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A MYSTERIOUS KARST: THE "CHOCOLATE HILLS" OF BOHOL (PHILIPPINES)

SKRIVNOSTNI KRAS: "ČOKOLADNI GRIČI" OTOKA BOHOL (FILIPINI)

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Jean-Noël Salomon: A Mysterious Karst: the "Chocolate Hills" of Bohol (Philippines)

A public showcase by the Philippine tourism authorities, and rightly so, are the "Chocolate Hills" of Bohol (Philippines), the strangest karst landform known. These numerous residual relief forms are so perfectly symmetrical that, in order to explain their existence, natural explanations are systematically sidelined by legends, myths and many so-called "scientific" explanations. The object of many television broadcasts related to travel, these karst hills are a particularly original example of mogotes tropical karst; their almost "perfect" aspect had intrigued those who have studied their formation and have given birth to many hypotheses. The genesis of the "Chocolate Hills" is due to the emergence of the Pliocene limestone coralline platform, then to its karstification in a particularly homogeneous tropical climate conditions: rainfall, temperature, wind, pedologic and vegetable covers. In other aspects, their good overall porosity explains their mass impregnation by the runoffs as well as the appearance of important aquifers, exploited for the development of irrigated rice fields. Karst models are present, notably the caves and underground networks of which very few have been explored. Finally this original context (insularity, virgin tropical forest undisturbed for a long time) permitted the sustainability of a particularly original endemic fauna including the famous Bohol tarsier. In June 1998 the "Chocolate Hills" were declared the National Geologic Monument and this national park definitely merits a visit.

Keywords: geomorphology, tropical karst, mogote, cave, hydrology, rice cultivation, natural park, Bohol, Philippines.

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Jean-Noël Salomon: Skrivnostni kras: "Čokoladni griči" otoka Bohol (Filipini)

Glavni adut filipinske državne turistične organizacije, in to z razlogom, so "Čokoladni griči" na otoku Bohol, ena najbolj nenavadnih kraških pokrajin. Ti nenavadni reliefni ostanki so tako popolnoma simetrični, da se za razlago njihovega nastanka izogiba naravnim procesom na račun legend in mitov, da niti ne omenimo številnih lažnoznanstvenih razlag. Ti kraški griči, pogosto predmet televizijskih oddaj o potovanjih, so posebni primer tropskega krasa z mogotami, ki so takorekoč "popolne", kar je povzročalo težave vsem, ki so se ukvarjali z njihovim nastankom in vzbudilo številne podmene. Glavni vzrok nastanka teh "čokoladnih gričev" je dvig platforme koralnih apnencev nad morsko gladino tekom pliocena, čemur je sledilo zakrasevanje v tropskem podnebju v izrazito ustaljenem okolju, tako glede padavin, temperature, vetrov ter pedološkega in rastlinskega pokrova. Zaradi močne poroznosti celotnega območja in posledično prepojenosti celotne mase apnenca z vodo, so v njej pomembni vodonosniki, ki predstavljajo osnovo za namakalno kulturo riža. Zakrasevanje dokazujejo predvsem jame in podzemeljski spleti, med katerimi pa so le redki raziskani. V tem izvirnem okolju (otok, dolgo časa porasel z nedotaknjenim tropskim gozdom) se je ohranilo tudi posebno izvirno endemično živalstvo, vključujoč slovečega boholskega tarzija. Leta 1998 je bil ustanovljen Narodni geološki spomenik "Čokoladni griči", ki je brez dvoma vreden obiska.

Ključne besede: geomorfologija, tropski kras, mogote, jama, hidrologija, pridelava riža, naravni park, Bohol, Filipini.

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INTRODUCTION

The Archipelago of Philippines (about 300,000 km^2 and 90 millions of inhabitants in 2005) is located about hundred kilometres off the Asian continent between Pacific and South China Sea, between 4040´ and 21010´ of the north latitude. It comprises more than 7,100 islands positioned towards the south; Bohol, lying in the Visayas, is about 500 km off Manila (Fig. 2). The island covers about 5,000 km^2 having about 1.3 millions of inhabitants. The island boasts a very original flora and fauna including the famous tarsier (*Tarsius syrichta*) called also Kobolmaki of Philippines being the smallest primate of the world (Fig. 1). The economy is mostly based on agriculture; rice production is especially developed around the *barangays* (villages). The island is almost entirely of limestone, and one of the most beautiful karst landscapes of the world are the "Chocolate Hills", feature that raised a lot of questions related to their genesis.

Fig. 1: The tarsier of Bohol is extremely rare. This is the smallest world primate (from 9 to 15 cm). His DNA is almost 97% of the human (Photo: J.N. Salomon).

NATURAL CONTEXT

The origin of the name Bohol is controversial: either it comes from *Bo´ol*, that is the name of a small tree very common on the island, or, it comes from *boho* (= hole, shaft or even spring), which is also quite plausible as many caves have been registered on the island. But the tourists come to visit the most extraordinary central region full of mogotes (famous "Chocolate Hills").

Smith (1924, p. 195) called this region Haycock Hills (the name was much later used by the geomorphologist Enjalbert for similar areas in Mexico and Central America), meaning the mogotes: he counted 1,268 of them. A bit later (1932) Faustino described this particular region as "*stacks of palays, arranged on both sides of the road, as if the area had just completed a great harvest*". Without a doubt it is Voss (1970) who introduced the term "Chocolate Hills" partly also because of the brown aspect during the dry periods and especially after savannas fires. The term was accepted and finally adopted by the tourist agencies.

GEOLOGY AND GEOMORPHOLOGY

It seems that Philippines are the remains of geological system of mountainous arcs connected to Vietnamese cordillera. The oldest rocks are gneiss, schist and serpentine together with intrusions of gabbros and diabases. At Bohol and Palawan (Longman & Brownlee 1980) the metamorphic base consists of igneous rocks and serpentine (Boheli formation, the Cretaceous–Palaeogene) overlain by Tertiary marine limestone (more than 950 m thick) (Fig. 3). Afterwards the continental erosion developed detritus cover of alluvia, colluviums and different sediments.

In the Eocene the nummulitic limestone was formed resulting in a succession of sedimentation periods cut by huge collisions starting about 60 million years ago. Originally the lowering of the tectonic plate started at the lifting of Borneo and South Philippines, to which belong Visayas and Bohol, together with active volcanism which is recently still going on (at the archipelago 12 active volcanoes are known: Pinatubo, Mayon etc.). Due to lowering of the ocean plate, supporting the bottom of South China Sea below the Asian plate, thick layers of sediments were transported to be accumulated at the border of the second one, below the sea (Fig. 3).

In the Tertiary, 7–5 million years ago, the coral formations started to appear; at some places they lie at the

Fig. 2: Location of Bohol, Philippines.

altitude of 1,000 m. Especially at Bohol, where the Pliocene limestone is lifted and now covers an area of about 2,000 km². Starting at about 280 m at the South China Sea side it goes to 600 m towards NE of the island. This limestone comprises the majority of plains and plateaus base. At the beginning this limestone seemed very homogeneous but in fact it comprises substantial differences in the lithology, mechanical strength and permeability. There are many impurities and layers of gravels. Deep boreholes (> 100 m) cut through resistant less porous limestone facies and also the lenses of conglomerate and sandstone (Fig. 4). These lenses play an important role in the hydrology of the island.

The karst occurrence typical of the interior of the island shows evidences that at a certain time this island

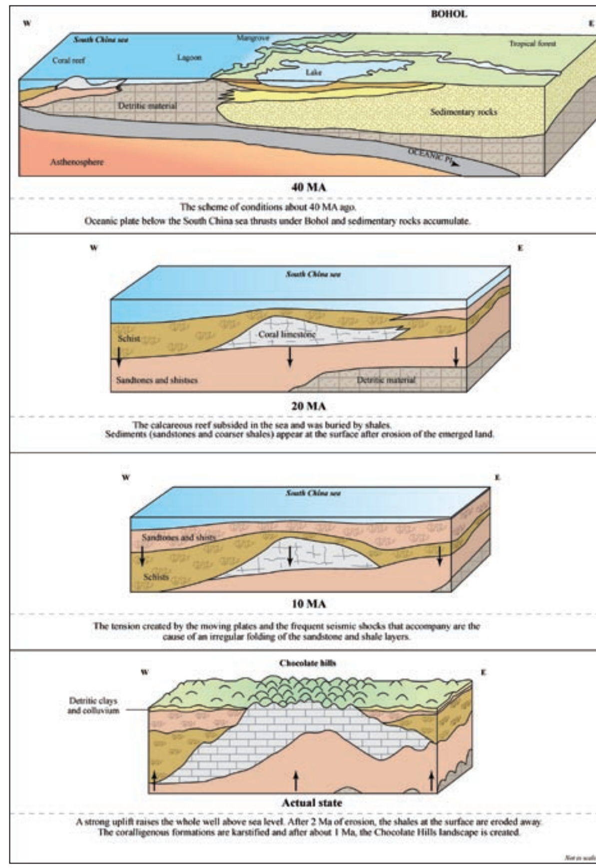


Fig. 3: Hypothesis of the “Chocolate Hills” formation.

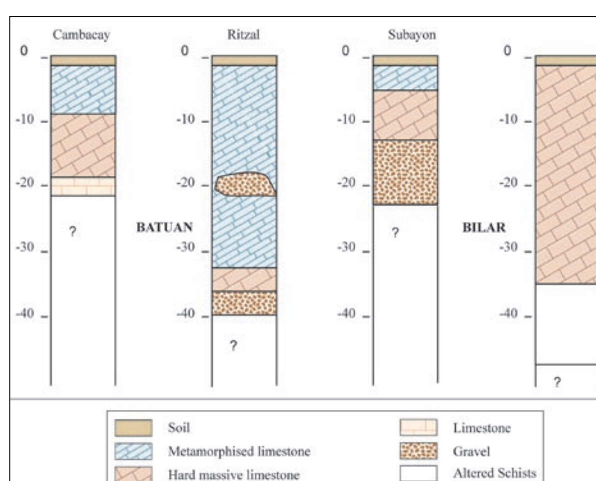


Fig. 4: Lithology of Batuan and Bilar sections. (source: drilling of the Department of Public Works of Bohol).

was below the sea level. Boreholes into the sediments and ^{14}C dating of the marine notch indicate changes of the sea level in the Holocene and thus causing the migration of mangroves around the Abatan River (South west of Bohol). These recent variations were taking place as follows:

– about 8,000 BP the sea level starts to rise and attains -2 m;

– about 4,500 to 4,000 BP it reaches between 0.70 and 1 m;

– finally, from 2,500 BP to today the level remains between 0.70 and the actual level.

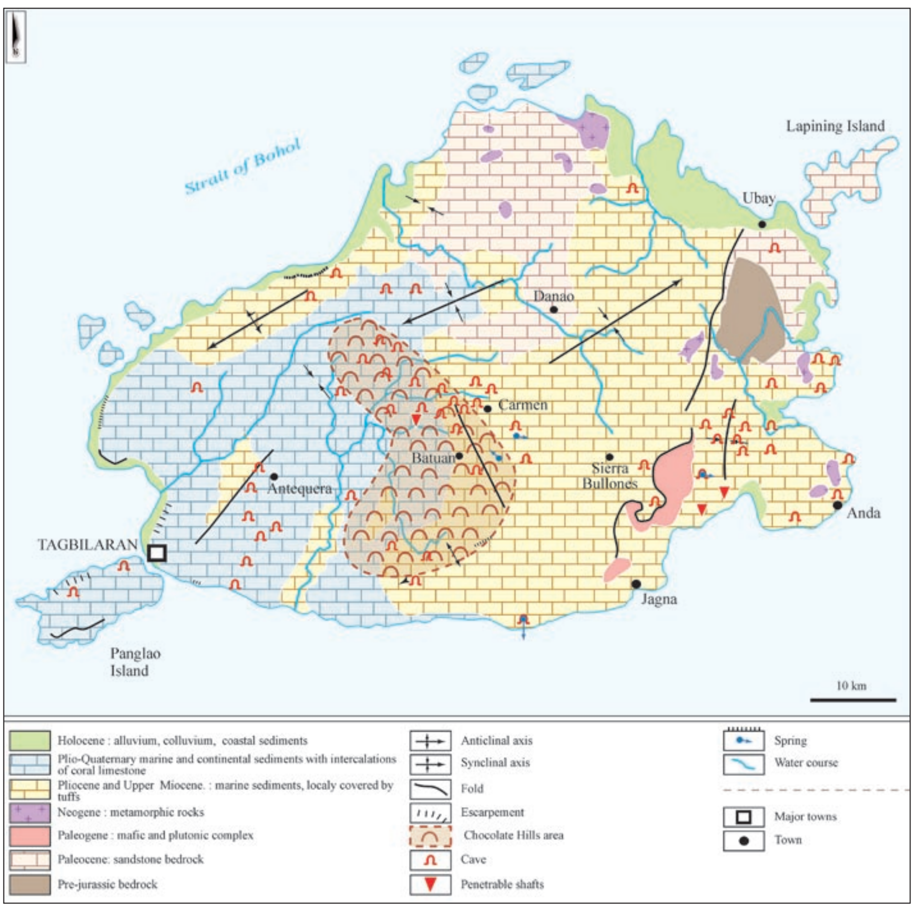


Fig. 5: Geomorphological sketch of Bohol (partly after the map of Philippines 1:1,000,000).

In general Bohol, is composed of a vast karst plateau and narrow coastal plains (Fig. 5). Very schematically four large units may be distinguished in this island:

– north–east consisting of a hilly landscape bordered to the east by a small, slightly elevated ridge;

– west, where dissection is more stressed;

– in the southeast lies a narrow coastal plain bordered by a series of mountains directed east–west;

– in the west, opposite to the limestone plateau, a large coastal plain, distinguished by platform and elevated marine terraces, developed (Hillmer & Voss 1987).

The interior is thus composed of a limestone plateau where one can identify two large groups of features:

1. Three big and large syncline valleys developed in limestone – some refer them as poljes. Nevertheless these are valleys although their origin is partly due to karst. They are gently inclined (few degrees) draining flowing waters towards southwest. Generally these valleys are well fed by numerous karst springs and some small springs flowing from isolated mogotes (a type of hum); all of them at the level of the local base.

2. These valleys are separated by limestone blocks corresponding to well-defined anticlines oriented SW–NE direction. These blocks rise above the valleys for several hundred metres and play a role of impluvium (recharge area for caprock) as they receive a lot of rain (> 3,000 mm against 1,750 mm in the valleys). Feeding is either directly by the rain or by condensation as the area is wooded. In general the groundwater is 30 m deep. This situation is very favourable for formation of karst systems.

In general it is very difficult to see the contacts between anticlines (strongly dissected) and synclines because of alluvium and colluvium and; generally they are complex. Regarding the limestone the inclination is sub horizontal (from 00 to 40) in the SW–NE direction.

The signs of karstification are well visible in details: it is possible to see poljes, karst towers, mogotes, dry valleys, canyons, blind valleys, cenotes, estavellas, many big karst springs (> 1,000 l/s) and swallow holes, in the local language called "*hophopan*". The borders of these swallow holes are mostly planted by taro and thus the locals call them "*taro-pits*". The existence of cultural plants may be explained by the fact that the phreatic nappe is close thus providing excellent growing conditions especially during droughts.

But the principal focus of interest for a karstologist are "Chocolate Hills". There are many mogotes emerging from karst plains covered by thick layers of clay with rice fields (Fig. 6). The most representative terrain is spread over more than 50 km^2 between the Barangays de Sabayan, locality of Carmen and Sierra Bullones. The surface of "Chocolate Hills" has been the object of many evaluations: Wermstedt & Spencer (1967) mention 20 square miles, Teves (1947) speaks of 50 square miles, Faustino (1932) of 100 km^2 and Gonzales of 400 km^2. In fact, it is really difficult to be precise because on one hand one must define what is the precise meaning of "Chocolate Hills" and on the other hand there are many localities where these mogotes appear. Alluvial valleys and cockpits (star-like dolines) are situated between 30

Fig. 6: The "Chocolate Hills" landscape is exploited by tourism (Photo: J.N. Salomon).

and 120 m. The inclination of mogote slopes varies, yet in general it is high (> 8%) but the one of the valleys is modest (< 3%) and ideal for rice growing. Several tufa deposits aer formed in the rivers, often with cascades (downstream the river formed by the Bonogan spring up to 5).

Mogotes are composed of limestone and samples proved that this is mostly coral limestone of red algae (Fig. 7) containing numerous Foraminifera (Myogypsina, *Lepidocyclina*, *Heterostegina* etc.). Their primary porosity in a great deal lowered by the cement fill and matrix was often recrystallized (microsparite). However, this is still poorly consolidated chalky limestone (Formations of Maibojoc and Carmen; Quiazon 1979) acting as a real sponge as it is confirmed by abundant aquifers and numerous subterranean rivers. On slopes there are less water flows due to infiltration.

CLIMATE, SOIL AND VEGETATION

Bohol, as a part of the Philippines, has a tropical ocean climate with intervention of the monsoon. Generally the north-east monsoon prevails from mid October to March and the one from south-west from mid May to September. Thus the climate is hot and especially humid. Annual precipitation is high, more than 3,000 mm in heights and 2,000 m in lowland, most of it from May to June. Also typhoons and tropical depressions (some twenty per year) may occur during the whole year (most often between June and November) causing severe floods. There is only one relatively short dry season from February to April. This is a good time to visit as otherwise the humidity and rainfall as well as temperatures are high. During the year the temperature is rather stable; the annual average is 26 °C. The main factor for strong karstification is a lot of rain and this explains the abundance of caves and subterranean systems.

Fig. 7: A breakdown from a mogote clearly showing the coral origin of the limestone (branch section of Acropora) (Photo: J.N. Salomon).

All the studies related to vegetation cover of Bohol agree that once the whole island was densely covered by tropical forest, but no it has almost disappeared: only 3% remain. Probably this is connected with "*kaingin*" practice (slash-and-burn agriculture) – a type of cultivation where it was partly burnt and used in migration or assigned to be permanent after many years of such use. In Bohol the commercial wood cutting was never present but only exploitation of forest for domestic use (wood for cooking, building, tools). The problem arises with demographic increase and enlargement of cultivated land. Natural forest is rare and appears only in some places at mogotes or steep slopes. In the valleys and coastal plains the actual vegetation is mostly anthropogenic (coconut palm, banana, "useful" trees, etc.) and particularly rice field and other food crops.

On the other side the limestone of mogotes presents a perfect support for trees of the original tropical forest. What is left is mostly a secondary forest (= "*libon*") which consists of of *Dipterocarpacea* and higher up *Podocarpus* with some pines and Asian chestnuts. The mogotes are also due to certain edaphic dryness without a doubt a good terrain for trees with hard wood such as molave (*Vitex parviflora*) or in local language "*tugas*". But even on the slopes less favourable for cultures, the "*kaingin*" slowly disappears as the last protection of soil. And when these last trees will be overcome by erosion the savannah type of vegetation takes place where the grasses such as "*Imperata cylindrica*" will be definitely installed.

THE PROBLEM OF "CHOCOLATE HILLS" GENESIS

Without a doubt the landscape of "Chocolate Hills" gives us a strange purity of forms that the Nature creates from time to time. Numerous mogotes, from 10 to 80 m high, have different shape, but all of them have a remarkably perfect identical geometrical and symmetrical shapes (Fig. 8). From some hill-tops at the area of Carmen or Sagbayan the visitor is captured by admiration of some 1,776 hills (they were counted!) (Fig. 9) with perfect domes lying in front of him and continuing as far as the eye reaches.

Fig. 8: The extent of "Chocolate Hills" (section of Batuan) (Photo: J.N. Salomon).

And one tries to understand how it is possible. How, by which mysterious mechanisms the erosion creates these domes and hills so perfect? These questions gave birth to many strange theories and I could not resist to cite some of them:

– for some these are volcanic peaks later covered by chalk (sic !). This explanation also appeared in a TV documentary about Philippines. It does not have make sense as all the mogotes are made of coral limestone;

– for some the cupolas were modelled under the sea water by sea currents and emerged to air later. Again, there is no explanation of processes;

– others, enriched by strong imagination, explain that the hills were constructed by highly carbonated water flowing from soil under pressure and depositing the carbonates and thus building mogotes (no comment!);

– the theories, narrated by the locals, belong to legends. A giant, called Arogo, due to unhappy love shed tears on the ground and as they were drying the hills grew... And another one: two giants fought and threw rocks to one another. The fighting lasted several days and giants were tired. Due to common exhaustion they became friends but they forgot to clean the fighting ground; the "Chocolate Hills" remain as witnesses to these days.

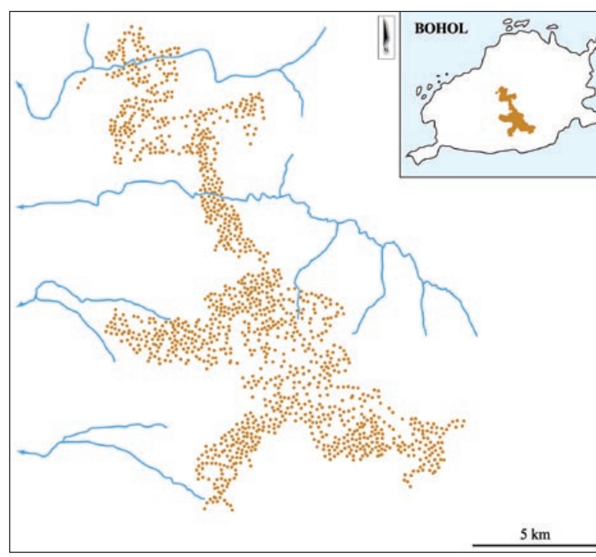


Fig. 9: Distribution of mogotes in Natural Monument "Chocolate Hills".

Of course, these explanations are false; the scientific reality is something else: the formation of mogotes started by emersion of coral limestone and was followed by karstification. They were later reshaped by certain number of parameters (see below) to attain their actual look.

TYPICAL TROPICAL KARST RELIEF

The mogotes can develop in any type of limestone, homogeneous or not, by only under a condition that facies is relatively pure and that the thickness above the aquifer is moderate: mostly some tens of meters (Nicod & Salomon 1990). Most of the time they appear when the is blocked at rather constant level and their evolution needs lateral dissolution; this is very typical of Cuba. Although many studies (Ireland 1979; Gerstenhauer 1987) stress that tropical mogotes (specially in Porto Rico) are covered by a hard and thick crust (of 5 to 10 cm; case-hardening) below which the limestone is much softer (chalk-like and powdery); this is not the case in Bohol.

The distribution of hills looks to be without a precise order, irregular and even if in some cases they stand one near the other giving a U-passage between them in other cases they are perfectly isolated and separated one from the other by a vast flat terrain. The relative mean height of mogotes is from 40 to 120 m and their density varies according to sections (Fig. 10). Mean diameter is about 65 to 80 m.

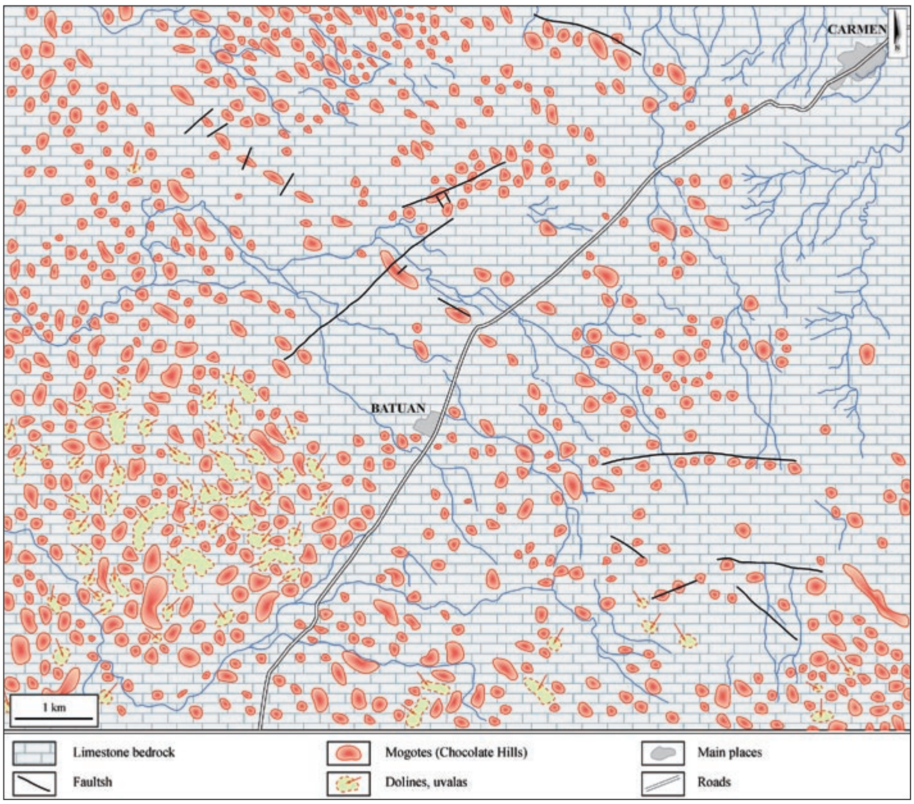


Fig. 10: The "Chocolate Hills" of the Batuan section.

The rock features (slope karren, diaclased and karstified fractures, grikes) are missing or rare and usually replaced by solifluction of blocks due to clay matrix which, when filled with water, increases the sliding. It is interesting that that the foot notches, which can be observed in most other karsts with tropical mogotes, are absent. It is true that relatively steep slopes drain the water quickly and do not permit the flooding of the plain.

On the contrary other features in this relief remain undefined such as hills (mamelons) in some places badly differentiated one from the other and yet elsewhere remarkably isolated in perfect cupolas jutting out of decalcified clay and alluvium. Considering the profile of the slope one can observe all the transitions from arch-like cones, more or less pointed, to flattened domes and cupolas (Fig. 11).

With the comparison with other Kegelkarst regions some specific aspects of Bohol can be pointed at: regular and rather flat summit surfaces; relatively gentle slopes (cliffs are very rare). It seems that mogote is always placed on a round or oval base and never has the basal (foot) notch (no moor or flooding of the plain).

THE FUNDAMENTAL ROLE OF THE LITHOLOGY

When the original carbonate surface was uplifted and undulated the karstification at Bohol took place in the formation called the Maribojoc. It is composed of poorly consolidated limestone, rather chalky and marly, intercalated between limestone and schists belonging to the below lying Carmen formation. Composed of fine grains it is rather resistant. There are also more massif blocks of metamorphic limestone showing the influence of magmatic lifting.

Thus there are a lot of differences in the limestone lithology connected to its genesis and age. In general one can distinguish relatively old limestone (Mio-Pliocene) located at the east and northeast of the island and recent Plio-Quaternary limestone appearing in the western part. The oldest in the shape of ridges and watersheds are the less dissected. There is less micro-relief and more swallow holes, shafts and caves, and more small springs and estavellas. More recent limestone areas are more dissected with discontinued valleys and isolated mogotes. The corrosion plains extend towards north-west. This limestone also contains fewer caves and springs (the latter being more abundant). Yet all this limestones are very much karstified.

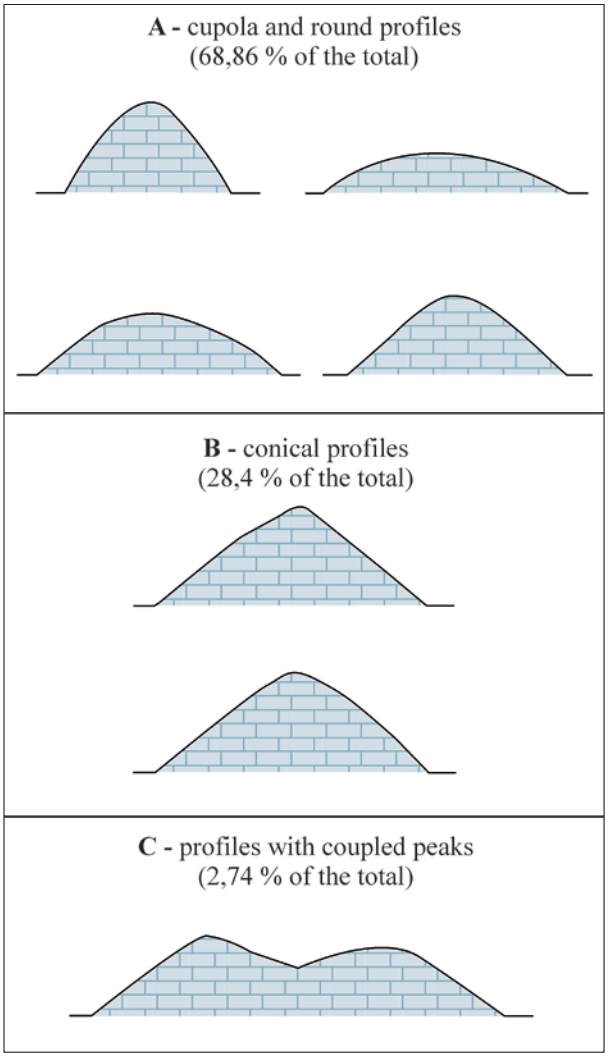


Fig. 11: Profile types of the “Chocolate Hills” (472 analysed mogotes; the profiles are symmetrical, B has a slight asymmetry, C are individual mogotes).

In other places with the same total amount of rainfall but with more pure and very recrystallized limestone, such as formation called St. Paul limestone in karst of Assegai, Palawan, there is a tower karst or karst with tsingy (Longman & Brownlee 1980). However in the karst of “Chocolate Hills” one can see the landscape with mogotes without remarkable grikes: even the dissolution scratches are rare. This is probably due to lower purity of carbonates and greater ratio of insoluble parts. This limestone is often whitish and of dolomite type (41% of magnesium carbonate) containing a lot of insoluble particles (Tab. 1).

It should also be noted that in the valleys clay and alluvia coming mostly from the mogote slopes cover the relatively more resistant limestone in a considerable thickness. Generally limestone is very porous and on the surface very much altered (more than 20 m in a quarry lying between Maribojoc and Loon; Fig. 12) thus allowing rapid infiltration of water down to impermeable base (favourable for the genesis of caves at the foot of mogotes).

Fig. 12: Cross-section of a “Chocolate Hill” (under rich vegetation the soil is rather thin, alteration is powerful: > 20 m) (Photo: J.N. Salomon).

The same properties were found in the cupola karst of Nord-Bone (Sulawesi) described by Sunartadirdja & Lehmann (1960) showing that porosity parameter has a certain importance.

THE ROLE OF CLIMATE

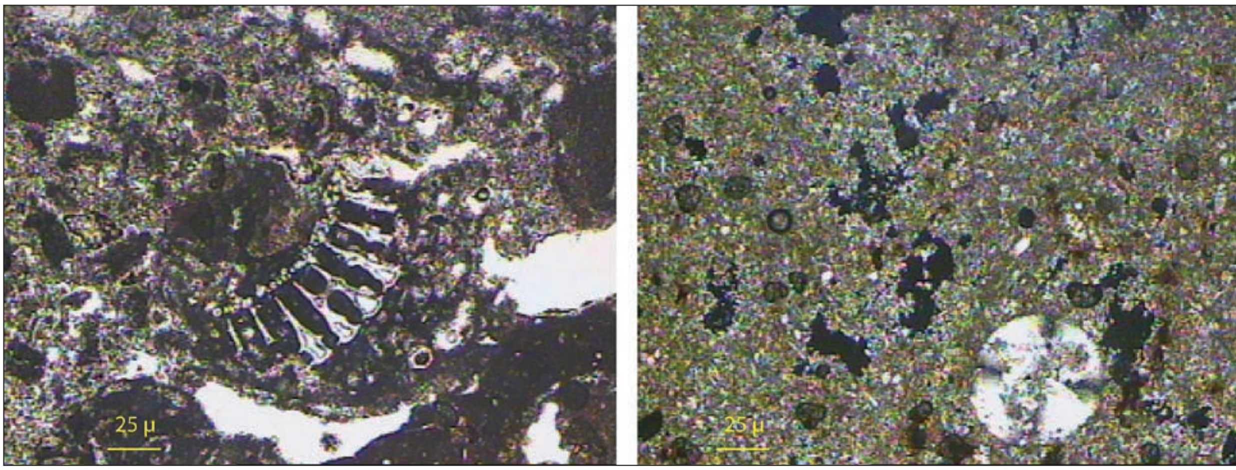
The climate influences the genesis of the Bohol karst in two ways::

– The first one is quantity of precipitation which is very high (2,000 to 3,000 mm) and, most importantly, relatively well distributed over the whole year. As Bohol is an island surrounded by warm water, the atmosphere humidity is always very high (> 80% by hygrometer),

Tab. 1: Calcimetry of two limestone samples from “Chocolate Hills” (the second one was taken in a quarry (see Fig. 12).

Sample	*Aspect*	*TH (mé/40)*	*Ca (mé/40)*	*Mg (mé/40)*	*% Mg*	*Ca (mg)*	*Mg (mg)*	*CO3 (mg)*	*Σ carbonates*	*Total RNS*	*% Σ carbonates*	*% RNS*
n° 1 mogote	yellowish limestone	6.6	6.28	0.32	**4.85**	125.85	3.89	198.03	327.77	72.23	**81.94**	**18.06**
n° 2 quarry	whitish limestone	7.44	4.32	3.12	**41.94**	86.57	37.92	223.23	347.72	52.28	**86.93**	13.07

supported by a still dense vegetation especially on mogotes. This factor seems very important as it controls the homogeneity of the karstification time: it is going on constantly over all the exposed surfaces or near the surface of the limestone;



Figs. 13 & 14: Thin sections of "Chocolate Hills" limestone. Analyses were done by Optilab Pro microscope, version 2-6.

A: *Sample taken at mogote near Sagboyan. Limestone with shell facies, micritic with traces of sparite (secondary origin). Fossils are bivalves, gasteropods and echinodermes. Porosity of 6% is strong, insoluble parts about 3.5%. It is just slightly altered with little iron and manganese.*

B: *Sample taken in a quarry between Loon and Monbojoc (see Fig. 12). Limestone contains less shells than the first one, facies is micritic and porosity strong (24%). Porosity is due to dissolution as the shells are dissolved and only a little of micritic cement is preserved.*

– The second is related to the wind. In many tropical karsts the authors were puzzled by the asymmetry of numerous mogotes, in particular in Porto Rico (Monroe 1980). These authors have often attributed the asymmetry to the winds bringing the rain and watering one or the other side of mogotes: on a long term the more watered slopes have more dissected relief. In the case of Bohol, although the preferred directions exist, they are not tyrannical: from November to March the monsoon is generally directed north–east and north, as for the other period it is directed to south-west and thus achieves a relative equilibrium. Maybe this is the reason of a remarkable symmetry of mogotes volume having the bases generally sub-circular or ellipsoidal, according to Voss (1970) observations on aero photos.

Finally, we must state that the great stability in time both of tectonic structure and climatic environment were favourable factors for karstification of mogotes, very homogeneous, strikingly resembling each other especially by almost perfect cupolas.

THE ROLE OF SOIL, VEGETATION AND CRYPTO-CORROSION

The thickness of soil differs as limestone is impure and the peaks of mogotes are very much eroded. Additionally the slopes are so very steep that the rocks appear everywhere in the sub-surface (Fig. 15). From the pedological point of view this is a lithosoil or soil with layers of brown-red clay or argilo-limestone, with little organic matter quickly passing to transition horizon with a lot of limestone grains. This is a typical soil of tropical karst. The most important regarding the genesis of mogotes is moderate thickness of soil cover (often less than 10 cm). This cannot really support lush vegetation but only poor savannas and some bushes. Only the slopes of mogotes at the contact with the valley are forested growing on th accumulation and colluvium coming from top. Nevertheless this pedological and vegetation covers play an essential role at karstification it favours the production of

Fig. 15: Erosion at one of "Chocolate Hills" and loss of soil (Photo: J.N. Salomon).

CO_2 (by respiration) and thus carbon acid but at the same time also many organic acids (humic, fulvic, formic, etc.). It seems clear that this cover (vegetation and soil) played an important role at the formation of a significant crypto-corrosion, well-distributed over the slopes, and also at the regularity of "Chocolate Hills".

Today this traditional activity changes a little due to threats menacing the traditional karst environment. In fact, this cover has almost disappeared because of human activity. At first we must know that demographic pressure is very high (in Bohol the population density is 180 hab./km^2) and it is still growing. Yet in the last decades the cultivation of rice is in decline (Urich *et al.* 2001) (Figs. 16 & 17).

The reasons are numerous but the demineralisation of the soil plays a certain role. In general these soils are rather carbonate (53.1 ppm against 10.4 ppm in Asia, Kawaguchi & Kyuma 1997) which is normal regarding the base rock, but the use in the last years (pastures and dry cultures) in the elevated parts of the island (these are also the slopes of many mogotes) caused an important deforestation and thus erosion of soil. This soil generally remains in endokarst by fast infiltration (fissures, diaclases, cracks etc.) where it remains caught especially in underground systems and reservoirs. This results in rice plains with predicting loss of microelements (N, P, K). The other reason lies in fact that the people are introducing new agricultural plant species requiring more water and due to deforestation edaphic dryness occurs on heights of the "Chocolate Hills" as soil (eroded) does not play its role of tampon anymore. So, the hydrology is also changed by acceleration of cycles, much more brutal and contrasting as before.

Figs. 16 & 17: Professional hydraulic development of traditional rice-fields by karst water (Sierra Bullones section) (Photo: J.N. Salomon).

HYDROLOGICAL ASPECTS AND ENDOKARST

In karst the hydrology is fundamental and its knowledge, either intuitive or gained by experience, brings the best solutions. Living in such an environment the farmers of Bohol have understood it for a long time already.

HYDROLOGY

From hydrological point of view Bohol is characterised by shallow aquifers (with exception, logically, at watersheds fed by ponors) and thus vegetation heavily depends on the quantity of rain and they are is sensitive to drought. The inhabitants of Bohol have known how to get the best results from the karst aquifers for a long time already. We observed:

– a lot of small water flows (sometimes ephemeral);

– many sources located at the foot of mogotes and frequently connected with caves; as they are accessible, one can often see travertine barriers retaining water; discharge varies from 0.5 l/s at the smallest (they may dry during dry period) to 7 l/s at the most important. Local names are explicit. The word *tubud* means a source in general yet there is distinction between *sapa ang tubig* (gravitational spring) and *bugwak* (artesian spring);

– phreatic conduits with important drainage capacity (this prevents the floods).

It is thaught that the water resources have diminished in the last thirty years (according to some up to over

30%). As the quantity of rain did not change one may suspect that deforestation plays an important role (Fig. 18) followed by the erosion of the soil cover (see above). The increase of quarries (for road construction) has the same effect. Many farmers complain that small endokarstic sources (underground reservoirs) that they elaborated during time are now dry during the dry season. Obviously the second reason for diminishing of discharge is increase in domestic use, especially for irrigation (Fig. 19).

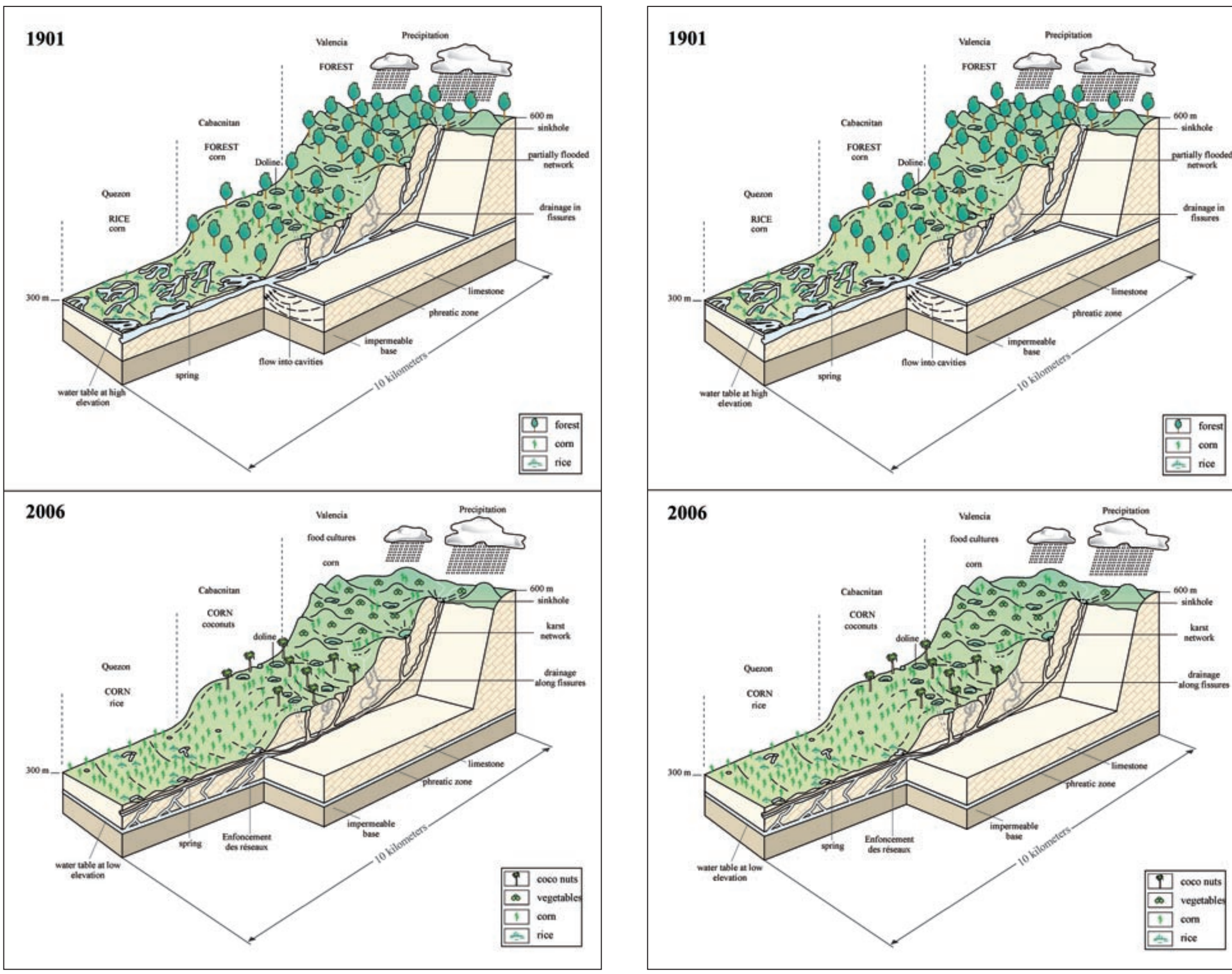


Fig. 18: Evolution of the Bohol landscape in one century (1901–2006) (deforestation, field crops – corn, coconut palms, food crops, rice – and thus lowering of the water table; party after Ulrich).

Anyway the problem of running short of water is not new as it is shown by water tanks carved in limestone. At Bohol this practice looks ancient as archaeological data show. For agricultural purposes a study of all the springs used in the section of Batuan giving the average of 14 km[2] (Urich 1989) was conducted. Certain springs were built up and captured for crop irrigation purposes and sometimes decorated. Others were used for feeding the tanks carved in rock (domestic use). Almost all of them are located at the foot of mogotes as they serve as impluvium (Fig. 20).

The underground water is warm (22.5 to 28 °C on average) and its pH (7.5 to 8) indicates saturated water. Looking at the problem of the underground water quality we see that it is heavily polluted by pesticides, phytosanitarian products, chemical fertilizers, phosphates (washing powder) and animals waste (buffalos, pork). All this induces the algae growth and a certain eutrophisation. The consequences are catastrophic for natural environment (extinction of cave-dwelling fishes and cave crustacean) and man (dysentery, parasites, typhus). But, since Martel the harmfulness of some karst springs is evidented.

SPELEOLOGICAL SYSTEMS AND CAVES

Many speleological expeditions visited Bohol. Among them let that of Reeder, Day & Urich (1989), and es-

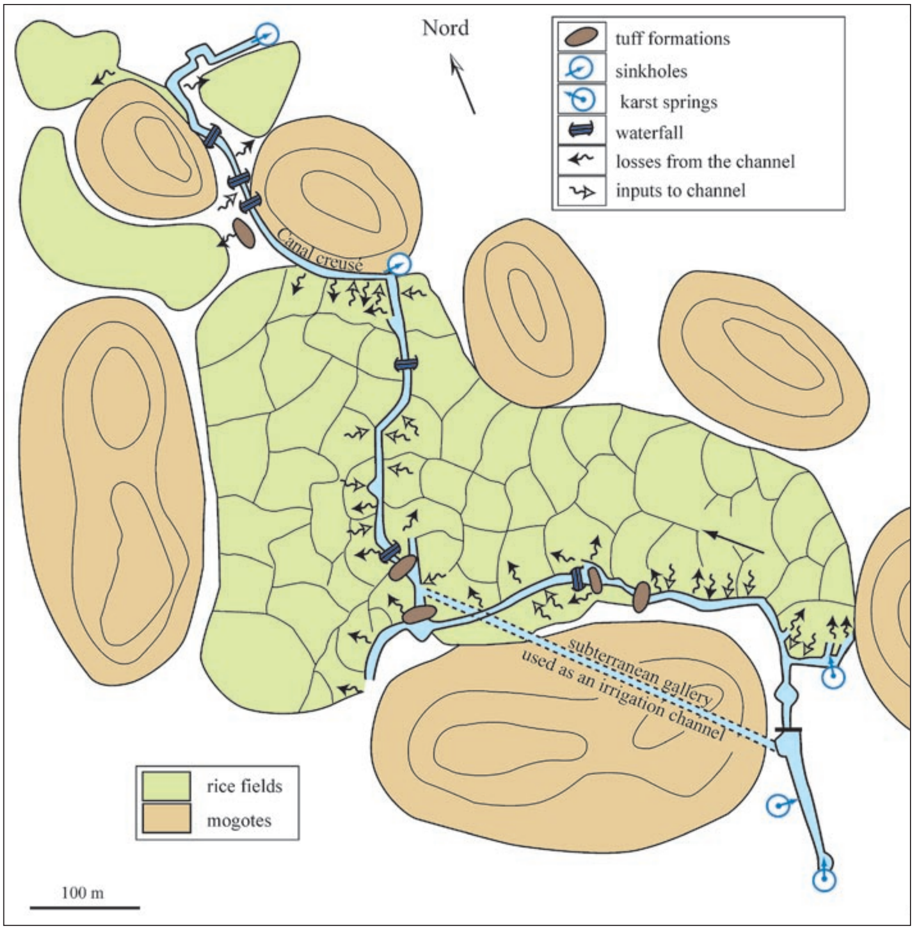


Fig. 19: Irrigation system from the mogote aquifer (eastern Batuan) for rise terraces (average slope 6%, party after Ulrich).

pecially the international expedition in 1995 made by Australians, Slovenians and Philipinians with the aim to study the aquatic fauna of the Mio-Pliocene limestone in inner parts. About thirty caves were registered. The most important is Carmolaon 2, located at Jagna and reaching 149 m in depth which places it as the second deepest cave of the Philippines (Tabs. 2 & 3).

The Bohol island is also called "the island of caves" as there are so many, without a doubt many more than 1,400 already registered; 26 were explored but there are a lot of them still to be discovered. Bohol emerged from the sea as all the islands in the vicinity in about Mid-Tertiary, this is before 20–30 million of years. The island is composed mostly of limestone with shafts, ravine and mogotes perforated by cave systems and many caves, most of them not yet explored. Certain hills may be passed by underground rivers for several kilometres (long time ago the albino crabs became adapted to darkness). Some of these caves played an important role in the history of Bohol, as for example the one of Francisco Dagohoy near Danao where the general quarters of Bohol patriots (1744–1829) were located. Let us mention the best known caves:

– **Ughob Cave**, 257 m long, is interesting to human as it contains a natural reservoir with capacity of 400,000 l (Reedes *et al.* 1990); in its water one may observe non-pigmented crabs. The water temperature is 24 °C. Sand banks indicate that floods occur frequently.

– **Bonogan Cave** consists of two separated sections: one is 78 m long, and the other 106 m. The floor is covered by bat guano and the cave is richly decorated. A river, up to 1.5 m deep, meanders through the cave. It is dangerous to enter the cave during high waters because the river reaches the ceiling. By damming the cave it would be possible to construct a reservoir of about 480,000 l of reserve that may be used for irrigation.

– **Hinagdanan Cave**, on the island of Pangalo is a large well-decorated chamber with underground lake. Developed for tourism (access by staitr) and being near Tagbilaran this is the most visited cave. It contains a small underground lake and ancient inscriptions (Fig. 21).

– Around Antequera, surrounded by mogotes, there are a lot of caves such as **Buhong Tiawan** with the entrance at the foot of a

Tab. 2: Five deepest caves in the Philippines.

Name	Location	Region	Depth (m)
Sumaging-Latipan-Lomyang	Monts de Sagada	Moutain Province	163
Carmolaon 2	Jagna	Bohol	149
Jackpot Cave	Quibal, Penablanca	Cagayan	115
Saint Paul Cave	Bohile	Palawan	100
Carol-An Bito	Carol-an	Negros occidental	88

limestone wall. The real entrance part is 3 to 5 m large and leads to a passage of about hundred metres long. In the interior there are different types of flowstone giv-

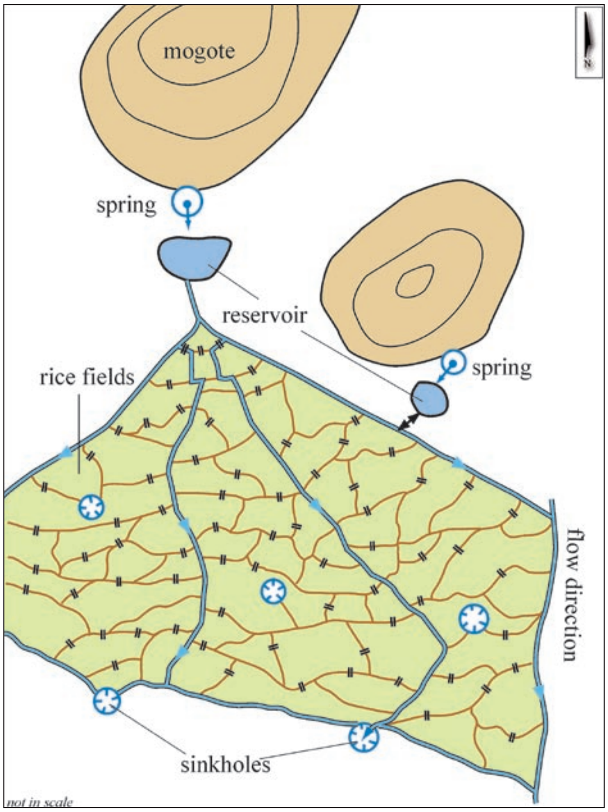


Fig. 20: A typical irrigation system.

(- karst springs are captured to provide water for a network of small channels where the water flows gravitationally;

- the role of passages is to connect two rice fields;

- the karst areas with the access to the losses are developed/arranged)

ing shelter to bats and cave birds. About two kilometres away lies the **Hagakgak** cave; the access leads through a dense vegetation. The entrance is a large opening of about fifteen metres at the bottom of a collapse doline. The passage is very muddy with many narrow passages but also many beautiful stalactites. It is a home of cave animals such as albino crab (*Sundathelphosa filipina*) and fishes. In the same region of Antequera one may visit the "Snake Well" where in fact some pythons live.

Fig. 21: Two generations of glyphes on the walls of the Hinagdanan cave: one, ancient by ochra and the other, looking recent is black, but not dated (Photo: J.N. Salomon).

Also near Antequera there is an easily accessible cave **Inambacan**. In the interior there is a waterflow up to 1.20 m deep in some places leaving only some thirty centimetres between the water surface and the cave ceiling.

– Near **Jagna** towards the south-east coast of Bohol many, mostly vertical caves are located (the relief there is important); the deepest is Visayas : Carmaloan 2,149 m deep. The biggest cave is Sudlon which lies lying in the middle of a beautiful mountain. In the cave lives a large colony of bats, at dusk emerging out of the cave in a dense cloud.

– At Panglao, near Tagbilaran lies a large cave called **Bingag**. Its exploration was very dangerous as it consists of many sections with so narrow passages that it was a problem to progress. A life rope was highly recommended. There are many legends connected to this cave.

– In a cave near **Anda** a great quantity of neatly arranged bones of boars were found, suggesting some religious ritual.

Most caves are horizontal (Fig. 22) because the karst water infiltration meets the base which acts as an

Tab. 3: Five longest caves in the Philippines.

Name	*Location*	*Region*	*Length (km)*
Saint Paul Cave	Bohile	Palawan. Rivière souterraine en partie navigable	15
Odloman Cave system	Mabihag	Negros occidental (exploration inachevée)	8,870
Odessa-Tumboli Cave system	Penablanca	Penablanca Cagayan	7,650
Langun-Gobingol system	Colbiga	Colbiga Samar, 2 entrées dans des dolines, énormes salles	5
Sumaging-Latipan-Lomyang	Crystal system	Crystal system Moutain Province-Sagada	4

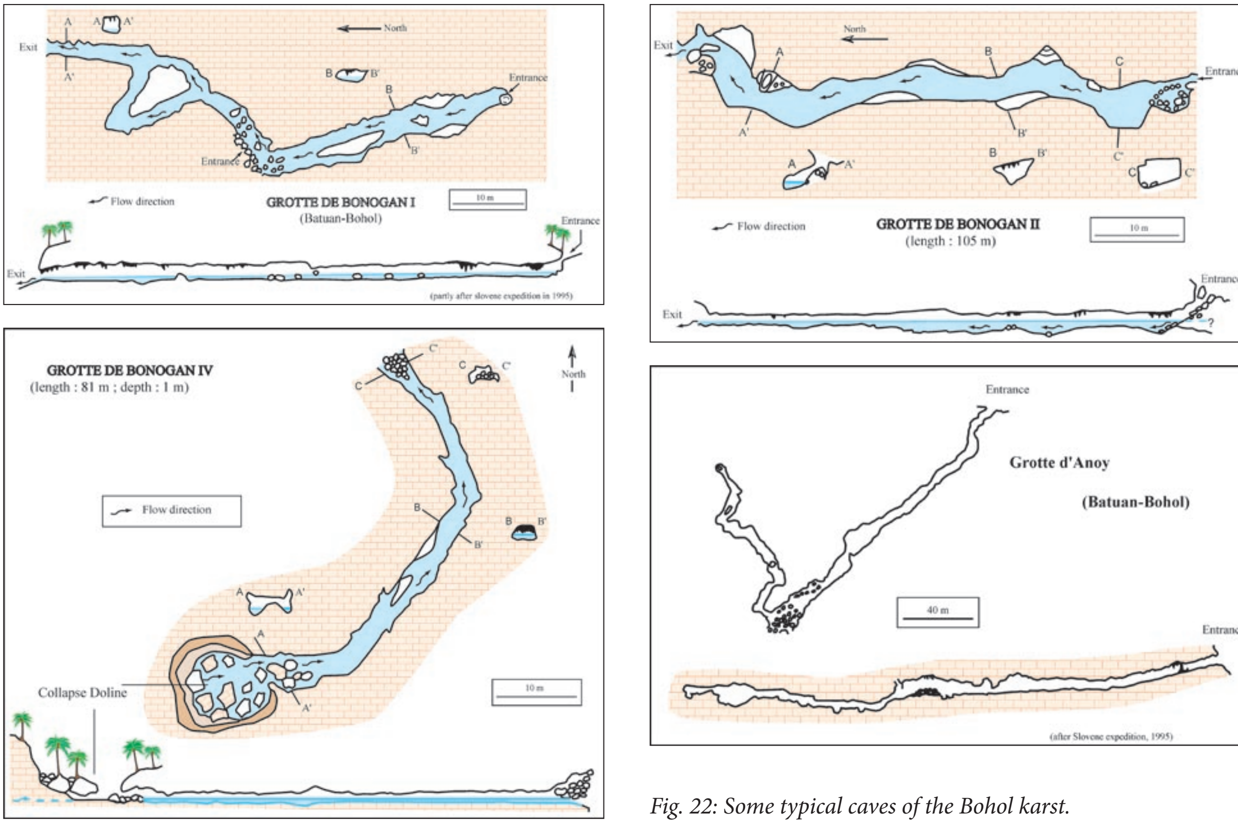


Fig. 22: Some typical caves of the Bohol karst.

impermeable level. The entrances vary; they are either at the bottom of collapse dolines (Grotte de Bonogan IV) or at the foot of mogotes (Bonogan I, II, III). Nevertheless there is a potential for vertical shafts as we have seen at the Carmolaon 2 cave (149 m deep). In the section of Guindulman some speleothems show the signs of seismic activity.

Among numerous other problems the endokarst also presents the hazard of collapse. A good example is the one from July–August 2005 when a lot of collapses occurred in the region of Barangay, Mayana and Jagna. In only two months they destroyed 70 houses, crops and infrastructure. The hazard affected about 70 ha, the damage was estimated to more than 15 million pesos and 174 families had to be moved to a safer place.

CONCLUSION

Without a doubt the "Chocolate Hills" present one of the most beautiful karst scenery in the world. Dickerson (1924) was the first interested in the genesis of this exceptional karst landscape, followed by Faustino (1932), Teves (1947) etc. but nobody succeeded to explain the problem of "Chocolate Hills" regularity. Yet, the explanation of their genesis is relatively simple: about 2,000 mogotes are the result of a simple differentiated karstification, sculpted by the time in the tropical humid environment helped by an important role of lithological structure (porosity).

In the Philippines today out of 35,000 km^2 karst surface one third, this is 10,000 km^2, is protected (Urich & Day 2000). The Rajah Sikatuna National Park (9,000 ha) was established in 1990 and the "Chocolate Hills" Natural Monument (14,435 ha) in 1997, renamed on June 18, 1998, to "Chocolate Hills" National Geologic Monument. The establishment of these protected areas was not achieved without problems. In fact the farmers thought that they are deprived of their legitimate rights of exploitation. The conflict was so severe that in 1999 the government had to intervene with army and several tens of people were killed. In spite the quarries of construction stone and building of roads are augmenting thus diminishing the number of mogotes. The intention to protect the tourist (and speleological) sections in a form of natural parks is without a doubt good but it is far from being accepted by the farmers who see the violation of their traditional rights. And there are a lot of ways to avoid the legislation ...

Nevertheless there is a national and international consensus to consider the "Chocolate Hills" as an important part of nature wonders inscribed into the World List at UNESCO Cultural Heritage due to their aesthetic and scientific character. It is appropriate to protect them and to give them resources. And to visit them.

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