KARST

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Important Karst Regions of the Northern Hemisphere

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Preface

Karst areas with their specific morphologic and hydrogeologic features are widespread throughout the world. Since ancient times there has been a lively interest in deciphering the relationships of strange superficial erosional relics, ponors, dolines, vauclusian springs, caves, caverns, and so forth. The discovery of saw dust, leaves and some fresh-water animals suggested an entangled connection of underground water courses which at the beginning led to rather strange explanations. The first attempts to explain karst phenomena were recorded by ancient civilisations. But not until the nineteenth century was there any clear evidence of the origin of karst features. Until recently a descriptive method of presenting karst was dominant. With the improvement of detailed geologic investigations, karst relations have gradually come to be understood as the logical consequences of various geologic forces working under specific conditions.

Practical interest, especially in the areas of water supply and the positioning of power plants, has hastened the introduction of more exact methods in karst investigations. Every day new data are collected and new theories are put forth. However, new developments often do not reach the professional journals or are published in various reviews in different languages; therefore, they are not readily available to all who are interested in them. This fact led to the publishing of this book in which are presented karst relations and the problems of various countries having advanced theoretical and practical experience.

The number of countries was limited by the size of the book as well as by the willingness of the invited experts to cooperate. We endeavoured to present contributions covering all the main types of karst.

We are conscious that we have taken only the first step in preparing a common base for wider comparison and exchange of ideas for future theoretical and practical advances in the area of karst investigation and exploration. A proposed second edition may be the result of still greater cooperation in order to complete karst notions concerning the space, ideas, methods of investigation, and application. For that purpose any further suggestions would be very much appreciated.

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Chapter 1

Historical Review of Morphologic Concepts

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INTRODUCTION

Karst includes the circulation of water in fractures, fissures, joints and other cavities, and the development of corresponding forms in soluble, mostly carbonate rocks. The process and the produced forms reach to great depths in the rock complexes, but, in this review, as in geomorphology in general, it is mainly the surface, i.e., the visible forms, which will be treated. Since the surface features cannot be understood without knowledge of the process as a whole, the connection between them will be adequately respected. Analogous superficial forms also occur in some other deposits, e.g., in loess; these are called "pseudokarst", and will not be a subject of this article.

Limited space, the scope of the subject, and clearness required suggest a concentration on the essential problems, and on those which are interconnected in the historical development. Several papers are omitted, and those cited are used only for documentation of the explanation. This review is only an introduction to the up-to-date scientific endeavours, which are presented only by means of the basic data.

EARLY INVESTIGATORS

Like geomorphology in general, the scientific investigation of karst relief is very young, in fact the term "geomorphology" was first mentioned by NAUMANN [1858]; the first textbook on the subject was written by PENCK [1894]. Only by means of the first results of the mapping and on the basis of more reliable investigations at the end of the 19th century, were the global relief features established. At that time the basic data concerning the composition and structure of the earth were known. In connection with practical works, and especially with the construction of railways, features of relief became important elements in the natural inventory. In the course of acquiring new ideas and of solving practical problems the Alps occupied a central position and were of predominant significance.

It is normal that perialpine Vienna, at that time one of the leading scientific centers in the world, also became the center of geomorphologic investigations, especially those concerning the karst. A second important fact was that the Dinaric karst was the main source of ideas and that it thus influenced the formation of con-

cepts. Admittedly there are in the surroundings of Vienna the Moravic karst and some calcareous areas in the Alps, but with respect to the extension and variety of their karst features, they can hardly be compared with the Dinaric karst. However, the comparative study was highly important for defining and improving scientific thought.

The classical connection of karstology with the Dinaric karst was not accidental but was dependent on the proximity of the scientific center in Vienna. Even in the present-day global endeavours, the Dinaric karst is still the most complex and attractive, and is still regarded as a classical karst area both in its content and in historical significance. Its importance is also emphasized by the many scientific terms which, regrettably, are not always correctly used.

Dinaric karst has remained almost until recent times in the shadow of cultural events, its existence being "discovered" at the beginning of this century. However, a small, narrow and marginal area between the northern part of the Adriatic Sea and the Pannonian Basin, was an important passage and a stage for interesting events and movements leading to the prehistoric legend of the Argonauts who might have come through this area from the Ister (Danube) to the Adriatic Sea. This karst threshold is exceptionally rich in specific features which attracted early attention and which required explanation. It is in this most peculiar part of the classical karst that the term "karst" has originated, based on the Indo-European word "kar" = rock. The Italian term is "carso", the Slovenian word is "kras", while "karst" is a Germanized form of the original expression. With the development of Trieste, the classical karst area got the name "karst of Trieste".

The impressive karst forms, the facts based on them, and the richness of the folk legend inspired VALVASOR [1689], a master of drawing and descriptions, to publish the legends and beliefs concerning karst which are still alive. Local people proceeded even further, in trying to explain the origin of some features. GRUBER [1781] was especially interested in long-lasting inundations of Cerkniško polje in Slovenia, considering these impressive "jamas" to be a consequence of collapses. His contemporary HACQUET [1778] gives useful data and observations on karst features. He considers dolines a consequence of the weathering of limestone. These observations were too early for the general scientific climate, and the country was outside the main flow of cultural aspirations and decisive events. Therefore, these problems had to wait during seven more decades before again becoming the subject of investigations. The French scientist VIRLET [1834] regarded the dolines in the southern Jura Mountains as the effects of collapse of the roofs of subsurface cavities, i.e., he followed the former idea of Gruber. Hacquet's idea was a forerunner of LYELL's [1839] explanation of the genesis of the "geologic organs" in the chalk of southern England by means of the solution process by atmospheric water. In France, FOURNET [1852] also explained the dolines in connection with collapses.

SCIENTIFIC APPROACH

Since the middle of the 19th century (1850–1857), when a railway was constructed over the karst threshold from middle Europe to Trieste, the karst area has become a feature of modern life. Civil engineers of the Southern Railway were confronted with karst reality which required explanation and practical measures. Karst then became an object of scientific interest.

The Viennese speleologist SCHMIDL [1854] investigated caves in the karst of Trieste with good support and for practical purposes. He maintained, in accordance with predominant views, that dolines were formed as a result of collapses. In addition to speleologic explanations, other opinions were very numerous. The English geologist PRESTWICH [1854] agreed with Ch. Lyell's explanation that dolines were formed by the infiltration of water.

Shortly after, analogous explanations were published by American geologists. OWEN [1856] studied the karst of Kentucky (U.S.A.), whilst Cox [1874] expressed the opinion that the dolines in the karst of Indiana were produced by the solution of limestones. He recorded joints through which water infiltrated. Of special importance are the investigations of the English geologist SAWKINS [1869] in Jamaica; according to his opinion conspicuous dolines (cockpits) originated due to the solution of limestones.

First phase of karst morphology investigation

A new and more complex approach to karst problems coincided with the first geologic investigations of the middle and most complicated part of the Dinaric karst, following the occupation of Bosnia and Hercegovina (1878). The leading geologists in Vienna, E. Mojsisovics, E. Tietze and E. Bittner wrote about the geologic relations of that area and gave a scientific explanation for the genesis of the karst forms [MOJSISOVICS et al., 1880]. E. Tietze supported the collapse theory. MOJSISOVICS et al. [1880] pointed out that folding and erosional forces were factors in the development of karst depressions. They compared the Dinaric dolines with the Alpine karren. Thus, Hacquet's forecast and the practice of several English and American geologists were introduced into the explanation of the Dinaric karst. DIENER [1886] explains the dolines of the karst of the Lebanon on the basis of solution. Carbon dioxide was already commonly taken into account. In a lively discussion among the Viennese geologists, the advocates of the collapse theory were in the majority, constantly introducing new contributions into the speleologic investigations, especially those of the karst of Trieste. Most prominent among them was KRAUS [1887, 1894].

At the same time geomorphology was evolving as a separate discipline concerning karst relief. In Vienna the most prominent protagonist of the new discipline was A. Penck, respected in the whole world thanks to his observations and investigations of Alpine glaciation. The master suggested to his talented student J. Cvijić, that he

should prepare a doctor's dissertation on the subject of karst.

At first Cvijić was occupied with the karst of eastern Serbia. But his main ideas were based on the observations on the karst of Trieste.

CVIJIĆ's work "*Das Karstphänomen*" [1893] was a turning-point and at the same time the beginning of an intensified study of karst morphology. He also paid the most attention to dolines, "which give to the karst a special landscape character". In a cutting of the railway for Trieste, he recorded the connection between the formation of dolines and joints as COX [1874] had done. "Normal dolines" originated under the influence of water which percolated from the surface into the interior, enlarging joints and fissures into "funnels". He argued against the generally accepted importance of collapse of the roofs of caverns. He probably considered karst as primary relief on soluble rocks. This work of Cvijić was not only a pioneering monograph on karst, but also on geomorphology in general. Its special significance lies in the fact that as a result attention was paid to the problems of karst in Penck's world-renowned school of geomorphology.

In 1899, Penck, together with his students, and in company with the American geomorphologist W. M. Davis, gave instruction on field trips in Bosnia and Hercegovina. This meeting in the karst area of two outstanding masters of geomorphology and their discussions were of decisive importance for the further development of geomorphologic concepts.

PENCK [1900] and DAVIS [1901] pointed out conspicuous plains in the karst of Hercegovina and Dalmatia. According to general views and the logical deductions of DAVIS [1884], the formation of the plains was ascribed to denudation and fluvial erosion. Thus, two more schematic views entered into the explanation of karst relief: (*a*) fluvial erosion occurred first, followed by "karstification"; and (*b*) stages of morphologic evolution or of cyclic evolution became obtrusive. Karstification and cyclic evolution dominated the explanations of karst relief during the next four decades.

The reputations of Penck and Davis, as well as their convincing concepts, had also influenced Cvijić, already a leading researcher in karst morphology. CVIJIĆ [1901] accepted the priority of fluvial erosion and used the term "karstification". Among karst features he recorded cyclic relation of evolution, whereby the coalescence of dolines creates uvalas and by their coalescence poljes are formed as the final and largest karst features.

Penck's school was active in developing theoretical treatments of new concepts. GRUND [1903], a disciple of Penck, published a work which meant a new milestone in the development of karst morphology. He accepted the existence of "karst groundwater" rising progressively from sea level towards the hinterland. Above this stagnant level, during the wet seasons, joints and fissures are periodically filled up by water called "karst water" which, being unstable, discharges again very soon. Morphologic evolution occurs toward "karst groundwater" with the final results which represent plains, in the sense of the cyclic theory of Davis. Such treatments were resolutely

supported by PENCK [1904], whose own ideas were thus elaborated.

The concepts of Penck and Grund, deduced with "juridical logic", were followed by numerous disciples of the Viennese morphologic school (E. Richter, N. Krebs, etc.). Grund himself was especially active. Objections and antagonistic concepts were not strong and logical enough to counter-balance the Davis–Penck–Grund concept. Speleologists like KNEBEL [1906], MARTEL [1910] and several others pointed out that the investigations did not confirm the existence of a groundwater level in karst; moreover, individual water streams flowing along fractures and fissures were established. An especially resolute opponent of the Penck–Grund concept was geologist KATZER [1909], who knew the geology of the Dinaric karst very well and was skilled in practical knowledge. According to him water circulates in karst in separate systems of channels instead of interconnecting channels of groundwater with a water table. However, his knowledge of geomorphology was limited.

Although its opponents could not push the Penck–Grund concept aside, they did call attention to its weak points. It was obvious that the evolution of surficial karst features can not be explained without taking into account the circulation of waters through fissures and fractures. This inspired Cvijić to look for a specific explanation of the genesis of the plains which form the basis of the Penck–Grund concept.

According to CVIJIĆ [1909], the plains are formed by means of specific "karst erosion". Surficial erosion is a consequence of sinking water, while in the underground, karst rivers cut in, wash out, and enlarge the fissures. This double action characterized the erosion and planation of karst. His considerations were generalized, and without concrete and illustrative examples. He did not discuss the question of whether the plains were formed independently, or by dislocation of an originally uniform level, although the last may be concluded from the headline of the study. Afterwards he did not return to this specific explanation, but he accepted more schematic ideas of fluvial formation of the plains in karst, which were indicated by Penck and Grund. Such a procedure is curious, because in the same year SAWICKI [1909] published an analogous explanation of plain formation in calcareous terrains.

Sawicki maintained that "terra rossa", which remains after the solution of limestones, closes joints and fissures in karst making a continuous cover, i.e., "Evolutionsniveau", which prevents the sinking of the water and dominates its horizontal flow. His conclusions and deductions are based on the conditions which were recorded in the Slovakian karst. It is noteworthy that not so long ago BIROT [1954a] returned to this explanation of plains, as proposed by Cvijić and Sawicki.

In 1910 GRUND [1910] published his work on the karst relief of the Dinaric Mountains. Very skilled in constructions and deductions he argued against objections to his theory concerning the groundwater level in the karst. On the basis of his observations in the karst of Bosnia and Hercegovina, he delivered his concepts on the evolution of the main karst features and especially of poljes and plains on limestones. He ascribes the formation of poljes to the tectonic movements distinguishing different types. With this work, and the arguments connected with it, the concept of Penck and