西藏岩溶溶蚀微地貌分布和形态学分析

章 典
(西印度群岛大学地理系)

摘 要

在寒冷、干旱、高海拔的西藏,多种岩溶溶蚀微地貌形态分布在几乎所有石灰岩出露地区。在西藏北部的安多、中部拉萨和南部定日,三个地区有不同的气候条件,但石灰岩溶蚀性相差不大。

研究表明,现代气候条件和气候区控制着活形态的分布和发育。现在正发育的活形态中,只有一些溶盘,雨痕和梳状溶沟。在降水较多的拉萨和定日的者不日山顶,都有较多的活形态发育。但由于降水形式不一,活形态的发育也有差异。雨痕只发育在降水主要是阵雨的拉萨,而且梳状溶沟也较多。但在以降雪为主的者不日山上,没有活雪痕和较少的梳状溶沟,但确发育起源于降雪的曲沟。在定日山谷内,由于极为干旱,没有活形态出现。在安多,土壤的发育给一些小型溶盘和溶槽发育创造了有利条件。分布最广的溶盘属生物成因。

在任何石灰岩地区都可以发现大量各种类型被风化的岩溶溶蚀微地貌形态,这些形态的尖棱部位都被寒冻风化破坏。这些形态曾被用于去证实第三纪古气候,但这种形态在青藏高原要保存几百万年是不可能的,最可能的情况是这些形态发育在全新世暖湿时期(例如大西洋期)和晚更新世。

地表水流的水量和微地形也影响形态的发育。例如线性水流导致了梳状溶沟和曲沟的发育,但梳状溶沟产生在较大倾角的岩面并且水流较为分散。曲沟在微倾的岩面上,水流较为集中。对形态的测量、统计和形态分析并没有发现他们与其它地区同种形态的形态学差异,但活形态的发育表明在这世界屋脊上,现代仍有微弱的岩溶溶蚀作用在进行。

DISTRIBUTION OF TIBETAN KARREN AND THEIR MORPHOGENETIC ANALYSIS

Zhang Dian
(Department of Geography University of the West Indies Jamaica)

ABSTRACT

Study areas for karren investigation are Lhasa, Dingri to the south and Amdo to the north with different climatic conditions in Tibet. Morphometric analysis shows no significant differences between the karrens in Tibet and those in other part of the world. There are many types of karren even in such cold, dry and high plateau like Tibet. The important factors to control them are form of precipitation, type and quantity of surface water flow, and land slopes. Active karrens are found extensively in Lhasa and on the top of Mt. Zebri in Dingri for the relatively heavy precipitation, a few of them found in Amdo area. Thus, under the present climate in Tibet karst actions can still be going on , though not very extensive. Most of the karrens are relic forms with edges or crests blunted or half-blunted, and with bottom covered by tufa films. They may have been developed in the warm and wet period of Holocence, mostly during 8000～3000 years Bp — — Atlantic, or the time not earlier than Late Pleistocene, for no karren developed before could still be preserved after so long time.

INTRODUCTION

The major karst landforms encountered on limestone outcrops throughout Tibet were caves and karren, varieties of karren being found during the expeditions to the Tibetan Plateau (Tab. 1). As some authors thought that such landforms could not develop under the present Tibetan climate and used them as the evidence to infer the Tertiary hot and wet climates in Tibet (Chui, 1979 and 1983). This paper examines how the development of such forms is influenced by the climatic, morphological and hydrological conditions in Tibetan Plateau.

The author: Zhang Dian, Male, 40 years old. 1981 MSc in Geography(karst) of Guizhou Normal University, 1991 Ph. D. in Geomorphology(karst) of UK Manchester University. Senior Lecturer of Geography, University of the West Indies, Kingston 7, Jamaica.

Karren are widely developed on carbonate and sulphate rocks. They are the dissolutional landforms most frequently encountered on other rocks such as sandstone, quartzite and granite (Ford and Williams 1989). According to Eckert (1895, 1902) from the old High German word char (kar) which means a bowl, karen or karren are usually named according to their hollow form (Bögli, 1980). The name "karren" originally being used to describe a solution runnel cut into limestones, but now used for the whole complex of microforms that occur on the outcrops of karst limestones (Sweeting, 1972). Previously these micro-forms were given local names according to their features. The names of the Tibetan karren used in this study are based on the classifications of Sweeting (1972) and of Bögli (1979) with some omissions and additions.

The genetics of karren are complicated, especially those in tropical karst areas. Although there is a lot of literature concerning them (Sweeting 1966, 1972; Bögli 1951, 1960, 1979; Bauer 1964; Jones 1966; Dunkerley 1979; Ley 1979; Ford and Williams 1989), many problems remain unanswered. Fortunately, the main forms of karren in Tibet are not so complex and can be readily classified according their form characteristics (Tab. 1). Karren in three Tibtan karst areas has been investigated, where are 1) Lhasa at the elevation of 3700～4300m a. s. l. in central of Tibet with annual average temperature and precipitation of 6℃ and 485mm; 2) Amdo in northern Tibet, from 4500m to 5300m and annual average temperature being 2℃ and precipitation 300mm; and 3) Dingri in southern Tibet, its annual average temperature being 1℃ and precipitation from 200mm in valley (4200m) to 500mm on the top of Mt. Zebri.

The main factors affecting karren are petrology, climate (past and present), hydrology, hydrochemistry, biology and landforms (Sweeting, 1972). The solubility experiments of Tibetan limestones have already shown that there is no large difference between solubilities of the limestones and the hydrochemical analysis presented that $CaCO_3$ in fresh waters reduced with rising elevation (Zhang, 1991). However, as karren vary in size, type and form and the influence of these factors on variable types of karren is different, an individual analysis of karren will be carried out in this paper.

RAINPITS

Rainpits are nearly circular in plan view and are shaped in cross-section and appear in groups on horizontal and inclined bare limestone surfaces. They range in size from 0.4 to 0.9 cm in planar diameters and from 0.1 to 0.7 cm in depth. They occur throughout Tibet, but vary in size in different areas, as indicated by measurements of rainpit depth, diameter and radius of curvature. Measurements were only done on horizontal limestone surfaces to avoid errors in diameter measurement due to the influence of slope.

Tab. 1 Karren classification of Tibet

Type	Average size	Free or covered	Horizontal or inclined	Sharp or Smoothed crests and edges
Rainpit	5~10mm in diameter	free	horizontal	sharp or blunt
Rillen-karren (Solution flutes)	6~25mm wide up to 50mm long, 3~10mm deep	free	inclined	sharp or blunt
Solution pan	2~100cm in diameter, 1~20cm deep	free or covered	horizontal or inclined	smoothed or sharp
Wall solution runnel (waud-karren)	3~15cm wide 3~10cm deep up to 10m long	free	vertical	sharp or blunt smoothed
Solution grike	0.5~10cm wide, up to 10m long	free or covered	horizontal or inclined	sharp or blunt
Meandering solution runnel	5~20cm wide, 3~10m deep, up to 20m long	free	inclined	sharp
Wall solution trough	10~40cm wide, 5~20cm deep	covered	horizontal or inclined	smoothed

The mean diameter and the ranges of diameters of rainpits are nearly the same in the three areas (Tab. 2). The diameter of rainpit is not related with the amount of precipitation and the limestone petrology because these areas have large precipitation and petrological differences. Compared to the diameter measurements, differences in mean depth are quite large. The mean depths of rainpits in the Lhasa Valley are the largest, which may be related with the higher precipitation in the Lhasa Valley area (485 mm/a). The mean radii of curvature of rainpits vary less than their depths.

Tab. 2 Measurements of geometric parameters of rainpits in three karst areas in Tibet

Area	Depth(mm)			Diameter(mm)			Radius of curvature(mm)			Number
	mean	max.	min	mean	max.	min.	mean	max.	min.	
Lhasa	4.2	9.8	1.0	7.9	11.9	5	6.8	14	3.6	139
Dingri	3.1	5.6	1.5	7.5	12	4.5	8.5	21	4.1	36
Amdo	3.0	6.7	1.1	8.1	11	4.7	9.2	19	3.6	45

The explanation of why these disparities occur is provided by field observations. The surfaces of most rainpits in Dingri and Amdo are covered by a film of tufa 0.2 to 3 mm thick, the thickest part of the film being at the bottoms of rainpits. The crests of Tibetan rainpits present three forms (Fig. 1): a, sharp; b, half-blunt and c, blunt. The half-blunt and blunt crests are not the original forms, but result from partial destruction as their rough surfaces indicate. Almost all the crests of rainpits in Amdo are blunt as the outline of most rainpits has been smoothed. The half-blunt crests appear in low and high mountains of Dingri and on the mountain of Lhasa. These phenomena are obviously the results of variable frost action characteristic of particular local altitude and latitude. The destruction of crests and the acquisition of the tufa film decrease the depth of rainpits and influence the radius of curvature of rainpits, but not their diameter. Therefore, most rainpits in Amdo, Dingri and the mountain area of Lhasa are fossil forms, which are not developing under the present day. Only the rainpits in Lhasa Valley are presently developing as higher precipitation, most of which falls in shower form at night (TETCA, 1984). Although the mountain areas of Dingri and Lhasa might receive more precipitation than adjacent lower areas of them, at such elevations, most of the precipitation is snow and hail, which do not promote the formation of rainpits.

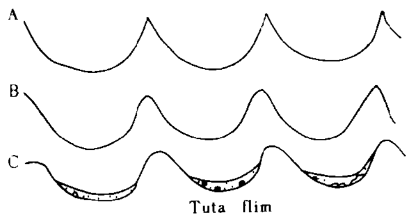

Fig. 1　Rainpits cross—sections

RILLENKARREN (SOLUTION FLUTES)

Rillenkarren are the most common micro-form of karren and have been studied by many authors. According to the classification (Tab. 1), small and geometrically regular rillenkarren belong to a group of features whose form results from very rapid dissolution with no CO_2 diffusion to solution involved, occurring when fresh rainwater meets a limestone surface. Bögli's specific statements about rillenkarren provide a model of the first morphogenetic type of corrosion effects (Bögli, 1979). Dunkerley (1979) studied rillenkarren by morphological measurement and field observation in southern Australia and suggested that extraordinary uniformity of solution flute widths is related to textural characteristics of the exposed limestone surfaces. The quite considerable variation in cross-sectional form of solution flutes is more due to the effects of limestone solubility and mean ambient temperature on the dissolution process, than to rainfall intensity or the hydraulic characteristics of the flow of water over the rock surface.

In Tibetan karst research, Chui (1979) found these forms on the pinnacles in Tibet and used them as a evidence to infer that the pinnacles are relict karst towers or cones which developed in Tertiary. However, any karren would not be preserved for such a long time on the surface. Sweeting (1972) has inferred that formation of rillenkarren is rapid, possibly, in many cases, in the space of a few months to years. In Manchester, England, the surfaces of limestone blocks for building were dissolved into rillenkarren within a few years. In the field solution experiments of the limestone tablets, many frost broken features on the tablets have occurred in only one year time (Zhang, 1991).

In order to investigate the genetics of Tibetan rillenkarren, both field observation and morphological measurement are necessary. Tibetan rillenkarren have the following characteristics apparent in the field:

a)Rillenkarren generally develop on inclined outcrops of finegained pure limestones and marbles in all areas, with slopes of 10° to 74°.

b)All crests between runnels, except some in the Lhasa Valley and on the top of Mt. Zebri, have been destroyed by frost action and planation to differing degrees (half-blunt and blunt) and have a film of tufa, resembling those in the rainpits. Such rillenkarren develop only on the limestone surfaces with yellow coloured tufa. Fresh limestone surfaces exposed recently by physical weathering do not have rillenkarren development.

c)On gently inclined slopes (8° to 17°), runnels are meandering, becoming straightened when slopes become steeper (Fig. 2).

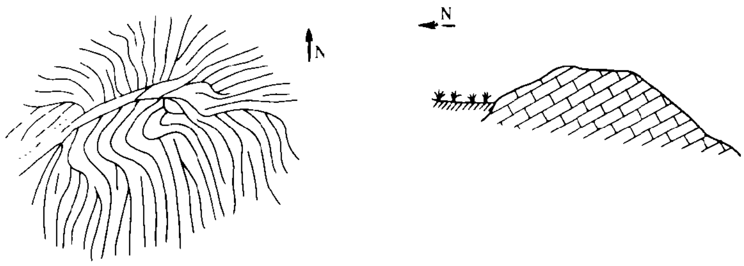

Fig. 2 Plan and cross-section of rillenkarren

d)Wider runnels are occasionally produced where two or more flutes are subsumed into one, with the wider flute disappearing rapidly.

e)The appearance of small scallops in runnel changes with the longitudinal profile of runnel. They occur on steeper profiles and die out before the crest disappears.

As rillenkarren are well-developed on fine-grained limestones, as inferred in other limestone areas by Ford and Williams (1989) and D. Zhang (1982), measurements were made on such limestones and marble in order to eliminate some of the petrological influences. The statistics of the measurements of width, length, radius of curvature, depth and angle of slope are summarized (Tab. 3). From Tab. 3, the following general morphological characteristics emerge:

a)The mean width of rillenkarren in Lhasa area is smaller than those in other areas.

b)The mean length of rillenkarren is variable, but it in the Lhasa Valley is shorter than those in other areas.

c)The mean radius of curvature present similar results to those of rainpits, but the difference is larger;

d)The mean depth of rillenkarren in the Lhasa Valley is the greatest.

Tab. 3　Geometric parameters of rillenkarren in Tibet

Parameters	Lhasa			Dingri			Amdo		
	mean	max.	min.	mean	max.	min.	mean	max.	min
Width(cm)	1.08	2.5	0.6	1.9	3.2	0.9	1.6	3.3	0.6
Length(cm)	11.3	25	5	20.4	74	7	19.3	63	5
Depth(mm)	7.1	15	3	4.2	12	3	3.9	8.0	2
Angle of slope(°)	36	65	12	42	78	21	34	69	11
Radius of curvature(mm)	7.8	48	3.1	14	56	8.1	16	49	7.5
Statistical numbers		204			74			93	

As the statistical analysis presented above is insufficient for full regional comparison, the relationships between the rillenkarren parameters in different parts of Tibet and on different types of limestone are assessed. Like the results of Goudie's study (1989), no significant statistical relationships between the four parameters in different areas and on different lithology were obtained, except for the relationship between slope angle and length of fresh rillenkarren in the Lhasa Valley (Fig. 3).

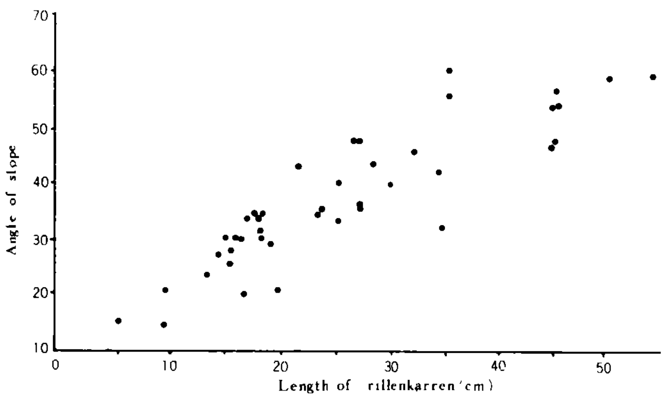

Fig. 3　Plot of length and slope of rillenkarren in the Lhasa Valley

The relationship between slope and length in the Lhasa Valley on the same limestone is clear. Ford and Williams (1989) point out that at many sites it appears that, setting aside textural factors, length of rillenkarren increases with an increase of gradient. It is thus less clear why this relationship of slope and rillenkarren length does not apply elsewhere in Tibet. Possibly, elsewhere the rillenkarren have been partly destroyed by physical (mechanical) weathering, as the half-blunt and blunt rillenkarren sometimes have lost their crests and their original lengths could not be measured. The blunt crests and additions of tufa film lead to the depth of rillenkarren in other areas being more shallow than in the Lhasa Valley and cause the difficulties in establishing relationships between karren parameters in other parts of Tibet and on different types of limestone.

Sweeting (1972) suggested that the rillenkarren in arid and semiarid areas are very fine and small. Bögli (1979) considered that rillenkarren are longest and best developed in the tropics and smaller in colder and seasonal snow covered areas. Lehmann (1953) also pointed out that rillenkarren length increases with slope, temperature and the amount of rainfall, reaching 1 m or more in the tropics. On the contrary, the rillenkarren in warmer and wetter Lhasa are smaller in length and width, but deeper than those in other areas of Tibet. It must be pointed out that the rillenkarren with destroyed crests and tufa film in these areas are dead and dying forms of rillenkarren and they do not reflect present-day climatic conditions. If the conclusions of above authors are correct, there may have been periods when the climate in other higher areas of Tibet was warmer than the present-day climate in the Lhasa Valley.

SOLUTION PANS

Solution pans are basin-shaped, closed depressions on horizontal limestone surfaces. Their initial form is a small closed hollow created from a humus patch or rainpit, or concavity on limestone surface, with the small hollow being subsequently enlarged by solution under the soil and vegetation or by stored water. Solution pans may be divided into two types: covered and free pans. Covered pans form the cover of soil and vegetation. The soil cover often is not very thick and grass grows in it. The vegetation cover is commonly fungi and bryophytes. Solution pans covered by plants are smaller with diameters ranging from 2 cm to 15 cm and depths from a few millimetres to 1 cm. Pans covered by soil are bigger, with diameters of 10 cm to 50 cm and depths of 1 cm to 30 cm. Covered solution pans originate through solution of water with a high CO_2 content and organic acids produced by biological processes in soil. Covered solution pans may be exposed by soil erosion and the death of vegetation.

The initial form of the free solution pan may also be a covered solution pan whose overlying material has been eroded, such a pan forms by solution of the water stored in hollow and often has some rillenkarren at its edge, while the edges of covered pans are smooth. Different types of solution pans are found in different areas of Tibet. In the Lhasa area, especially in the Lhasa Valley, a lot of fresh solution pans covered by grasses and some exposed solution pans are developing. Solution pans of small diameter, covered by fungi and bryophyte are mainly produced in Amdo, where small exposed solution pans also occur but are all relic features. In the lower parts of Dingri no solution pans, either covered or exposed, are developing, but some relic solution pans still exist. Solution pans covered by grasses and many small relic solution pans may be discovered in the mountain areas of Dingri.

SOLUTION GRIKE (KLUFTKARREN)

The greatest amount of solution in compact limestones takes place along lines of weakness in the rock , i . e . along either bedding planes and joints or other kind of fissures (Sweeting, 1972). Where such fissures are horizontal, inclined or vertical, solution along them may take place into limestones forming solution grikes. Bögli (1979) classified kluftkarren as a form produced by gutter and rill water. Actually, it is difficult to determine in the field whether they are formed by solution under soil or by gutter and rill water, because most of them, not only in Tibet but also in many other areas in the world, have been filled with soil. Only when grikes are in their initial forms, they may be distinguished as to whether they are fissure-controlled or hydraulic controlled, the latter is the real form produced by gutter or rill water.

Some grikes are exposed but are rarely found. The widths of exposed solution grikes range from a few millimetres to 40 cm and their lengths from a few centimetres to 10m. The forms of exposed solution grikes differ from those of covered solution grikes. The latter have a smooth cross-section surfaces, but the former mainly have rough cross-section surfaces with some debris infilling. The rough surface is the secondary form, mostly formed by physical weathering. Therefore, it also is a kind of relic feature.

WALL SOLUTION RUNNEL AND WALL SOLUTION TROUGH

Both these forms develop on the walls of limestone outcrops. Wall solution runnels descend parallel to each other vertically down the upper parts of vertical walls in a group. Unlike the rillenkarren, their formation needs a larger water Supply, their size (width, length and depth) is bigger and the distance between adjacent runnels and their relative widths are uncertain. Their size is related to the amount of water flowing along the runnel. Most wall solution runnel are also relic features as their edges have been smoothed by physical weathering and some small solution pans and rainpits have formed within them.

Wall solution troughs develop in the contact zones between soil layer and wall of rock outcrop. They are horizontal or gently inclined and are formed by biokarst action in soils. Their length depends on the length of the compact zone. They are predominant karst forms in northern Tibet, where many wall solution troughs develop at the contact zones between soil polygons and limestone outcrop. However, the depth of the troughs in northern Tibet is less than of those in the Lhasa Valley.

MEANDERING SOLUTION RUNNEL (MÄANDERKARREN)

The meandering solution runnel is a groove cut directly into a limestone outcrop a few centimetres wide and deep. Such forms are on flattish surfaces (Jennings,1971). They remain the same size, decreasing only slightly downslope and usually have small meanders which show both typical undercut and slip-off slopes. The formation of a meandering solution runnel needs a considerable water discharge. Some fresh meandering solution runnels formed by snow meltrunoff have been found in the high mountainous area of Mt. Zebri, a few such features occasionally appear in the Lhasa Valley and in the low mountain area of Dingri. Relic meandering solution runnels, with many small solution pans and rainpits in their grooves, are to be seen in Lhasa, Dingri and Amdo.

CONCLUSION

Summarizing the above analysis, the various karren types in different parts of Tibet (Tab. 4) reflect the characteristics of karren forms in different climatic zones and their evolution through changing climates. At the present day, only wall solution troughs and small solution pans covered by bryophyte and fungi are developing in northern Tibet. Therefore, biokarst action is very important in this area at the present day. In the Lhasa area, many rillenkarren, rainpits, solution pans and wall solution troughs and some solution grikes and wall solution runnel are developing. All karren types discovered in Tibet are being formed on top of Mt. Zebri in Dingri area, where has more precipitation, except for rainpits. But lower part of Dingri has no active karren at all, because of its extremely dry condition. The amount of active rillenkarren of Mt. Zebri is not as great as in the Lhasa area. The difference between Lhasa and Mt. Zebriu results from the form of precipitation, while both of them have relatively more precipitation. Snow meltwater on the top of Mt. Zebri leads to the formation of meandering karren but is not suitable for the development of rainpits and rillenkarren.

The type and volume of surface water flow and the micro-landforms are important factors influencing the type and size of karren. For example, raindrops bring about the formation of rainpits and linear water flow produces solution runnels. The amount of concentrated linear water flow decides whether rillenkarren or meandering karren forms develop on inclined slopes, while the slope gradient of micro-landforms (horizontal, vertical and inclined) determine whether meandering karren or wall solution runnel occur and the differences of rillenkarren length.

Most karren in Tibet are relic karst landforms, and represent the influence of wet and warm periods before present day. These relic karren were identified by field observation and morphological analysis and major types of them are found in all limestone areas in Tibet. They may have developed in the warm and wet periods in the Holocene, highly possibly during 8000～3000 yeas B. P., as they form and are eliminated rapidly in gromorphic terms. Some of bigger karren might occur in the Late Pleistocene, as they could be preserved by tufa film.

Tab. 4 Importance of karren in different areas

Types	LV	LM	DV	LMD	HMD	A
Fresh rainpits	XX	X	—	(X)	(X)	—
Rainpit with destroyed crests	XX	XX	XXX	XXX	XXX	XX
Fresh rillenkarren	XX	X	—	XX	X	—
Rillenkarren with blunt crests	XX	XX	XX	XXX	XXX	XX
Soil covered solution pan	XX	X	(X)	X	(X)	(X)
Planation covered solution pan	XX	XX	—	X	XX	XX
Exposed solution pan	XX	(X)	—	—	—	XXX
Dead solution pan	X	X	XX	X	X	XXX
Fresh wall solution runnel	X	—	—	—	X	—
Dead wall solution runnel	XX	X	—	X	XXX	X
Fresh meandering solution runnel	X	—	—	X	XX	—
Dead meandering solution runnel	XX	X	—	X	X	—
Covered solution grike	XX	X	X	XX	X	(X)
Relic free solution grike	XXX	X	—	—	XX	—
Wall solution trough	XX	X	—	X	XX	XXX

LV:Lhasa Valley,LM:mountain area of Lhasa ,DV:Dingri Valley,

MLD:low mountain area of Dingri,HMD:high mountain area of Dingri,A:Amdo:XXX dominant,XX some,X minor,(X) exception and -none.

References

Bauer,F. 1964, Kalkablagerrungen in den "sterrichschen Kalkhochalpen,Erdkunde 18,95-102

Bögli,A. 1951, Problem der Karrenbildung. Z. Geomorphologie. Geogr. Helv . 3. 191-204

Bögli,A. 1960, Kalkl" sung und Karrenbildung,Z. Geomorph. , supplement issue ,2,4-21

Bögli,A. 1978, KARST HYDRGRAPHIE AND PHYSICAL SPELEOLOGIE. Springer,Berlin

Chui,Z. 1979, Palaeokarst on the Qinghai-Xizang Plateau,Nature 2,14,China

Chui,Z. 1983, Karst,in TIBETAN GEOMORPHOLOGY,Science Press,155-166

Dunkerley,D. C. 1979, The morphology and development of rillenkarren,z. Geomorph. ,N. F. Vol. 23,3,322-348

Ford,D. C. and Williams,P. 1989, KARST GEOMORPHOLOGY AND HYDROLOGY. Unwin Hyman Ltd.

Goudie,A. S. et al. 1989:Lithological control of rillenkarren development in Napier Range,western Australia,z. Geomorph. Suppl. Bd. 75. 95-114

Jennings,J. N. 1971, KARST,London:M. I. T. Press

Jones,R. J. 1960, Aspects of biological weathering of limestone pavement,Proc. Geol. Assoc. London 76,421-423

Lehmann,H. 1953, Karstentwicklung in der Tropen,Umscan in Wiss. Tech. 18,559-562

Ley,R. G. 1979, The development of marine karren along Bristol Channel coastline,Z. Geomorph. N. F. Suppl. Bd. 32, 75-89

Sweeting,M. M. 1972, KARST LANDFORMS,London:Macmillan

TETCA (Tibtan Expedition Team of Chinese Academy)1984, TIBETAN CLIMATES,Science Press

Zhang,D. 1982, KARSTOLOGY,Guizhou Normal University

Zhang,D. 1991, EVOLUTION OF TIBETAN KABST AND LANDFORMS,University of Manchester