L. J a k u c s

THE ROLE OF CLIMATE IN THE QUANTITATIVE AND QUALITATIVE CONTROL OF KARSTIC CORROSION

In the classic period of karst-morphological researches, highlighted by the names of ECKERT, GRUND, CVIJIC, KREBS, KATZER, MARTEL, PENCK etc. and by a deductive analysis of the karstic phenomena and processes of the temperate zone, a synoptic approach to karsts was developed, an approach that generalized on a global scale the forms and contents of the system of karst categories characteristic of Central and Southern Europe. In other words, the geomorphologists, of that time considered the characteristic features of the Dinaric Karst, of La Causses /France/, etc. to be the morphological criteria of karsts in general, For this reason, any limestone area in which these features could not be indentified was not even considered a karst in most of the cases.

This principle is reflected by almost all karst definitions of the first half of this century and the approach of various authors to the problem is also basically brand-marked by this attitude. The geomorphologists recognized no qualitative but quantitative differences to be manifested in by the various climatic zones with regard to karstification. Hence, those early descriptions of totally different type, which reported on limestone denudations /e.g. DANES 1914, 1916. H. LEHMANN 1936, MEYERHOFF 1938, etc./, could enjoy a rather limited scope of interest and did not awaken any attention even though their authors may have spoken of karstification in these cases, too. Inspired in their developments by DOKUCHAEV's teachings, Soviet geomorphologists /MAKSIMOVICH 1947, APRODOV 1948, GVOZDETZKY 1947, 1950/ were the first to emphasize that the notion of karstification should be widened on the basis of certain criteria of climatological zonring. Thus, besides normal karstification and associated classical karstic forms, they already distinguished the thermokarst /forst-induced karst/ of the glacial belt and of the tundra areas and did describe both the processes of pseudokarstic mechanism and the resultant specific landforms. /For additional information, see BOC 1957/.

These studies were soon followed by pioneering publications evaluating the variety of specific high altitude karstic forms /RATHJENS 1951, 1954/ and then, almost simultaneously with the Soviet developments, by H. LEHMANN's /1948/ and BÜDEL's /1951/ first works which, unlike their earlier publications, presented in the light of genetic classification the qualitatively quite peculiar morphological products of tropical karstification.

After that, in the 1950's and 1960's the number of studies on climatical karstic morphology by both Hungarian and foreign authors increased by leaps and bounds, and a considerable progress was made, above all, in the understanding of tropical karstic processes and phenomena. On one hand, papers of general character on phenomenological investigations were published, on the other hand, newer regional descriptions were produced.

Of the first group the works of H. LEHMANN /1954/1, 1956, 1960/, WISSMANN /1954/, KOSACK /1952/, CORBEL /1954, 1955, 1959, 1961/, SZABÓ /1957/, GVOZDETZKI /1958/, KLIMASZEVSKI /1958/, BIROT /1959/, RENAULT /1959/, BÜDEL /1963/ and SWEETING-GERSTENHAUER /1960/ are most important, whereas of the regional landscape descriptions, which might be regarded as being of classical weight, the publications of H. LEHMANN /1954/2, 1955/, CRAMER /1955/, GLENNIE /1956/, WISSMANN /1957/, GVOZDETZKI /1958/, KUKLA /1958/, SAINT-OURS /1959/, SUNARTADIRDJA-LEHMANN /1960/, GERSTENHAUER /1960, 1966/, WHITE /1962/, SMITH /1963/, DOUGLAS /1964/, MAXIMOWITSCH /1964/, VERSTAPPEN /1965/, TSCHIKISCHEV /1965/ and ROSE /1966/ have to be quoted. As for the Hungarian authors, a few comparatively more important literary products of this kind have even be on critically reviewed by A. KÉZ /1959, 1960, 1963/, and D. BALÁZS. Moreover, D. BALÁZS was in the lucky position that he could supplement the data known from literature sources with his local observations of his own.

However great number of works of general and regional object were published on the morphological effect of climatic changes on karstification, the lack of a uniform stand as to the differences in dynamism of karstification of different climatic zones is still obvious and the conception some authors have inherited from the classical karst-morphological school with regard to the interpretation of karstic corrosion mechanism is still confronted with irreconcilable contradictions when compared with the ever increasing multitude of observed facts.

In fact, according to the conventional model of the mechanism of karstic corrosion, as expounded in text-books, the CO_2-absorbing capacity of wated and, consequently, its corrosive power would be inversely proportional to temperature. Thus its dissolving power in polar and other cold regions /e.g. high mountains/ would be higher than that of waters of higher temperature characteristic of the tropical zones. In reality, however, the karstic forms virtually observed in tropical karst areas are suggestive of denudation phases incomparably more advanced as compared to those occuring under cold climates, in almost all of the cases.

With the impressive results of J. CORBEL, the prominent French investigator of karsts, who published in a series of papers such information on the chemical composition of the waters of rivers draining karst areas of different climate which, beside being virtually observed and controllable facts, would readily contribute to the sharpening of the above contradiction it became particulárly difficult to unravel the puzzle. Nota bene, CORBEL pointed out /1954, 1955, 1959/ that the waters of rivers draining karstic surfaces of cold climate were carrying tenfold the amount of dissolved calcium carbonate transported by rivers originating in limestone areas of hot climate. From this observation, he drow the unambiguous conclusion that the rate of karstification in a cold zone is much more rapid than under a warm climate.

For a comparison of the rates of karstic denudation, he compared his regular, daily measurements in the rivers Kissimmee, Florida, USA, and Tanana, Alaska, USA, with data on river waters of other regions. His published results of these comparisons, which are selectively presented in Table I. have since become - we might say - classical.

Table I

Quantitative characteristics of the karstic denudation of limestone surfaces according to J. CORBEL

Characteristics and location of investigated area	Rate of denudation m^3/year/km^2 or mm%-/ year
Mountains with 2000 to 4000 mm of precipitation:	
a/ cold belt: /Northern Norvey, Britisch Columbia/	450
b/ warm belt:/Rio Usumacinta/	45
Low hills and plains with 1000 to 1600 mm of precipitation:	
a/ cold belt: /Quebec, Western Shotland/	160
b/ warm belt: /Rio Champotón Yucatan/	16
/KISSIMMEE, Florida/	5
Plains with 300 to 500 mm of precipitation:	
a/ cold belt: /TANANA, Alaska/ /Central Lapland/	40
b/ warm belt: /Chélif, Orleansville/	4
Plains with less than 200 mm of precipitation:	
a/ cold belt: /Lower reaches of the Mackenzie/ ...	14
b/ warm belt: /Rio Grande at Acacia/	1,4

With the knowledge of the chemical factors of limestone solubility in CO_2-containing water, however, it is aesy to realize that even though in case of the studied rivers of Florida and Alaska the figures calculated from observation data may apparently support CORBEL's suggestion, this approach to the problem has led to one of the most spectacular but false doctrines of geomorphology. This is a tragically typical example of how grave errors for science can ensue from a student's biased approach.

What should be noted in this connection is that in his basic assumptions CORBEL seems to have disregarded a few essential circumstances. Let us quote them herewith:

1. The carbonic acid content of water coming into contact with limestone is also controlled by factors other than the CO_2 contents and temperatures of meteoric waters and of the free air strata met with.

2. The role of the topmost soil layer of vegetation-clad karstic surfaces, layer containing decaying organic matter too, is much more important than that of the atmospherical CO_2 factor, as its soil "atmosphere" exposed to infiltrating water over a large area can have a CO_2 content several hundred times that of the free atmosphere /air/.

3. Also, marked differences /even in order of magnitude/ in the composition of soil atmosphere can be recognized when studied from the point of view of climatic zonality.

4. The CO_2 content of soil atmosphere may largely vary even within one and the same soil, a phenomenon for which the temperatures controlling the life rhythms of soil biotopes are primarily responsible.

5. According to investigations in France by TROMBE /1951/1-2, 1952/, the rendzinas, which in summer have a CO_2 content as high as 10 %, do not show in winter any carbon dioxide just like this component is virtually absent in the lean, vegetation-free soils of high-altitude mountains and polar to subpolar climatic zones.

6. In the humus-rich, rapidly maturing soils of high dynamism of the tropics the carbon dioxide regime is characterized by figures attaining the multiple of even the summer-time concentration levels of the soils of the temperate belt.

7. Limestone corrosion is not only due to the action of the carbonic acid of water; in fact, the other anorganic and organic acids and other compounds are also effective agents, their presence and activity being increased by heat and abundant moisture.

If J.CORBEL would have taken into consideration the above circumstances too, he would surely have formulated diametrically opposite statements as to the intensity of limestone corrosion in the different climatic zones, statements which would have been in accordance with both the up-to-date solubility theories and the inambiguous conclusions deduceable from the analyses of geographic forms. By the way, as would result from conclusions of this kind, tropical karstification must have a rate at least tenfold the figure of glacial karstification rather than just one tenth of it.

Would CORBEL ot mechanically and disregarding the other ecological circumstances - have considered the chemical compositions of river waters drained off from climatically different karsts, he must have realized that not even the data quoted by him did warrant that which the French student wished to prove with them. Namely, CORBEL totally disregarded the fact that even that fraction of precipitations is a limestone-dissolving agent which is finally re - absorbed from the soil by the plants and which then re - enters the atmosphere via evapotranspiration just like it is, say, that fraction which is lost to rived recharge on account of direct soil transpiration and evaporation. This water fraction is the more considerable, the warmer and humid the climate is, for the value of the coefficient of runoff for any area is defined, beside relief and lithology, first of all by the climatic factors of the region.

CORBEL, himself, indicates that wheras out of the 450 mm amount of annual precipitation of the area drained by Tanana river in Alaska, 450 mm /!/, i.e. 100 %, was found to run off a year, of the 1200 mm of annual rainfall of the warm drainage area of Kissimmee river in Florida as little as 175 mm /i.e. 14.58 % that is just one seventh of the annual rainfall in round figure/ could travel down the river.

As shown by the French writer, the 14.58 % runoff fraction of the rainfall carried away 5 m^3 of dissolved limestone a year from each km^2 area of the surface drained by the river. If, however, the total amount of the precipitations could flow down the channel of Kissimmee river too, this would mean that the amount of limestone waste would be as high as five times seven, i.e. 35 m³, per year per km², a figure not so much different from that given for the drainage area of Tanana river - 39.9 m³ per year per km². And yet, we have every right to make a calculation like this, unless we want to make ourselves believe CORBEL's naive argument /which the French writer did not formulate in strict terms, but which he still applied in his conception/ that the $CaCO_3$-dissolving power of rainwater would be defined by river-drianed percentage of rainfall.

Naturally, CORBEL's sophisticated theory has also other essential shortcomings. For instance, he does not take in to consideration that the carbonic acid reaction of $CaCO_3$ dissolution is expressed by a so-called reversible equation, in other words, that the equilibrium balance of the solution is very unstable being sensibly upset by any slight change in environmental conditions. Thus the water of a river affected by typical water--softening agents so eloquently illustrated by CORBEL himself/would not remain hard even if it were fed by hardest possible karstic waters in the source area of the river. For CORBEL writes, himself, that "in the environs of the Kissimmee the grassland is enmeshed by open water tables and by a promiscuous network of tributaries and ox-bows and that the temperature of river water is very high. Its mean daily temperature does rarely drop below 20 °C, being close to 30 °C for 3 months".

All the above circumstances must result in a rapid evaporation of the CO_2 content of the water and its intensive softening during the precipitation of lime. In other words, under circumstances like these, the composition of river water does not give any valuable information about the rate of karstification in the remote parts of the drained area. It does particularly not in the tropics where the degree of carbonic acid agressivity of the infiltrated waters primarily responsible for $CaCO_3$ dissolution and, consequently, for the actual corrosion too, are controlled by a soil atmosphere of high partial CO_2 pressure, and where the amount of dissolved CO_2 in surface rivers is very limited because of most unfavourable conditions for gas absorption. Let us recall in this connection the following chemical regularity: the dissolved gas content of the waters is defined by the partial pressure and temperature conditions existing in both the zone of infiltration and the stretches of runoff, and the higher the temperature of the space of reaction, the sooner a diffusion--absorption equilibrium between environment and solution will be established for one and the same interface.

Otherwise, it is quite natural that the composition of brooks and other watercourses, originating in karsted, barren surfaces of polar regions or high mountains, shows hardly any difference from that of waters in fissures of limestone masses or getting exposed in springs. Nota bene, in these cases there is not practically any noteworthy difference in temperature or partial CO_2 pressure between the air spaces coming into contact with the zone of infiltration on one hand, and with the zone of linear drainage /stretch of runoff/ on the other.

However, the grater the role of soil atmosphere and of ists, mainly biogenic, CO_2 concentration in defining the chemical character of infiltrated meteoric waters, i.e. the warmer the climate, the sharper the difference between the percentage of dissolution and that of removal by running water, to the point that the amount of river-transported calcium carbonate will be practically insignificant as compared to actual wearing away due to karstic denudation--circumstances mostly characteristic of present-day tropics.

Our above dispute with CORBEL has now led us to the formulation of one of the most important axioms of climato-genetic karst morphology. Accordingly, glacial karsts will develop into leached skeletal karsts, whereas the karsts of the tropical belt will be converted into massive karsts because the calcium carbonate masses dissolved in higher levels will reaccumulate in situ or in deeper levels, where $CaCO_3$ is transported vertically, only for the most part or where lateral transport, if any is confined to isolated, local spaces.

This is the explanation for the absence of tufa accumulations in polar karst areas and this is why polar caves are poor in dripstones /TELL 1962, ROHDENBUR-MEYER 1963/. On the other hand, this relationship also accounts for the extremely high rates of tufa accumulation both on the surface and underground, and of stalactitization in tropical karst areas.

It stands to reason that the karstic phenomena of the temperate zones are intermediate, in both quantitative and qualitative differences, between their tropical and glacial counterparts both on account of their geographic situation and climatico-genetical conditions.

However, it is only with a precise knowledge of the complexity and controlling factors of the processes of corrosion that all the above may become logically understandable. Therefore it is quite natural that CORBEL, who had disregarded almost all virtual facts and agents, must have arrived at erroneous results.

That the present writer still has had to enter into details with his criticism of CORBEL' theory /which may have deserved a better lot/ is basically due to the fact that his teachings have embarassed a number of outstanding, modern students of karstic phenomena. Neverthelcss, CORBEL's investigations of climatic karst morphology have produced quite positive results as well. We mean here that the Fench worker has deeply astonished a number of research workers. These went then into defence and set to develop their "anti-CORBEL" which, of course, required to have hosts of new observed data.

The present writer is perhaps not wrong, if he supposes that a part of the valuable contributions to climatical karst morphology which appeared in the late 1950's and the 1960's and which have already been reviewed, were produced as a result of efforts made from these considerations. In Hungarian literature it is the paper of BALÁZS 1963 that provides a cross-section of the matter, though it appears that, as regards a virtually universal answer to the question, there is still a gap to be filled even in the internacional literature which is seemingly due to difficulties of data-collectin - a rather labourintensive and expensive work. Nota bene, CORBEL himself has collectend his 3000 /!/ data of measuring of Tanana and Kissimmee rivers since 1930, so even in view of the mass of information available deos it look appropriate to give an answer in which one is not obliged to relie merely on the "naked sword" of one's conviction of being right.

Even if the international scientific information of the last twenty years of climatico-morphological investigations of karsts were possibly insufficient for a spectacular disproval of CORBEL's teachings, it must be abundant enough to enable one to determine the relative rate of karstic corrosion and, more precisely, the percentage ratios of the agents involved, for each particular zone of the different characteristic climatognetic facies of karst morphology.

The present writer should like to point out once more that he considers, himself, this experiment to be a first approximation which still needs closer scrutiny in many a detail. Further precision is expected to be provided by calculations and assessments by other authors as well as by potencial clarification of new aspects as a result of new information still unknown to the present writer. Still we hope that our calculations and conclusions may, in their basic trends, be devoid of such grave errors as the publication of these results as a basic of discussion ought to be feared.

Let us depart, first of all, of the fact that on the basis of the differences in the karstic dynamims of limestone corrosion the present writer would be able to discriminate five such distinct climatic zones which are though not correlable in some respects with the classical zones of climatical geomorphology /DOKUCAEV 1883, PENCK 1913, BÜDEL 1948, 1963, BULLA 1954/1-2, H. LEHMANN 1954/1, 1956, LOUIS 1964 etc./, but which can be readily distinguished from one another both quantitatively /rate of karstification/ and qualitatively /variety of karstic forms/, these differences being obviously of climatico-genetic nature. The following zones of this kind can be distinguished:

1. High-altitude and periglacial zone comprising the karsts of polar and subpolar regions, the tjäle and tundra belt as well as subnival reaches of high-altitude mountains.

2. Temperate fluvial zone inclusive of the zone of grasslands.

3. Mediterranean zone together with desert steppe areas.

4. Zone of deserts.

5. Tropical karst-morphological province considered here to include the savannah belt and the zone of subtropical monsoon rains, too.

It is a matter of course, that any of the above five groups could be further subdivided. With the present-day availability of information, it would not yet be justified to do so on account of the possibility of secessive assessment of the degree of karstic dynamics.

If the present writer wished to express in percentage values the relative rates of karstic corrosion for different climatical karst-morphological zones, so the results of his calculations, checked multilaterally, would lead him to the conclusion that the ratio of the karstic dynamics of the zone of deserts corresponds, approximate by to 1 %, that of the periglacial and hihg-altitude regions to 6 %, that of the temperate zone 9 %, that of the Mediterranean to 12 %, while that of the tropical province to 72 %. In other words, the rate of tropical karstification is about 72 times that of karstification in deserts, sixfold the figure of the Mediterranean, eightfold that of the temperate zone and about twelve times that of high mountains. On the other hand, the Mediterranean karstic processes them selves attain about one and a half times the intensity characteristic of the temperate zone and twice that of the subnival and sub-polar regions.

Even within these divergencies of the relative orders of magnitude of the rates of denudation, considerable differences are manifested with regard to the percentage shares of the various agents involved in corrosion, as illustrated numerically by Table II.

Table II

Percentage distribution of the genetic factors of corrosion in the most typical zones of climatical karst morphology

/original/. For explanation of numbers 1 to, 5 see Fig. 1.

	high-altitude + periglacial	temperate fluvial	medi-terranean	desert	tropical
1 =	45 %	7%	4 %	30 %	0,5 %
2 =	5 %	9 %	8 %	15 %	2,5 %
3 =	30 %	54 %	55 %	0 %	50,0 %
4 =	5 %	5 %	8 %	55 %	4,0 %
5 =	15 %	25 %	25 %	0 %	43,0 %

In Fig. 1. both the relative rates of karstic corrosion in the different climatical karst-morphological zones and the percentage distribution of the values of agents characteristic of the individual zones, have been shown combined. The figure readily demonstrates those substantial features which make it desirable to pay particular attention in these considerations to the qualitative specifics of the mechanism of dissolution which are at least as important and crucial as are the qualitative divergences of the dissolution processes of the individual climatic zones /Fig. 1./.

At closer scrutiny, however, Fig. 1. may also convince the reader that the single diagrams constituing the columns A-B-C-D-E can be compared with one another within one and the same column only and that comparisons both diagrams of adjacent or farther columns must be confined to relative terms comparisons in absolute figures being impossible. For, in exact quantitative terms, a 50 % share of the biogenic CO_2 factor in the tropical karsts accounting for 72 % of total dynamics /i.e. characterized by extremely high rate of karstification/ dinamics means substantially higher level of partial CO_2 than the same /50 %/ figure does for the temperate belt where the total intensity of corrosion is as low as 9 %.

Therefore, to make the absolute values of the factorial agents of karstic corrosion commensurable, the present writer has calculated these quantitative values by examining how great is e.g. the actual quantitative share corresponding to the 45 % ratio of atmospherical CO_2 in the periglacial zone. After that, the same was, successively calculated for an other percentage value and so on.

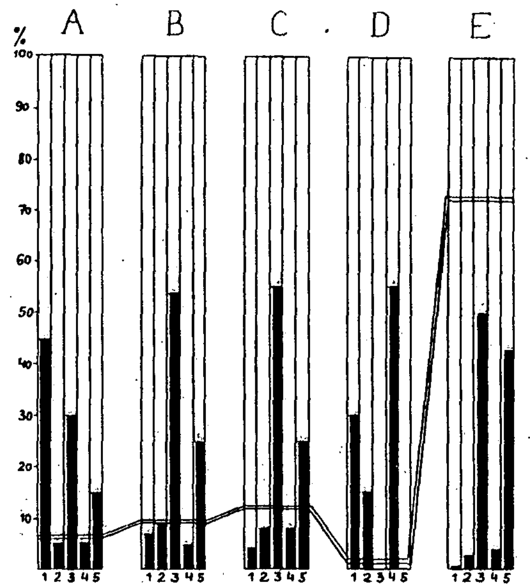

Fig. 1. Relative rates of karstic corrosion and percentage distribution of its agents in the most typical heteoclimatic zones of karst-morphological facies /original/.

Eyplanations: relative percentage intensity level of the dynamism of corrosive karstic denudation in the different climatic zones

Column A = high-altitude and periglacial /6 %/,
Column B = temperate-fluvial /9 %/,
Column C = Mediterranean /12 %/,
Column D = desert /1 %/,
Column E = tropical karst-morphological province /72 %/

Agents of karstic corrosion:
1 = CO_2 fraction of atmospherical origin,
2 = CO_2 deriving from inorganić soil processes /e. g. weathering/,
3 = biogenic CO_2 in the soil,
4 = share of other inorganic acids,
5 = share of organic acids /humic, acid, root fluids, etc./

The method of these new calculations consisted in determining the 45 etc. % values corresponding to 6 % characteristic of the periglacial zone and, naturally, the same method was used for the calculation of the values characteristic of the other climatic zones, too.

The resultant quantitative indices, which now can be really - and very instructively - compared both with one another and with other members of the same horizontal line, are shown in Table III. /In the last column of this table the sums of the quantitative values of the individual factors in the differenct climatic zones are given. Hence, this column is an expression of the global share in corrosion of the factor being considered./

Table III

Absolute values of the factorial agents of karstic corrosion in the most specific heteroclimatic zones as expressed by the ratios of the solubility levels characteristic of these zones /original/.
For explanations of numbers 1 to 5, see Fig. 1.

	high-altitude + periglacial	temperate fluvial	mediterranean	desert	tropical	global share of the factor in karst corrosion %
1=	2,70	0,63	0,48	0,30	0,36	4,47
2=	0,30	0,81	0,96	0,15	1,80	4,02
3=	1,80	4,86	6,60	0,00	36,00	49,26
4=	0,30	0,45	0,96	0,55	2,88	5,14
5=	0,90	2,25	3,00	0,00	30,96	37,11
Total	6,00	9,00	12,00	1,00	72,00	100,00

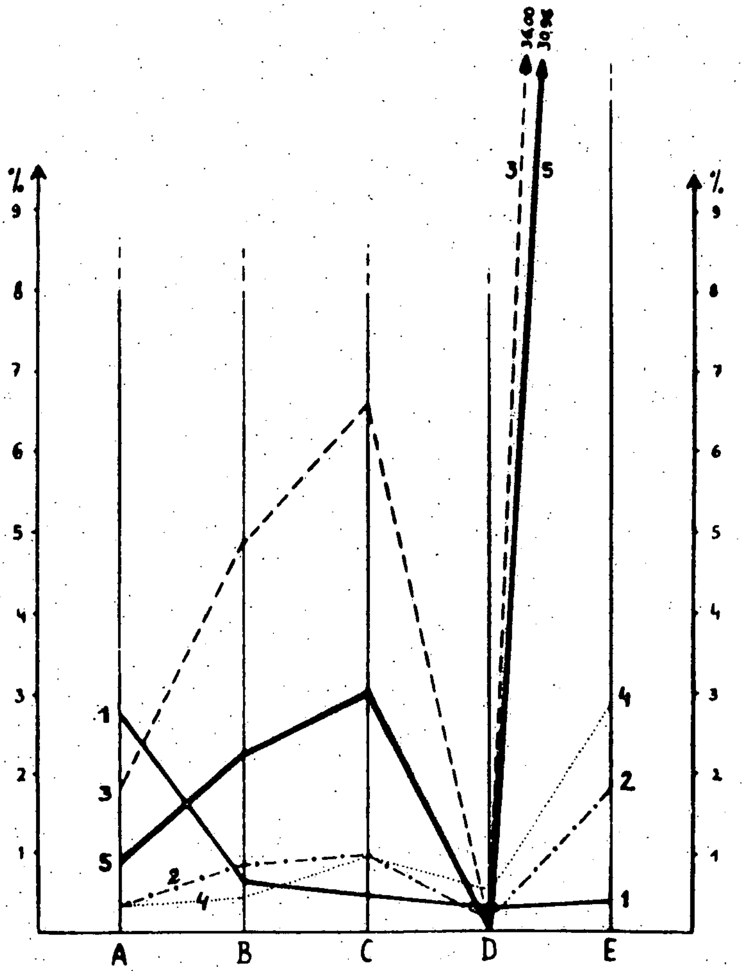

Fig. 2. Absolute values of the efficiency of the individual agents of karstic corrosion as found in the different climatic zones. For explanation of numerals and letter symbols, see Fig. 1. /Original./

If on the basis of Table II a complex diagram of the causal solubility factors of the different climatical facies is plotted, the undistorted, virtual order of magnitude of the manifestations of these agents will be brought into relief a result directly utilisable for the appreciation of karst-morphological problems /Fig. 2./.

In Fig. 2. the individual curves themselves are very instructive, but a comparison of the various diagrams may also prouve rather impressive. Let us review now in a little fuller detail the objective trends reflected by this extremely important figure.

First of all, the secessiveness of the behaviour of atmospherical CO_2 /Curve 1/, as compared to the curves representing the other corrosion factors, is obvious. Nota bene, whereas the lines of the other factors tend to rise markedly with the combined increase of temperature and rainfall, the line of atmospherical CO_2 shows, on the contrary, a trend of abating.

This abating trend is otherwise quite natural, for it reflects the validity for this case of HENRY-DALTON's gas absorption law, i.e. the fact that the amount of gas absorbed in cold water is higher than it is in warm one. /It is this law, and unfortunately just this one, that CORBEL referred to in formulating his ominous generalizations./

The HENRY-DALTON law in se does, however, not account for the differences in orders of magnitude between the "stages" of the descendent line, for the difference in degrees centigrade between the thermal levels of climatic zones A and B is not so high as to account for a considerable drop of this kind. This holds particularly true when considering the farther stretches of the curve, where some substantial thermal level differences /e.g. between B and E/ are though manifested but where these zones do still not differ so greatly from one another inasmuch as the corrosive action ot atmospherical CO_2 is concerned.

As for the cause ot the phenomenon, a possible explanation is certainly that, in A, much of water is precipitated /in form of snow or drizzle in other words, under conditions favourable for the absorption of gases/ and that, once precipitated on the surface, the snow will remain in contact with the air for a long time. It is quite probable that this is practically the only climatic stable dissolution-precipitation zone where an equilibrium of calcium carbonate is established in the infiltration zone mainly in depedence on the partial pressure of atmospherical CO_2 Accordingly, the total amount of absorbed atmospherical CO_2 here is defined by both simple physical gas absorption and the need for gases of the chemical reaction of hydrocarbonate dissolution.

Even though not striking, but still quite easily recognizable is another interesting feature of Curve 1. This consists in that the total amount of water-dissolved CO_2 of atmospherical origin in E /in the tropics/ is a little higher than it is in D. Since in E this cannot be due to a decrease in temperature one cannot help thinking in interpreting the phenomenon, that one has to do with a kind of reflection of the higher general CO_2 level of tropical atmosphere.

All in all, and in comparison to the other solubility factors, however, atmospherical CO_2 must be declared to be a factor rather little involved in karstic corrosion in all but the high-altitude and periglacial /subpolar/ climatic zones and that it is particularly in the tropical belt that its presence and action can be totally neglected in the background of other corrosion agents several times more efficient. /For instance, the effeciency of biogenic CO_2 is exactly 100 times that of atmospherical CO_2!/

Out of the additional diagrams of Fig. 2, the lines of No 2 and No 4 CO_2 produced by inorganic soil processes and other inorganic compounds /mainly acids/ testify to the fact that these factors show but a very low, and relatively subequal, rate of increase with the combined growth of poth temperature and humidity. This is a matter of course, since any higher temperature usually enhances inorganic weathering reactions and since moisture, the carrier of ionic reactions in the soil, renders all this possible. This is why the efficiency of these two factors in tropical limestone dissolution is, as a rule, twice to tenfold the figure characteristic of the other climatic zones, being under all climates except the polar belt, usually a little higher than that of atmospherical CO_2. And yet they have shared comparatively little in the dynamics of corrosion.

It seems to be proper to point out here already, than in climatic zone D /desert/ almost all corrosion factors are characterized by a very reduced rate of action. This is due solely to the lack of water so that the action of biogenic agents is radically cancelled and even the other chemical processes are heavily handicapped.

So it is essentially the poor CO_2, deriving from the air for the most part and transmitted mainly by dewfall, and the low-rate mineralogical reactions of "desert weathering" that are manifested, but their products, if any, are difficult to assess.

The behaviour of Curves 3 and 5 may look rather surprising. As pointed out above, these diagrams are expressions of the shares of the biogenic CO_2 and the organic acids of the soil as involved in karstic corrosion. As evidenced convincingly by the curves, both the factors are excessively sensitive to climate, being the essential agents of karstic corrosion over the major part of Earth's surface. Even in the mostly barren karst areas of cold climate category A, their role is of great importance, being readily manifested with the appearance of lichen over the smallest rock surfaces or with the poorest possible soil bacterial action. In temperate and Mediterranean karstic processes, however, they become crucial corrosive agents. The higher the compactness of the biosphere of earth's surface /particularly so, of its vegetation/ and the less its seasonal biological cyclicity, if any, the more progressive the growth of their efficiency. So in the tropics it is merely factors 3 and 5 that are responsible for the modelling of any karstic landscape.

By the way, the wealth of information published in international literature on geomorphology shows unambiguously, that in the tropics these two last-discussed corrosive agents /biogenic CO_2 organic soil acids/

may gain overhand with respect to the rest of the morphogenetic agents /e.g. linear erosion, sheetwash, derasion, etc./ not only in limestone-built areas, but in areas made up of other rocks as well. Thus in zones of this kind even polymineralic sectors /e.g. areas made up of granites, andesites, etc./ may often happen to exhibit macro- and microforms /e.g. bellshaped mounts, pinnacles, karrs, etc./ suggesting corrosive denudational processes.

An examination of Curves 3 and 5 in Fig. 2 may shed light upon another interesting realtionship. Nota bene, if the A-C stretches of the curves are compared with one another, it appears that the increase of biogenic CO_2 towards C is more progressive than in is the case with organic soil acids. In E, however, this initial realtive tendency of the two factors is rather eliminated, as compared to their absolute height levels 36.00 and 30.96, respectively. In other words, whereas in the Mediterranean zone for instance the corrosive efficiency of biogenic carbonic acid attains more than twice the figure of organic acids, under tropical climate this ratio tends to become an equation as one proceeds towards higher altitudes.

While exploring the causes of the phenomenon, one may have the impression as if the accumulation of biogenic CO_2 in the soil had a maximum level which the corrosive action of organic acids can even keep pace with under favourable conditions but which does not keep on increasing obviously because, one one hand, it is jeopardized by soil transpiration itself, on the other hand, because too high a concentration of CO_2 is a drawback

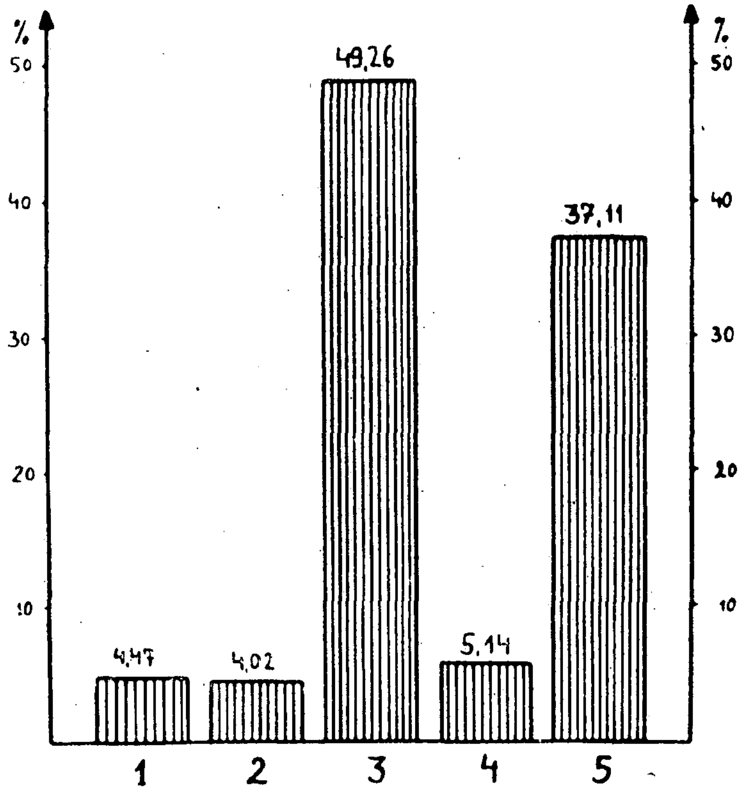

Fig. 5. Distribution of the main corrosive agents are reflected by the karstic denudation of calcereous rocks on the global /planetary/ scale /original/. For explanation of column numbers 1 to 5, see Fig. 1.

to the living conditions of the soil biotope itself /for it may stop the gas-producing biogenic processes themselves/. It if still very difficult, however, to formulate this theory in strict terms, for no direct investigations into this problem have sor far been undertaken under tropical climates. Thus it is quite possible that expedient investigations of coming years may bring into relief another aspect of the relationship.

To make clear the absolute global /planetary/ values of the limeston-eroding efficiency of the main agents of karstic corrosion, the present writer has also plotted in Fig. 3 the numerical data of the outside right vertical column of Table III.

In the light of the evidence provided by figure, we need not worry about formulating the most important result of the present writer's investigations. Accordingly, the natural karstic corrosion of calcareous rocks is geneticaly nothing else than the phenomena of the biological and chemical evolution of the rock-covering topsoil as reflected by the soluble bedrock.

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