short distances. Soil covered flat limestone surface, soil-filled shallow runnel and soil-filled deep runnel can be seen in a distance of a few metres. The ASC2-3-4 samples came from such an area. The ASC2 sample is in a flat lime-

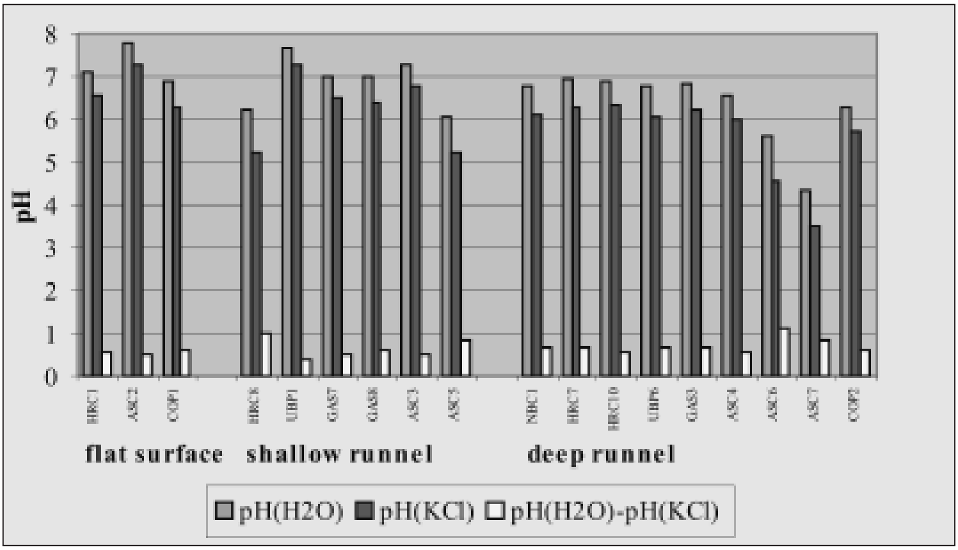

Fig. 2: pH of soils, which were collected from flat surfaces, shallow runnels and deep runnels.

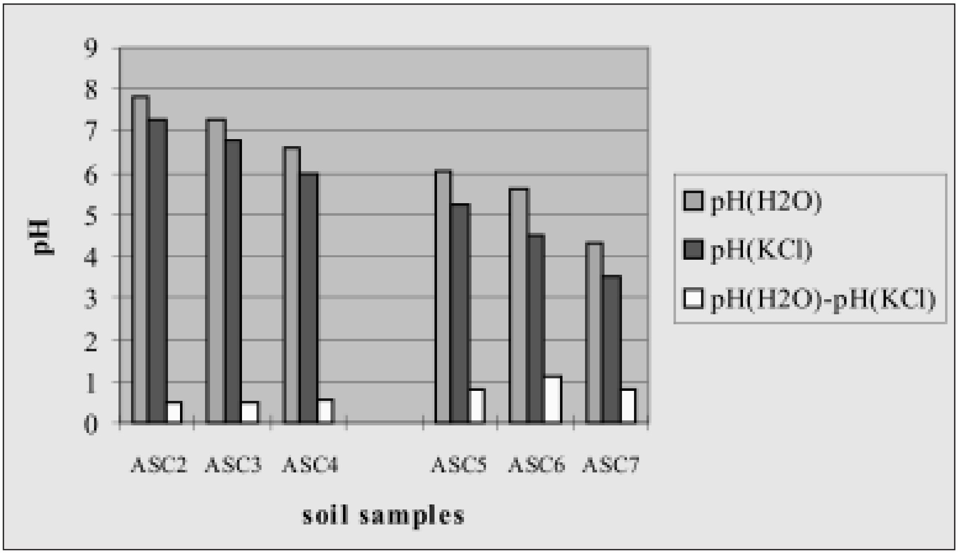

Fig. 3: Connection between pH of soils and the features of limestone.

stone surface, the ASC3 is from a shallow runnel a few metres away from ASC2. ASC4 is from a deep runnel a few metres away from ASC3. The situation is the same in the case of the ASC5-6-7 samples. So ASC5 is from a flat limestone surface, ASC6 is from a shallow runnel a few metres from away ASC5. ASC7 is from a deep runnel, a few metres away from ASC6. There

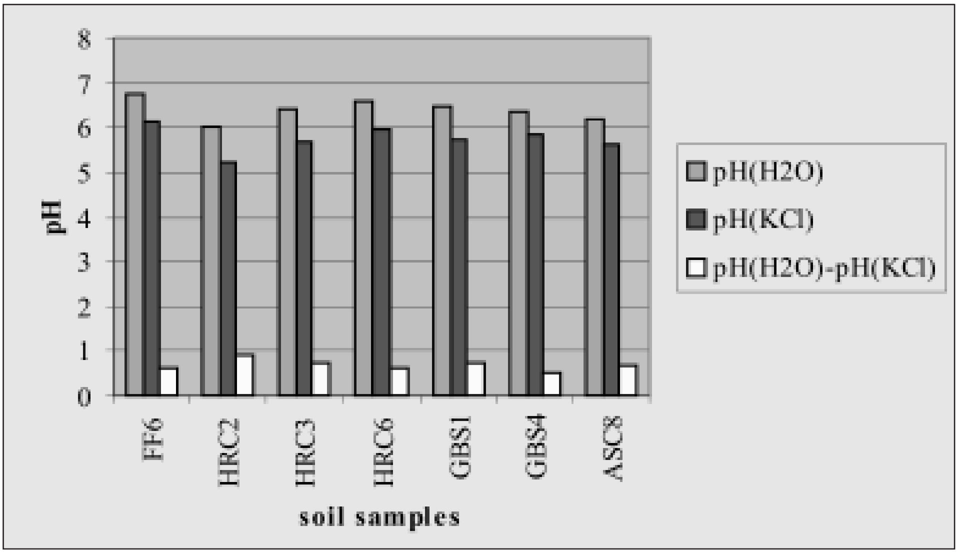

Fig. 4: pH of soils, which have direct contact with limestone.

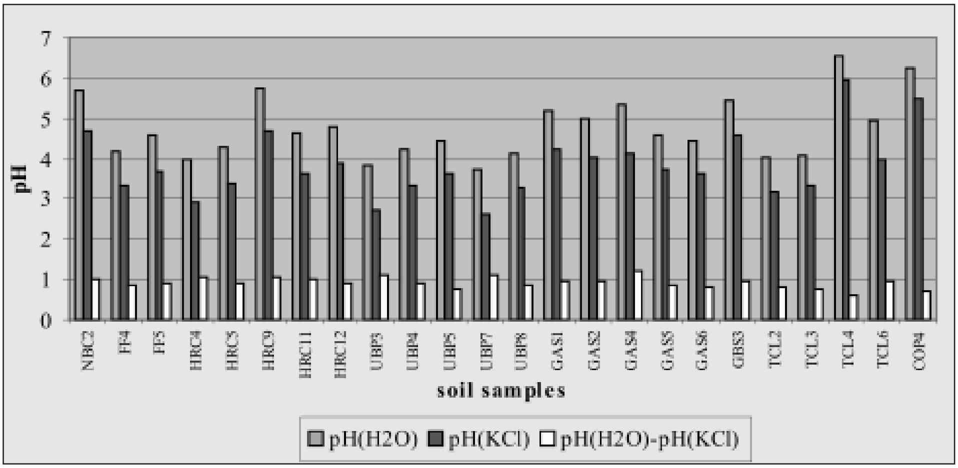

Fig. 5: pH of soils, which do not have direct contact with limestone.

is acid vegetation in the area of ASC5-6-7. The deepening of the solution features with the lowering of pH can be seen in the case of both series (Fig. 3). The high pH (=7,8) and high carbonate content (6 %) of the ASC2 sample protects the limestone surface under it from the solution. The lower pH and 0 % carbonate content of the ASC4 samples enhances the solution of the limestone. The pH and carbonate content of the ASC3 sample cause relative protection, but the shallow runnel indicates that solution can take place. A similar relationship of lowering of pH with the deepening of the solution features occurs in the ASC5-6-7 series. The soils have no carbonate content and the pH values are lower than that in the case of the ASC2-3-4 series. The acid vegetation reflects the lower pH. It is possible that, mainly in the case of the ASC5 samples, the pH was higher and the soil has been acid in the recent past. The flat surface under the ASC5 soil shows that the soil has protected the limestone from the solution. High values of ΔpH (around 1) show the tendency to acidification. From the measurements it is clear that there is a connection between the pH and carbonate content of soil and the solution features of the limestone.

Other soil samples are grouped according to whether they are at the foot of pavements where they are in direct contact with the limestone surface or in a few metres away from the limestone: in grass patches or in dolines. The soils far away from limestone can be a few decimetres in depth. So more than one samples was collected from these soil profiles. Such samples are (the bigger the number the deeper the soil sample): FF4-5, HRC4-5, HRC11-12, UBP3-4-5, UBP7-8, GAS1-2, GAS5-6. Except in the GAS samples, the pH is always higher downwards in the soil profile. But the decrease is not great in the case of the GAS samples. The increase of pH downwards in the soil profile may be connected to the decreasing effect of leaching and the effect of the limestone, which lies closer in the deeper part of the soil.

From the measured data it can be seen that the pH is higher in soils in directly contact with the limestone (*ZSENI, A. - KEVEINÉ BÁRÁNY, I.*, 2000.). The pH values of these soils are about 6,0-6,7 and the carbonate contents are 0 % (Fig. 4). The soils of grass patches and dolines (which are a few metres away from the limestone) have acid pH (around 4-5, except 2 samples, which have neutral pH) and the carbonate content is 0 % (Fig. 5). The ΔpH is always high, around 1.

Soil samples close to each other were collected to examine the differences of the soils, which connect directly and do not connect directly with limestone. These series are the FF4-5-6 and the

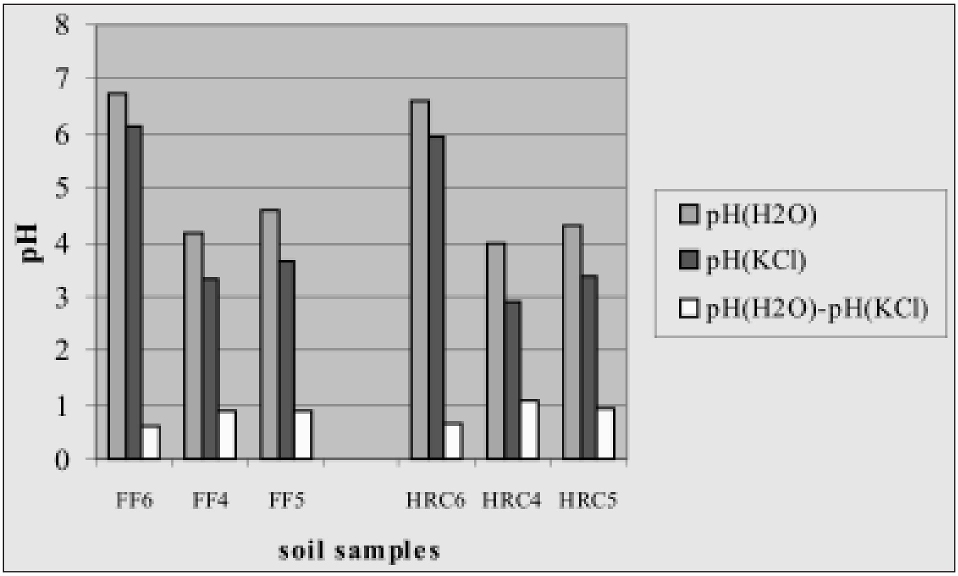

Fig. 6: Connection between pH of soils and proximity to limestone.

HRC4-5-6 samples. The FF4-5 and HRC4-5 samples are from grass patches a few metres away from limestone outcrop. The FF4 and HRC4 are from the upper 10 cm of the soils. The FF5 and HRC5 are from below the former. The FF6 sample is 5 metres away from the FF4-5 samples, directly at foot of runnels. The HRC6 sample is a few metres away from the HRC4-5 samples and directly connects with the limestone outcrop. The pH is much higher in the soils which connect directly with limestone, pH=6,6-6,7 (Fig. 6). They have no carbonate content. The soils of the grass patches are very acid. The pH is about 4 and it increases downwards in the soil profile (Fig. 6). The ΔpH-values are higher (around 1) than those in the soils, which have direct contact with limestone. They have no carbonate content of course. So not only does the soil have an effect on the limestone, the limestone also has an effect on the soils. Proximity to limestone causes a higher soil-pH, while the soils, which do not have direct contact with limestone have a lower, acid pH.

Soil samples were collected from grikes as well. The pH-values of these soils are very varied (5,5-7,5). In the acid soils the ΔpH has high, around 1 values.

REFERENCES

BÖGLI, A.: Kalklösung und Karrenbildung.: Z. Geomorph., Suppl. 2, pp. 4-21.

FORD, D. & LUNDBERG, H.: A review of dissolutional rills in limestone and other soluble rocks. - Catena Supplement 8, pp. 119-140.

FORD, D. & WILLIAMS, P., 1989: Karst geomorphology and hydrology. Published by Chapman & Hall, London, P601

GOLDIE, H.S., 1981: Morphometry of the limestone pavements of Farleton Knott (Cumbria, England) - Trans. British Cave Research Assoc. vol.8, No.4, pp. 207-224.

GOLDIE, H.S., 1986: Human Influence on landforms: the case of limestone pavements. - In: Paterson, K. and Sweeting, M.M. (eds) New Directions in Karst. Geobooks, Norwich, pp. 515-540.

GOLDIE, H.S., 1995: Major protected sites of limestone pavements in Great Britain. - Acta Geographica Szegediensis. Special Issue: Environmental Effects on Karst Terrains (ed.) Barany-Kevei, I., Szeged, pp. 61-92.

GOLDIE, H.S., 1996 a: The Clouds: an example of structurally complex limestone pavements. - Karren Landforms (ed. Fornós, J.J. - Ginés, A.), Universitat de les Illes Balears, Palma de Mallorca, pp. 195-208.

GOLDIE H.S., 1996 b: The limestone pavements of Great Asby Scar, Cumbria, UK. - Environmental Geology 28 (3), pp. 128-136.

GOLDIE, H.S. & COX, N.J., 2000: Comparative morphometry of limestone pavements in Switzerland, Britain and Ireland. - Zeitschrift fur Geomorphologie Spbd 122, pp. 85-112.

ROSE, L. & VINCENT, P.J., 1986 a: The kamenitzas of Gait Barrows National Nature Reserve, north Lancashire, England. - Ch. 25 in: New Directions in Karst (ed. Paterson, K. - Sweeting, M.M.), Norwich, Geobooks, pp. 473-496.

ROSE, L. & VINCENT, P.J., 1986 b: Alkalinity measuremnts in karst water studies. - Ch. 1 in: New Directions in Karst (ed. Paterson, K. - Sweeting, M.M.), Norwich, Geobooks, pp. 1-15.

ROSE, L. & VINCENT, P.J., 1986 c: Some aspects of the morphometry of grikes. - Ch. 26 in: New Directions in Karst (ed. Paterson, K. - Sweeting, M.M.), Norwich, Geobooks, pp. 497-514.

SWEETING, M.M., 1966: The weathering of limestones (with particular reference to the Carboniferous limestones of Northern England). In: Essays in Geomorphology (editor: G.H. Dury), Heinemann, London, pp. 177-210.

TRUDGILL, S., 1985: Limestone geomorphology. In: Geomorphology Texts 8. (edited by K. M. Clayton), Longman, pp. 53-70.

TRUDGILL, S., 1986: Limestone weathering under a soil cover and the evolution of limestone pavements, Malham District, north Yorkshire, UK. - Ch. 24 in: New Directions in Karst (ed.: Paterson, K. - Sweeting, M.M.), Norwich, Geobooks, pp. 561-471.

VINCENT, P., 1995: Limestone pavements in the British Isles: a review. - The Geographical Journal, Vol. 161, pp. 265-274.

WILLIAMS, P.W., 1966: Limestone pavements with special reference to Western Ireland. In: Transactions of the British geographiers No. 40., pp. 155-172.

ZSENI, A. & KEVEINÉ BÁRÁNY, I., 2000: Nagy-Britannia mészkőjárdái és a talaj hatása azok fejlődésében (Limestone pavements of Great Britain and the influence of soil in the evolution of them). - Karsztfejlődés V., Szombathely, pp. 181-194.