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THE ANKARANA TSINGY AND ITS DEVELOPMENT[1]

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Abstract: The Ankarana Tsingy is presented from Madagascar. Various investigations were carried out on the tsingy. The tsingy has two occurrences: the Ankarana Tsingy and the Bemaraha Tsingy. The Ankarana Tsingy is built up of giant grikes, which developed along cracks and such smaller different karren forms, which are on surfaces between the grikes. Assemblages of tsingy can be distinguished by analysing the patterns and the sizes of the grikes. According to its morphology the tsingy can be blade tsingy, clint tsingy and tower tsingy. The grikes developed during non-soil dissolution. Rainfall percolating into the cracks created grikes where as the karren forms of the clints were created by rainfall falling on the surface of the clints. By using our measurements and data we describe the development of the tsingy. The young tsingy can be clint tsingy and blade tsingy. Clint tsingy develops if the grikes are created along cracks which are perpendicular to each other and those are far from each other. Blade tsingy develops if grikes are created along creaks which have a single direction and their density is great. Old tsingy develops from the clint tsingy when grikes widen. It can also develop from the blade tsingy if grikes are created along a new direction. And these grikes dissect the ridges of the blade tsingy. Towers (tower tsingy) develop during the process. Destroying and destroyed tsingy develop if the towers fall due to their destroying process.

Keywords: karren, grike, blade tsingy, pinnacle tsingy, clint tsingy

1. INTRODUCTION

The forms of the Ankarana Tsingyes are presented. The development of the forms and the origin and development of the Ankarana are explained in this paper.

The tsingy which developed on the tropical zone is made up of giant grikes field where grikes perpendicular to each other. The tsingy occurs in two places in Madagascar (Fig. 1). Which are the following: the Ankarana and the Bemaraha Tsingy. As far as terminology and typology are concerned, Ford & Williams (1989, 2007)

[1] We organized a research expedition to research the Madagascar tsingy in 2003. The members of the expedition were researchers of the Physical Geographical Department of the University of West Hungary. We, the authors, represent the results of the researches of the Ankarana Tsigy in this study.

distinguished the following assemblages of tropical karren: Karrenfeld, pinnacle karst (including stone forest), and corridor karst (including labyrinth karst). The Ankarana Tsingy and the Bemaraha Tsingy are different in their morphology, size and their development too. Different karren forms dominate the Ankarana Tsingy while, there are great grikes, which developed from caves on the whole Bemaraha Tsingy (Veress et al. 2008). According to Salomon (2006) the Bemaraha Tsingy is a special tropical karst, which we must distinguish from Stone Forest. We think that the Ankarana Tsingy is tropical assemblages of karren because of their forms and their development, but we consider the Bemaraha Tsingy as a characteristic tropical karst because of its development, and concerning the publication of Salomon (2006).

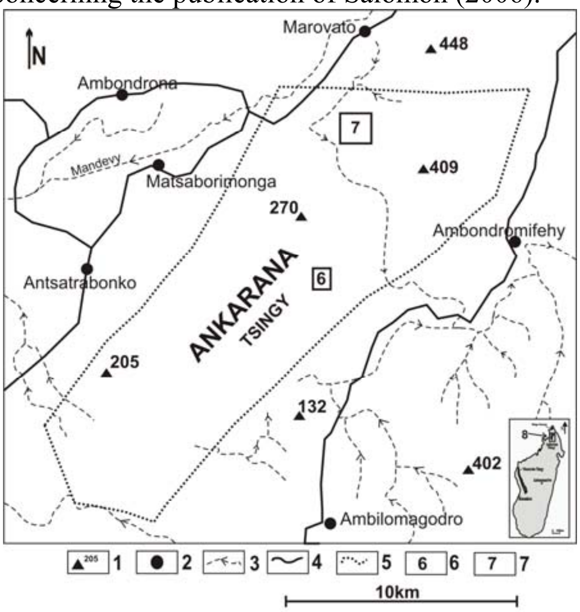

Figure 1, Map of the Ankarana Tsingy and its surrounding map based on the map made by Balázs (1980)

Legend: 1. altitude point, 2. settlement, 3. stream, 4. road, 5. board of National Park, 6. Little Tsingy, 7. Great Tsingy, 8. the place of the Ankarana Tsingy in Madagascar

Several different karren forms occur on the clints, which are between the grikes or on the top of the pinnacles and on their slopes on the tsingy. Karren forms are small forms of the karsts. Karren forms developed on surfaces without soil and assimilate to karren forms of high mountain such as rillenkarren, rinnenkarren etc (Fig. 2). The sizes of these karren forms are like for example the sizes of Alpen karren too, but their density is greater. The karren forms of the tsingy and their characteristics are the following:

● Rillenkarren are flutes with the same direction as the dip of the slope. The depth and width of the flutes are a few centimetres. Their length is of a few decimetres. They widen at their ends.

● Rinnenkarren create troughs. The direction of the trough concedes with the line of the dip of the slope. Their width and depth may be a few decimetres, while their length is a few metres. They are areics and do not taper out at the ends.

● The grikes of the grikekarren are bordered with vertically walls. The direction of these forms does not correspond with the line of the dip of the slope. The width and the depth of the grikes may be several metres on the tsingy. These grikes are already the grikes of the tsingy.
● Kamenitzas are bowl like depressions.
● Wallkarren line on steep slopes. They form channels or troughs.
● Pits are vertical tubes in the rock.

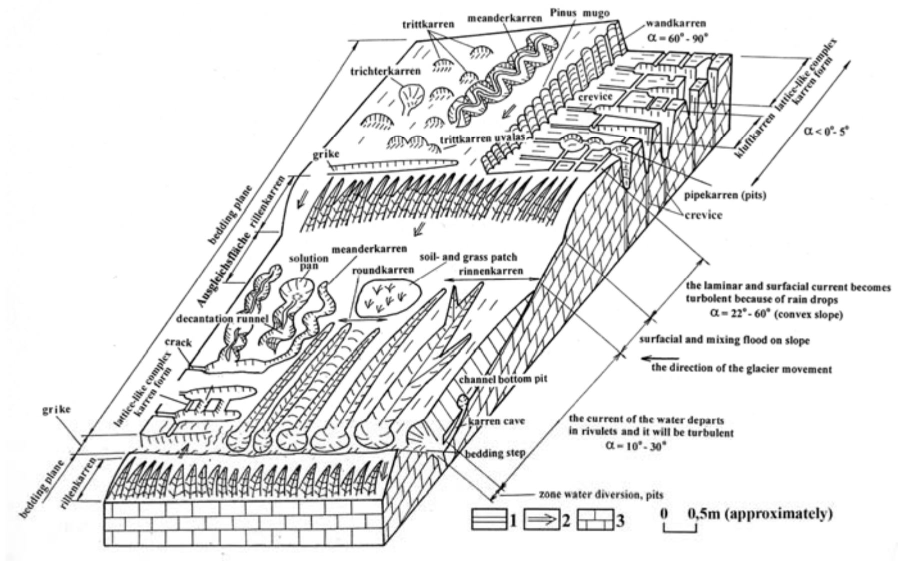

Figure 2, Main karren forms on bedding planes truncated by glacier in the high mountain (from Veress 2007), Legend: 1. crack, 2. line of the dip of the surface, 3. limestone

● Spitzkarren are created from conical-shaped forms. These are solution remain forms. Their height is from a few centimetres to a few decimetres. But forms which are several metres high occur on the tsingy. These forms are termed as pinnacles already.
● The side slopes of the rain pits are vertical. Their depth and width are a few centimetres.

2. RESEARCH HISTORY OF THE TSINGY

The Madagascar Tsingy was described primarily by Duflos (1966), Rossi (1974, 1983) and Salomon (1987). Rossi (1983) presented a few characteristics of the tsingy: for example separated grikes and sabre like mounts occur on the tsingy. The different expeditions researched mainly the caves and the fauna of the tsingy karst (Duflos 1966, Dobrilla-Wolozan 1994, Middleton 1996, 1998). A summary characteristic of the tsingy was given by Middleton (2004). Researchers described such karren which are like the Madagascar Tsingy for example from Brazil (Tricart-Cardoso da Silva 1960), from New Guinea (Verstappen 1964), from Sarawak (Willford-Wall 1965), from Tanzania and Kenya (Cooke 1973) and from West Australia or from East Australia

(Grimes 2005). According to Rossi (1983) tsingy develops due to direct rainfall on such limestone which is very well bedded, clean and has low porosity and full of joints. According to Rossi (1974) the intensity of the rainfall is also important for the development of the tsingy. A rainfall value of 105 mm/hour and 350 mm/24 hours could have been measured on the Ankarana Tsingy. According to Rossi (1974, 1983) and Balázs (1980) the rain water dissolves the uncovered rock and it infiltrates into the rock along the cracks, therefore grikes develop when cracks widen. According to Salomon (1987) the tsingy develops under soil and weathered residual – soil which it loses gradually therefore it becomes uncovered. Rossi (1974, 1976) researched the Great Tsingy first all. He described the characteristics of the rocks of the tsingy , various reasons and facts influencing the development of the tsingy (e.g. the quantity changing of the rainfall).He also distinguished the main features of the tsingy (mounds , which are like swords and needles, further more grikes).He also distinguished grooves in the side walls of the mounds. He also suggested its development, but he did not prove it. We describe and analyze the great forms and features of the tsingy in details in our study. Further more we introduce and identify the karren forms of the tsingy. We investigated the forms, the direction of the great features, and the role of the cracks in their development. We show and prove the development of the tsingy. We describe the development of the tsingy. The forms/features that we distinguished are considered to be the various phases of tsingy development.

3. METHODS

● Altitude and position were determined with GPS.
● A map from a part of the Ankarana Little Tsingy was made. A laser range finder was employed.
● Profiles were constructed by using our data.
● The directions of many grikes were measured (273 pieces). By arranging the data into intervals we gave the distribution of abundance of grike directions.
● We measured the width and depth of the grikes. We ranged the data into intervals.

4. THE CHARACTERISTICS OF TSINGY

The Ankarana Tsingy is situated in the northern part of the island, 70 km to the south of the town of Diego (Fig. 1). This tsingy appears in smaller or greater patches (its total extension is about 200 km^2).

The tsingy occurs in varied morphological surroundings. Therefore it occurs on the apical (on the interfluves on side of valley) or on undivided, low planar surfaces. Their smaller patches occur on bottoms of valleys too. (This occurrence is like Spitzkarren.)

The quantity of the rain water is more than 2000 mm on the Ankarana Tsingy, while the quantity of it is between 1000-1500 mm on the Bemaraha Tsingy. Both occurrences of the tsingy are low, hilly type karst, the altitude of their surfaces is under 320 m asl. The tsingy developed on Jurassic limestone. This rock is tilted along cracks; therefore their beds are tilted into Western direction. The eastern margins of the areas, which formed a cuesta and therefore those, are steep. Surfaces of the tsingy are destitute of various superficial forms. The following crack -directions can be distinguished in the tsingy: NE-SW, NW-SE and ENE-WSW.(Balázs 1980).

Thus canons (Duflos 1966) and valleys of different sizes and shapes occur on the surfaces of the Ankarana tsingy. As there are not solutional dolines, but there are a few collapse dolines and a few swallets (sinks) on the surfaces of the tsingy. The swallets can develop on the margins of the superficial basalt, too. There are inner karst swallets too (Ankarana Little Tsingy). These forms did not develop at valley junction, but they developed as a transformation of collapse dolines.

Ankarana Tsingy has two significant occurances: the Little Tsingy and the Great Tsingy, they are about 20 kilometres from each other. The Little Tsingy occurs on the slopes and top of the ridges, which are between a valley and the collapse doline of Bat Cave. Small sized patches (few meters) occur on the side slopes where the soil is absent. At these places the depth of the grikes are smaller than where the tsingy is on the top of the ridges. Here the area of the tsingy is about 1600 km^2 and its altitude is up to 295 metres asl. Its rock is Jurassic limestone, whose thickness is 200 metres and it is well-bedded. The thickness of the beds is between 30-70 centimetres and their line of dip is 82^o, their angle dip is 10^o. The altitude of the Great Tsingy is little (up to 318 metres asl), and its surface is gently undulated, because it is dissected by valleys and it is situated on the margin of a collapse doline. We estimate its extension about 0.5-1 km^2.

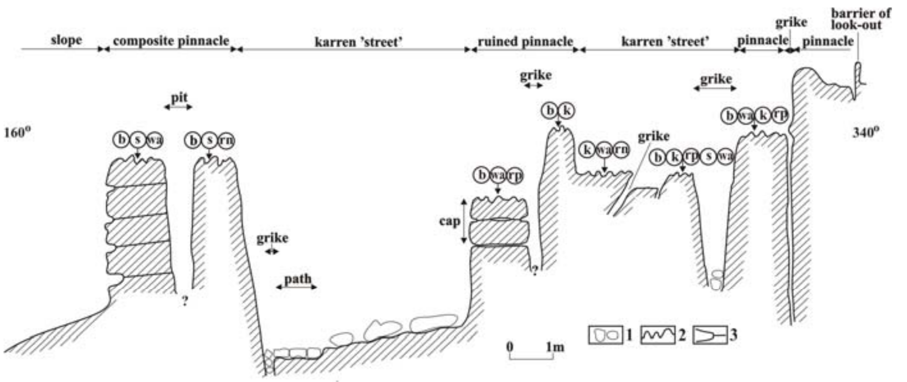

Figure 3, Profile of the Ankarana Little Tsingy

Legend: 1. debris, 2. karren formation on the surface, 3. grike along bedding plane, b: blade ridge, rp: rain pits, k: kamenitza, wa: Wandkarren, s: Spitzkarren, rn: rinnenkarren

The great karren forms of the Ankarana Tsingy are grikes, pinnacles, clints and ridges (Fig. 3, 4). The karrren forms of the tsingy are rillenkarren, rain pits, rinnenkarren, Wallkarren, kamenitzas, Spitzkarren and small ridges. In particular rain pits and rillenkarren are frequent. For example the number of rillenkarren is between 50-98 pieces/metres on different parts of the tsingy. Spitzkarren developed because of coalescence of rain pits. The rillenkarren are ubiquitous on the steep slopes. A series of rillenkarren edge out at the line of the bedding plane, but under the line of the bedding plane new rills occur. There are not solution bevels ('Ausgleichsfläche') on the slopes because of ubiquitous development of the rillenkarren.

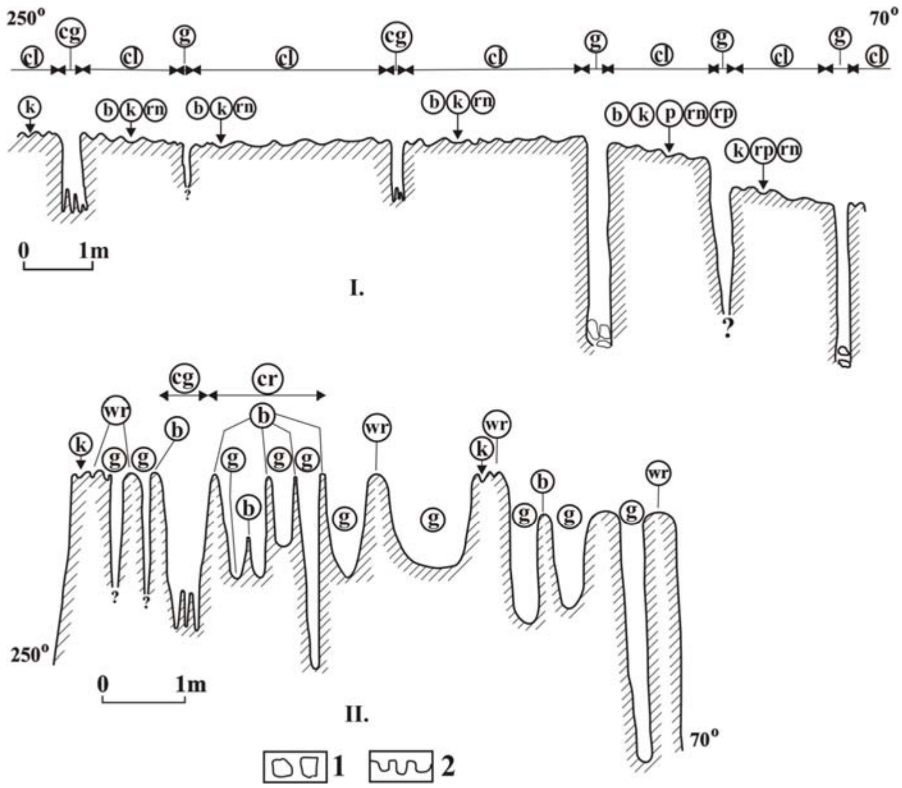

Figure 4, Profiles of the Ankarana Great Tsingy
Legend: 1. debris, 2. karren formation on the surface, cl: clint, b: blade ridge, wr: wide ridge, cr: composite ridge, rp: rain pits, k: kamenitza, rn: rinnenkarren, p: pit, g: grike, cg: composite grike, I. clint tsingy, II. blade tsingy

The width and the depth of the grikes are very varied. The depth of the grikes is between 1-6 metres, while the width of those is from a few centimetres to a few metres on the Little Tsingy (Fig. 6). The directions of the grikes of the Little Tsingy are varied too, and the abundance of those is along at least three directions NNE-SSW, ENE-WSW, NNW-SSE (Fig. 5a). The directions of the grikes on the Ankarana Great Tsingy are less varied. Those are concentrated along two lines which are perpendicular to each other and along directions NE-SW, concerning NNW-SSE (Fig. 5b). We can say that one of the grike directions of the Little Tsingy is the same as the crack direction of the rock. (ESE-WSW) Though two of the grike directions are nearly the same as the crack direction of the rock.(NNW-SSE,NNE-SSW).In the case of the Great Tsingy ,one grike direction is the same as the crack direction (NE-SW) ,though one direction is similar (NNW-SSE).

The depth of the grikes is between 0.5-11 metres, while the width of the grikes is from a few centimetres to 6 metres. But here narrow grikes are typical which have a few tens of centimetres width only on the Great Tsingy. While 78 percent of the grikes are narrower than 1 metre on the Great Tsingy, only 36 percent of the grikes narrower than 1 metre on the Little Tsingy (Fig. 6).

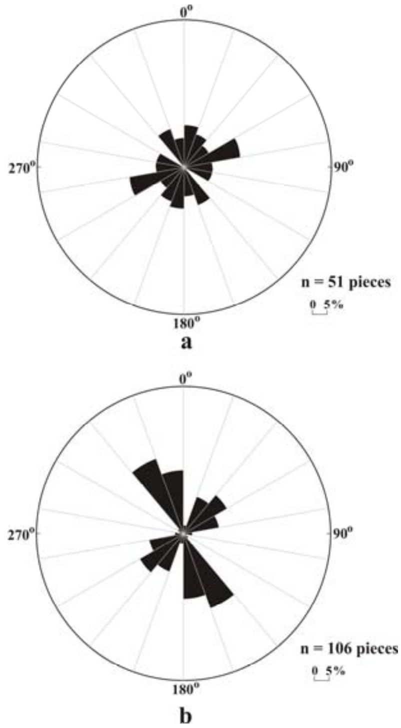

Figure 5: Distribution of abundance of grike directions on the Ankarana Little Tsingy (a) and Great Tsingy (b)

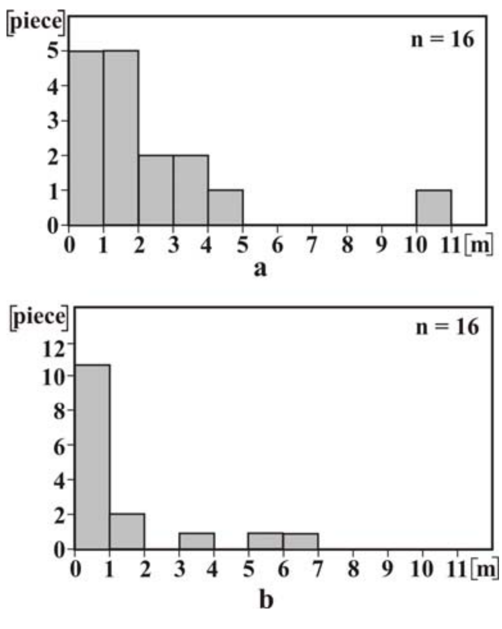

Figure 6: Distribution of abundance of the depth of the grikes (a) and width of the grikes (b) on the Ankarana Little Tsingy

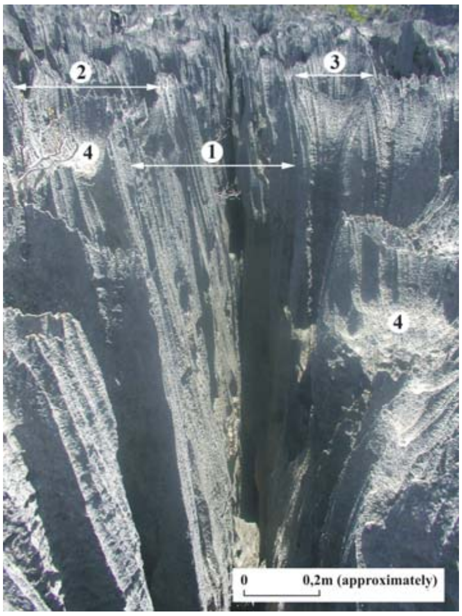

Figure 7, Clint tsingy (Great Tsingy),
Legend: 1. grike, 2. clint, 3. rillenkarren, 4. kamenitza

The following kinds of grikes could be distinguished: simple grikes, composite grikes and karren street. The width of the simple grikes is a few tens of centimetres and those become narrower towards their bottoms (Fig. 7). There are smaller grikes at the bottoms of the composite grikes. The width of the karren streets is a few metres. Those are bordered by pinnacles (Fig. 3).

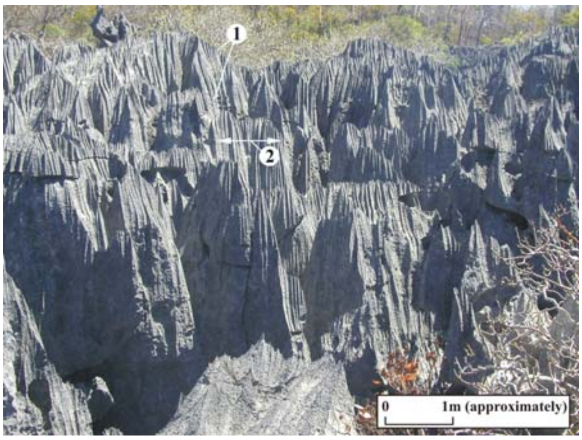

Figure 8, Blade tsingy (Great Tsingy)
Legend: 1. blade ridge, 2. rillenkarren

Figure 9, Blade grike which **is** formed from grikes and ridges (Great Tsingy)
Legend: 1. rillenkarren, with scallops, 2. blade ridge, 3. grike, 4. pinnacle

Figure, 10, Pinnacles build up of the ridges of the blade tsingy (Great Tsingy)

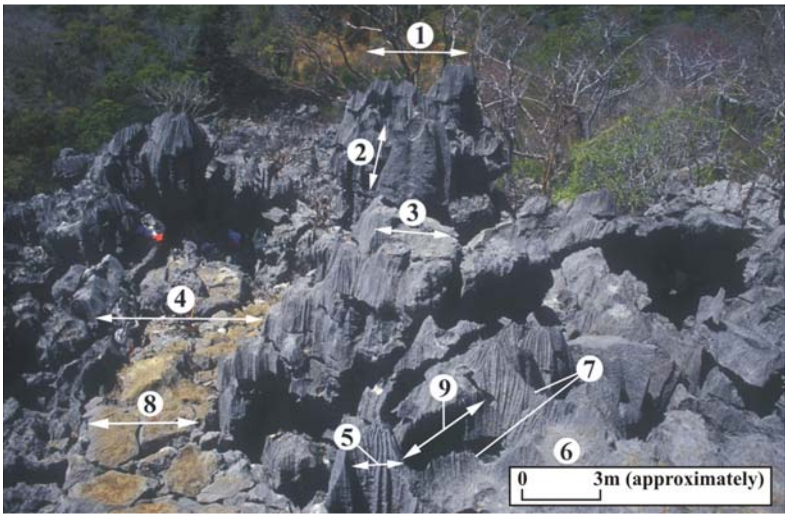

Figure 11, Old tsingy (Little Tsingy). Legend: 1. complex pinnacle, 2. cap, 3. ruined pinnacle, 4. karren street, 5. rillenkarren, 6. kamenitza, 7. blade ridge, 8. path, 9. pit

The ridges (Fig 8, 9) are remnant forms, their height and their length are very varied too. Larger ridges separate the grikes from each other. Ridges can be wide ridges, blade ridges, and composite ridges. The top of the wide ridges is between 0.2-1.0 metres. The top of the blade ridges is narrower than 0.2 metres. There are several blade ridges on the tops of the composite ridges.

The height of the pinnacles (Fig. 10, 11) is a few metres. Their shape is quadratic or elongated in the top-view. The shape of the pinnacles can be a conical tower (Fig. 10), a planar peak tower (the top of the pinnacle is planar, kamenitzas, rain pits, pits, Spitzkarren and blade ridges are frequent on the tops, Fig. 11), composite tower (there are several pinnacles on the top of the tower, different karren forms occur among them and also on them), ruined tower (the top of the pinnacle forms boulders, which are separated from the substance of the pinnacle along the bedding plane) and destroyed tower (the pinnacle has fallen).

5. VERSIONS OF ASSEMBLAGES OF KARREN

The versions of the assemblages of karren of the tsingy are: tower tsingy, clint (pinnacle) tsingy and blade tsingy.

Tower tsingy dominates the Little Tsingy. (They occur on the top.) This type of karren assemblage is made up of giant grikes and karren streets which are connected to each other and have various sizes and shapes and also of pinnacles which are between them and those have different sizes and shapes again (Fig. 3, 11).

The version of clint tsingy assemblage occurs on the Great Tsingy. There are grikes which developed in two directions and are perpendicular to each other and these surround clints (Fig. 4.I, Fig. 7). We distinguish two types of the clint tsingy. The underdeveloped type (younger?) whose grikes are narrower (between 20-50 centimetres) and less deep (their depth is 1-2 metres), the surface of the clints is less dissected. The width of the clints is between 2-5 metres. The karren forms of the clints (rinnenkarren, rillenkarren, blade ridges, kamenitzas) are smaller. Smaller grikes which are between blade ridges occur on the bottoms of the grikes. The grikes of the developed type (older?) are wider (the width of those is greater than 50 centimetres), their depth is greater than 2 metres. The surface of the clints is dissected by karren forms greater in proportion than the clints of the previous type. Great karren forms dominate the clints (for example kamenitzas and uvala kamenitzas with a diameter of a few metres, further more rinnes, blade ridges and Spitzkarren).

The 'blade tsingy' is built by the assemblages of the grikes and grike labyrinth which are parallel to each other but are separated from each other by blade ridges. The grikes can wedge out, connect to each other, they can be straight or winding. These forms are separated by ridges, whose altitude is similar. The depth of the grikes are not great mostly (their depth is between 1-3 metres), but their bottoms are dissected by smaller grikes and smaller blade ridges (Fig. 4.II, 8, 9). The ridges can be dissected into pinnacles (Fig. 10).

6. THE DEVELOPMENT AND EVOLUTION OF THE ANKARANA TSINGY

Basalt occurs on the bottoms of a few greater valleys in the area of Ankarana Tsingy. Therefore it is possible, that a few parts of the tsingy were covered by basalt. However basalt debris could not be found in the grikes of the tsingy, if basalt was created, the development of the tsingy could start after the denudation of basalt.

The grikes of the tsingy developed along cracks. Our observations on the spot, the distribution of the abundance of grike directions (Fig. 5), and concerning literature data can prove this theory. Our observations demonstrate that the development of the grikes happened by dissolution on bare rock surfaces. Namely we observed that there is not soil in the grikes. The sporadic, sickly plants could develop only secondary in the grikes. The soil could not be carried away from the grikes later, namely it does not exist in those grikes either on whose bottoms smaller or greater depressions can be found. The soil cannot be carried away from these places. The soil cannot be carried into the karst either, because the bottoms of the grikes do not continue in narrower grikes or pits. As forms are missing which develop on the walls of the grikes by under soil dissolution we can prove the absence of under soil dissolution. Pinnacle like karst can develop in caves (Tardis cave, Sarawak), too (Siffre 1999). Because this formation occurs in cave surrounding it proves that it can develop if the soil is absent.

We, the authors, think that the tsingy developed where the soil was destroyed. (The development of the tsingy could also begin under surface if this surface was covered by soil before.) The main phases of karren formation are the following (Fig 12):

● Much rainfall infiltrates into the limestone along the cracks and grikes develop from them because the cracks widen. Karren formation can begin already on the clint.

● Younger tsingy develops, which can have two kinds. Clint tsingy develops if the cracks are more distant from each other and they have two directions or only some cracks develop into grikes. Blade tsingy can develop if there is only one crack direction in the rock and the density of the cracks is great and many cracks develop into grikes.

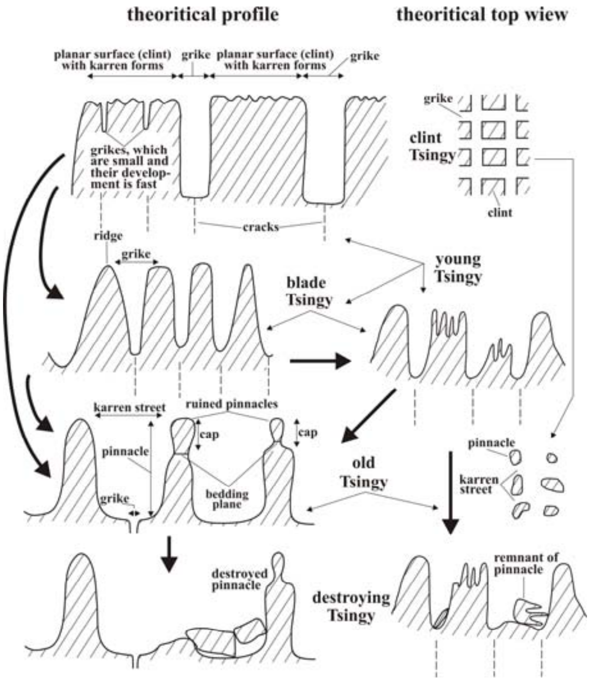

Figure 12, Forming and development of the Ankarana Tsingy

● If the angle of the surface is small, the rainfall which falls on the surface of the clints can be saturated on those places already. Therefore the development of the grikes is slow, but the denudation of surface of the clints is faster. In that case this phase of the clint tsingy development can stabilize. This exists if the denudation of the surface of the clint and the velocity of the deepening of the boundary grikes are identical.

● Pinnacle (tower) tsingy (old tsingy) develops if the grikes (clint tsingy) widen or the dissolution begins at newer cracks on the blade tsingy. In that case the blade grikes of the blade tsingy fall apart along the new grikes. We would like to remark, that Rossi (1974) separated primarily and secondary cracks. Primarily cracks border a clint. Secondary cracks are more characteristic on the inside of a clint. Several pinnacles can develop too on the inside of a single clint along the secondary cracks.

● Towers of the pinnacle tsingy are destroyed. According to Rossi (1974) the towers decrease because of the destroying of the side slopes. The towers fall if they become very thin (destroyed tsingy). The destroying of the pinnacles was described on Sarawak also by Willford-Wall (1965). Such formations occur for example on the Little Tsingy. Boulders develop, which accumulate in the grikes.

7. CONCLUSIONS

The grikes of the tsingy were created by dissolution which happened along the crevices and cracks. Different versions of the Ankarana Tsingy can be distinguished such as clint tsingy, blade tsingy and pinnacle tsingy. Clint tsingy develops when the density of crevices is small, or only few crevices develop in the grikes, or the grikes develop in the same the direction. Blade tsingy develops when the grikes are near each other and their direction is the same. Pinnacle tsingy or old tsingy may develop from both types tsingy. Destroyed tsingy developed from the old tsingy if some of its pinnacles were destroyed.

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