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# THE ORIGIN OF THE TERM KARST IN THE TIME OF TRANSITION OF KARST ( KRAS) FROM DEFORESTATION TO FORESTATION

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## ABSTRACT

*G.K.W.: environmental changes, land use, karst*
*Geogr. K. W.: Italy, Yugoslavia*

## INTRODUCTION

The term karst, in its original meaning of a forestless, stony, and waterless landscape, has its source in the outlook of the Kras region. But this region is a forested land by nature, and half of its surface has again been covered with forest by now. The article explains the role of the time in the origin of the term karst during the transition period, when the deforestation era, having lasted for several thousand years, was substituted by planned forestation.

## FORMATION OF THE TERM KARST IN VIEW OF AGRARIAN HISTORY OF THE KRAS REGION

The region between the Trieste bay, the Soca river plain, the Vipava river valley, and the flysch hills Brkini was settled only by the Slovenes a hundred years ago. The karst plane is called "Kras" by the Slovenes, "Carso" by the Italians, and "Karst" by the Germans. Since the time, when the only big port Trieste grew on the flysch margin, the name of "Trieste Karst" (Trzaski Kras) has been in use by foreigners, even though the north-west part of it has belonged to the Gorizia County in the last few centuries and has also been called the Gorizia Karst (Goriski Kras), while the southeast part belonged to Istria and has been called the Istrian karst (Istrski Kras). The state border between Yugoslavia and Italy, which was set after the World War II, made the common name for the Kras - one quarter of which belongs to Italy now - even more lax. On the Italian territory, the Kras is administratively divided between the Trieste region and the Gorizia region. The names of the Yugoslav part of the Kras are based on centers of communes, i.e. Sezanski Kras (upon the Sezana town), and Novogoriski Kras (upon the Nova Gorica town), and also in the form of Sezansko-Komenski Kras (upon the Sezana town and Komen village). The whole region is called the "Kras" (Carso, Karst) here, since local inhabitants of the whole area are equally called "Krasevci" in Slovene language (which means Kras Inhabitants).

Ever since the settlement of man on the Kras area in the Paleolitic era, the portion


Fig. 1 - Geopolitical situation of the classical Karst (Kras) in the middle of the XIX C.
1 - Classical Karst. 2 - Dinaric Karst. 3 - Boundary between the Austrian and Hungarian part of the Austrian-Hungarian Monarchy. 4 - Main traffic route Vienne-Ljubljana-Trieste. 5 - Boundary of Turkey.

of forest on this land has varied. The past periods of several thousand years - at the beginning of which the land had been whole forested but at its end a century ago it was almost a forestless Kras - can be called with a common name "the deforestation age". Its course was determined by the history of agrarian activities in Europe and was similar to that in other parts of the Dinaric Karst, to which the Kras represents the most north- eastern corner.

In the Holocene the region underwent, like most of the Dinaric Karst, the first settling intensification in the first millenium B.C. in the time of Illyrians who were known in history as pastoral livestock breeders. To obtain pastures they burnt forests, which had been composed on the Kras of *Quercus pubescens* and *Ostrya carpinifolia*. This forest is mostly composed of deciduous trees (with the tree species *Quercus pubescens, Fraxinus ornus, Ostrya carpinifolia, Quercus sessiliflora, Castanea sativa*, etc. PRIRODNA..., 1986). In the relatively humid submediterranean climate the annual fall of leaves is substantial in such forests, and since leaves can not be blown away because of the great thickness of woods, they are permanently spread also over less pointed outcropping stones. For this reason the stony karstic appearance was blurred in forests. It became

visible after the first mass burnings of forests, when the humus cover on the higher stones was also burnt, and wind could blow soil away also from the sporadic depressions. B. GUSIC (1957) could personally follow the changes of landscape character on the karst after the burning of forest at the end of the 19th century in the southeastern Dinaric Karst. This karstologist wrote the following: "I think ..... that formation of barren karst is the result of over-exploitation of the karst land, which has been practiced by man for millenia, and has not stopped yet." (op. cit. p. 48). The fact that burning of forests for obtaining extensive pastures in the period of slash and burn method was most fatal for soil erosion, has been proved by measuring the depth of the deepest Rillenkarren. Measurements performed on the Hvar island and on the Kras (GAMS, 1990) show that the formation of Rillenkarren started three to three and a half millenia ago. Measurements on the Kras were performed on Cretaceous dark gray limestone interchanging with rudist limestone, where very deep loamy clay was possibly dug for iron production in the Hallstatt age.

The name (Carsus, Carso, Karst, Kras) which includes a pre-IndoEuropean root "karra" (stone), occurred in the Antique period to denote this region (GAMS, 1973). Most probably the landscape was first called by this name by people living in the neighbouring regions, i.e. on the flysch hills within the Trieste syncline, in the Vipava river valley, and on the Soca river gravel plain, towards which the Kras plateau descends with steep slopes. But on steep slopes, soil solution after deforestation cannot be prevented to a greater extent by the layers jutting from the rocky basis. Therefore steep slopes are more rocky not only on the Kras, but also in other parts of the world (GAMS, 1988).

From the Middle Ages on, until the 19th century, pastoral livestock breeding prevailed on the Kras, where sheep breeding and goat breeding were very important. Sheep and goats pastured during winter as well. In summertime, livestock was taken to pasture on the neighbouring karst high plateaus in the hinterland. And peasants from hinterland pastured their livestock in littoral parts of the Dinaric Karst in winter (GUSIC, 1957). Sheep from the remote Bosnia and Herzegovina were brought to pastures in the Slovene part of the karst in wintertime until a few years ago. Making pastures at a loss of forests is to be considered the main reason of deforestation, and not the selling of oak timber for Venetian ships and pillars for the city of Venice, which can still be heard today from unprofessional mouths. The sale of oak timber to Venice for shipbuilding and wood for heating might have been the major reason of deforestation only in the Istrian part of the Kras at the foothills of the Slavnik range, which was almost the only part that belonged to the Venetian Republic in modern times. Further reasons were the following: the use of wood for heating homes of local inhabitants, sale of timber, protection against wild animals and invaders and robbers, wars, charcoal production, resin production, and, last but not least, making new arable areas and meadowas (GUSIC, 1957). In the first few centuries of modern times describers of the Kras stress the forestless and stony appearance of the landscape, and B. HACQUET mentioned as early as 1781 the name Karosch (= Kras) in such a manner that it can be understood as a regional name or/and a name for stony, desert-like landscape which the author compared to Arabia. In his guide to Postojna Cave (issued in 1830), F. HOHENWARTH explains in a footnote the name "Kras" as being a stony, waterless and forestless surface, spreading across the whole of the Dinaric Karst and further on. However, the term "karst" was not firmly established in Austro-Hungarian literature either, although it was the first one to introduce the term into natural sciences, and authors had to explain the meaning until the beginning of this century.

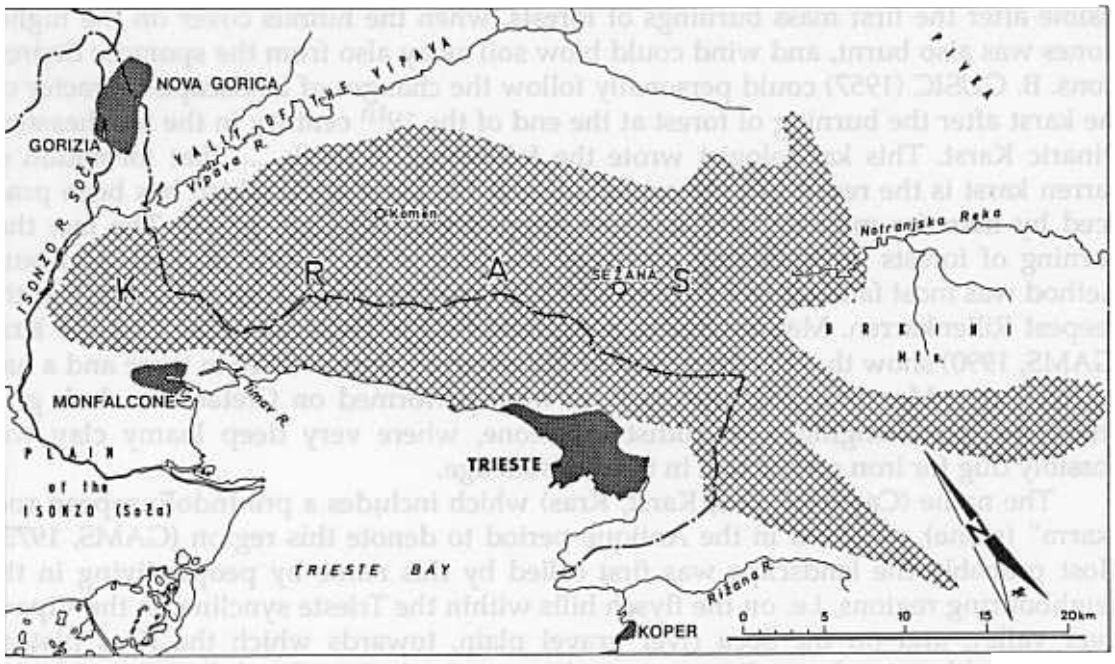

Fig. 2 - Situation of the Kras (Karst) on the Yugoslav (Slovene) - Italian border

The time of formation of the notion "karst" is concurrent with the time of the densest agrarian settling, when forests almost disappeared, or they survived only sporadically in the form of thin pasture forests. About half of the region was covered with pastures where there was no need to clear off the outcropping stones for the purpose of pasturing sheep and goats. Cultivated areas were located above all on the bottoms of the dolines and thus hidden from the eyes of a landscape observer; apart from these, many small-sized cultivable plots were tilled, not ploughed. Grass was also cut with sickles (MORITSCH, 1969). All this did not claim yet for intensive removal of outcropping stones.

Intensive transformation of the surface outlook of the Kras began in the past century, above all because of the more intense removing of stones (stoneclearing) and planned forestation.

## Stoneclearing on the Kras

The removing of stones was intensified during the period of transition from pastoral livestock breeding to stationary milker livestock breeding which was promoted on the Kras by selling milk and cheese to the inhabitants of the fast growing town of Trieste. A study on Krajna Vas showed that meadows on thicker, acid soil were being abandoned then and spread to former pastures, located on shallower soil, where grass is better for milker cows (GAMS et al., 1971). For this reason it was necessary to hew off, or even to take away, the outcropping stones from the pastures, so that grass could be mowed with scythe for haymaking. To increase the harvest, several smaller accumulations of stones were heaped into a bigger one somewhere, or stones were thrown into pits and unused dolines. The latter were discovered in the past few years under the soil when it was taken to the nearby meadows (GAMS, 1987). A lot of stones originating from stoneclearing and having been piled into scarps and dry walls were used for new buildings. Where during the World War I (1914 - 1917), the front between

Italy and Austria moved slowly, granades blew off almost all outcropping stones, fragments of which were later thrown into shell-holes and covered with turf by local inhabitants. In the rear of the front, troops used stones from walls for building new objects, roads in particular (GAMS, 1987). The whole of the western Kras underwent such a change.

## Forestation of the Kras

Like in the rest of the Yugoslav Littoral (Primorje), it was the Slovene coastal town communes that were the first to be affected by the harmful results of deforestation; the town authorities began to pass laws and regulations on forest protection as early as the 12$^{th}$ century. Hindered wood supply for heating was also one of the reasons for passing such regulations. The town of Trieste passed the first protective regulation in 1150 and has been passing them more ever since. Larger administrative units in the Austro-Hungarian Empire began by passing regulations in the second half of the 18$^{th}$ century.A Forest Regulation for the Duchy of Carniola was passed in 1771, and Venetian forest regulations for Istria, which extended over one part of the Kras, followed in 1778. In the middle of the 19$^{th}$ century a planned action for the forestation of barren karst land was started. After the short-living "Kras Forestation Society", having been founded in 1851 in Sezana, the "Forestry Society for Carniola and the Littoral" was founded in 1875. A few decades later followed a period of passing laws on the karst forestation in the Littoral (Primorje). Laws on karst forestation were passed as follows: for the Trieste region in 1881, for the Gorizia region (Goriski Kras) in 1883, and for the Kras within the Istrian region in 1886. A commision, founded according to these laws, chose about 30.000 ha of barren karst land for planned forestation. The project on forestation of barren karst land was a long-lasting study and field team work which, after years of experiences, resulted in successful methods of plant choice, planting techniques and plantation protection. The project was met with wide response in European forestry, and experts from many countries, even from East-European ones, came to the Kras to attend courses and take part in field work (JURHAR et al., 1963). However, the principal reason for success in the then begun forestation was the deagrarization of population. In communes located on the Kras, less than one tenth of population in average live on farming nowadays. The ban on goat breeding which came in force in 1953 on the Yugoslav side of border line successfully contributed to forestation. About 10,000 ha of plantations, mostly planted with *Pinus nigra*, are self-sufficient now to expand their territory by means of seeds, while the abandoned pastures and meadows have been overgrown mostly by deciduous bushes and trees.

## Transformation of land categories

The fact that the Kras has always been divided to various administrative units makes statistical researches difficult. In the Austro-Hungarian Empire it was divided among several crown lands and tax-collecting offices, and after World War II it was divided between two states and among several communes, many of which extend across the Kras. The data below show the period 1900-1985 (1989) which does not include the time of minimum portion of forests and maximum share of pastures on the Kras.

The table below was made according to the publication of data of Census taken in 1900; only those inland revenue offices were taken into consideration that have the greatest part of their land on the Kras.

Category data for the Sezana Commune in 1985 (1989) were taken from the stati-

## Land categories in 1900:

| | |
|---|---|
| Total area: | 587,5 km$^2$ |
| Arable land | 10,6% |
| Gardens | 0,3% |
| Vineyards | 1,6% |
| Meadows | 23,9% |
| Pastures and mountain pastures | 40,4% |
| Forests | 20,1% |

## Land categories in 1985 (1989):

| | Trzaski Kras | Sezana Commune | the Kras |
|---|---|---|---|
| Total area, (km $^2$) | 89 | 698 | 787 |
| Arable land, gardens,(%) | 1,8 | 4,3 | 4,0 |
| Vineyards and orchards (%) | 0,8 | 0,9 | 1,3 |
| Meadows and pastures (%) | 15,0 | 52,6 | 50,1 |
| Forests (%) | 41,7 | 42,2 | 42,1 |

stical yearbook of Slovenia "Letopis Slovenije", and data for communes that completely belong to the karst, i.e.the Trieste Carso (Trzaski Kras) (year 1985), like Duino-Aurisina (Devin-Nabrezina), Sgonica (Zgonik) and Monrupino (Repentabor) were taken from the Gazetteer of the Slovenes in Italy "Krajevni leksikon Slovencev v Italiji" (1900).

Yugoslav statistic institutions are belated in the registration of development, thus the unused farming land, overgrown with bushes or thicket, is also included among meadows and pastures.

Comparison between the above two tables shows that meadows and pastures were spread over two thirds of land in 1900, but now their share is hardly about one half, and on the Trieste Karst (Trzaski Kras) it is one sixth only. The share of forests has been increased instead, from one fifth in 1900 to over four tenths of the surface in 1985 (1989). In fact, this share has already risen to approximately one half. With such a share of forests, the Kras equals to the average share of forests in the Republic of Slovenia and highly outweighs the share of forests in Italy as a whole. A century ago, the Kras was the synonim of a forestless land, but now it is closer and closer to the notion of a forest region.

Fortunately, the notion of karst has essentially changed in the last century and a half. The discovery of the Postojna Cave in 1818, and explorations of the Labodnica - Abisso di Trebiciano abyss, and further on the deeper parts of the Caves of Skocjan have strengthened the awareness of cave cavities and underground water systems as being a component part of the notion "karst". Further deepening and expanding of the notion of karst, from carbonate to non-carbonate (sulphate-chloride) rocks, is still being in progress, for more and more voices are heard about the silicate karst. But a modern, more ecologically coloured definition is still held in common, i.e. the definition that the karst is a territory with effective karstic denudation (corrosion), with prevailing underground drainage of atmospheric water (precipitations); this definition is supposed to be the absolute postulate, and the presence of karstic surface forms is only supposed to be

the possible postulate. From this point of view, the Kras is still a typical karst territory. Annual karstic denudation (calculation made of the hardness of the Timav river and water run off) assumingly amounts to 40-50 $m^3$ $CaCO_3$+$MgCO_3$ per $km^2$ (GAMS, 1981), and there is complete underground drainage of atmospheric water. But the drastic decline of arable land and the doubled share of forests, such as can hardly be registered on any karst territory elsewhere in the world, increase the possibilities that the Kras could become the classic karst again, or said by the words of J.Corbel (1950), "Les Karsts proprement dite", if an inter- national research work was carried out as to the effects of the accomplished surface changes on karstic processes. These changes, originating from the theory of karstology, concern the following:

- Change of climate. The "Krasevci" (Kras inhabitants) know that there is less bora (northearst wind) nowadays and crops are harvested 2-3 weeks later than a century ago. It might be explained by reduced windiness and, related to it, higher daily temperature maxima;
- Increased evapotranspiration caused by greater number of trees. It means that less water runs off into the karst springs. In the caves, lesser quantity of percolating water means slower formation of calcareous sinter, although increased mineralization of percolationg water can be anticipated;
- Due to thicker shading of surface soil in forested and bushy areas, the surface soil and upper layers get less warmed in the warm half of a year, because direct solar radiation does not reach them any more.

This could cause a reduction of water temperatures in springs and air temperatures in aerologically static cave cavities.

A special method should be invented to explore all these changes; however, the lack of measurement results from a century ago is a great shortcoming. It would be easier to establish the following change: In the time of substantially greater share of arable land and stronger destruction of turf after the burning of forests and tree roots, atmospheric water washed more intensely clay-loamy patches into the underground world. Water, rich with these particles often containing iron oxides, deposits them on calcareous sinter formations, which causes their darker brownish red colour. Since turf was reinforced on the surface, and tree roots became denser, this washing off has been reduced and percolating water deposits calcareous sinter of lighter colour. These changes in recent calcareous sinter can be seen, e.g. in the rear of the tourist part of the Vilenica cave, in the Lipica cave (Lipiska jama), in some part of Tiha jama cave in the Skocjan caves. In some passages the changes were observed to take the opposite direction. If during their visits to the caves, speleologists on both sides of the state border, Italian and Yugoslav, registered these changes, the Kras might become the classic karst - a field of international study of changes in karst processes caused by anthropogenous interferences on the surface.

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# NATURAL HAZARDS AND ENGINEERING IMPACTS IN THE KARSTS OF MEDITERRANEAN FRANCE

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## ABSTRACT

*G.K.W. : human impact, collapse, dams in karst, natural hazards, water supply*
*Geogr. K.W. : France, Languedoc, Provence*

In this paper man differentiated two types of natural hazards in the karsts of mediterranean France : local accidents such suffosion phenomena and catastrophic events (flood). The impacts of mining activities and tunnels and the problems of dams and reservoirs in karst (Sainte-Croix du Verdon) are pointed. The exploitation of the karstic springs and groundwaters are described, as well as some impacts.

Résumé: Dans cette note, on a distingué deux types principaux de risques naturels, mais où l'intervention de l'homme est fréquente: des phénomènes de suffosion localisés et des crues catastrophiques. L'impact des activités minières et des travaux de génie civil est recensé, et on étudie particulièrement le cas des barrages-réservoirs en site karstique (Sainte-Croix du Verdon). Enfin on analyse divers types de captage dans les sources et aquifères karstiques, et quelques impacts récents.

Recent observations of the karsts of southern France (Provence, S. Alps, Languedoc and Grands Causses) have higlighted the existence of various phenomena ranging from local accidents to catastrophic events.

## 1 - NATURAL HAZARDS IN CONJUNCTION WITH ANTHROPOGENIC INFLUENCE

These may be grouped into two types

1.1. Suffosion phenomena are common in gypsum karst and rather very insidious in carbonate (limestone) karst.

Gypsum karsts pose many geotechnical management problems, especially in the Var Department (JULIAN et NICOD, 1990; NICOD, 1991). These include subterranean desorders in the oldest part of the city of Draguignan and in the part of the district near Trans-en-Provence (recent building at Négadis), subsidence phenomena at Bargemon and caving-in of the "Trou de Tourrettes" (late December 1987) wich took with it part of a cottage, and event wich receives extensive media coverage. RENAULT (1990) has

noted rapid formation of an underground mini-canyon cut into gypsum, below the Sueis viaduct at Sospel, Maritime-Alps (along the Nice-Cuneo rail-link), in response to stress-changes. This mini-canyon creates a real erosion hazard around of the piers.

1.1.2. Collapses can be recognised in the highly karstic areas of limestones and dolomites, especially in fill sediments at the bottom of dolines and uvalas. Areas of common occurence include the Causses, Plans de Provence and Montrieux Plateau (N of Toulon). This phenomenon locally affects walls, houses and even watertanks. A good example is that of the cobblestones of the "lavogne" near La Couvertoirade, a medieval town (information courtesy of P. AMBERT).

Moreover, we have noted the potential instability of foundations in areas where urban spread invades deeply cavitated karst zones, with many solution pockets resulting from active down-draining hydrological process. A good example is that of the site of the new technopolis of Sophia-Antipolis, to the west of Nice (MANGAN, 1989)

### 1.2. Catastrophic floods.

Whenever precipitation from strorms exceeds the infiltration capacity of epikarst, torrential floods occur in the dry valley, resulting in flooding of dolines and uvalas. Torrential rains of this type are common in the Cevennes region. An extreme flood event associated with such downspours occured in 1907, in south Larzac, resulting in September 1980, torrential rains on the Causse Noir flooded the dry valley of Servillières and resulted in severe erosion of the area around the hamlet aptly named "La Bouteille" (DORIA, 1986).

In October 3, 1988, heavy rains, with an intensity of over 420 mm in 6 1/2 hours,fell on the city of Nîmes and on the neighbouring hills to the north, causing overflow of a number of usually dry streams, locally known as "cadereaux" FABRE, 1989; DAVY, 1990). Although of only short duration, the catastrophic flooding of Nîmes was partly due to the reduction in infiltration in these karst valleys as a result of urban spread. Encroachment of riverside residences and the impermeability of road surfaces had considerably exhauced lood runoff.

The dry valleys and ponors in karst depressions recently set aside for the extension of Aubagne industrial zone can be equiped with storage and retention tanks.

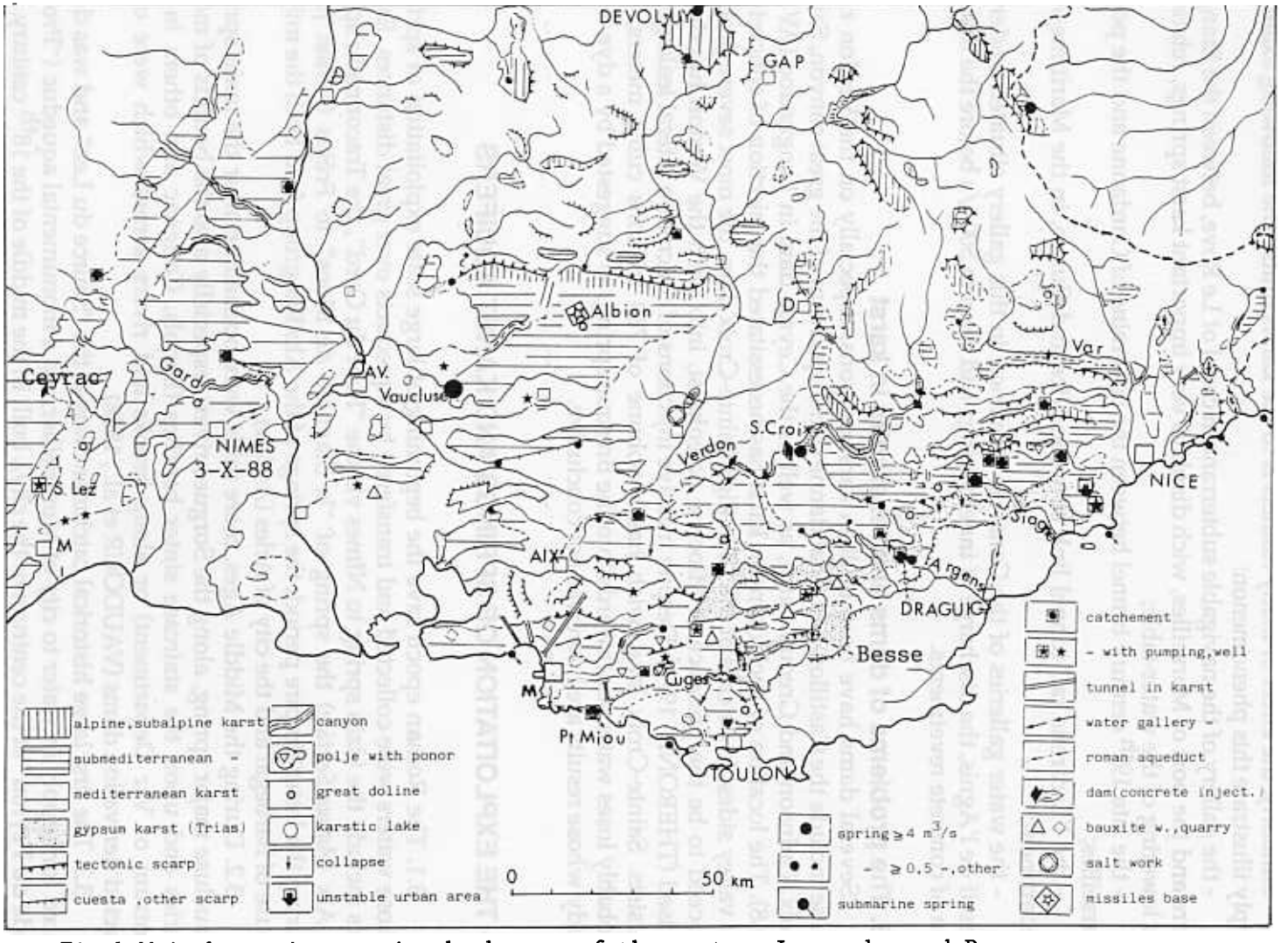
## 2 - THE IMPACT OF ENGINEERING STRUCTURES

In all cases, the implementation of engineering projects has led to major environmental changes.

### 2.1. Problems related to Past and Present mining activities

2.1.1. The working of bauxites presently on the decline, has leaved many strip quarries and waste dumps, such as near Brignoles and Mazaugues (Var Department), Villereyrac and Bédarieux (Hérault Department). The same problem is posed many limestone quarries. These holes are frequently used as dumps while the old gypsum quarries magnify the instability of the terrain. Examples are provided by canyon site below Chateaudouble (north of Draguignan) and at Allauch, in the greater Marseilles area.

2.1.2. Coal extraction in the Gardanne basin necessitates pumping of the groundwater flowing from the neighbouring karsts with, in consequence, the lowering of the water-saturated zone and the superficial drying-up of the springs around the




-Fig.1-Main human impacts in the karsts of the eastern Languedoc and Provence

Etoile unit, and any collapse phenomena (VANDENBERGUE, 1961).

### 2.2. The problems of the tunnels in karst

Similarly, the effect of many tunnels is to the karsts units. The following examples amply illustrate this phenomenon:

- the gallery of the navigable subterranean canal of Le Rove, between the Etang de Berre and the port of Marseilles, wich displays very important karst springs, related to the lowering of the water-table;
- the late 19$^{th}$ century tunnel between the coal mine of Gardanne and the port of Marseilles;
- the l'Escarène rail-tunnel link between Nice and Cuneo, in the Maritime-Alps Department;
- the water galleries of the Canal de Provence; in this gallery situated under the Massif de l'Agnis, the discharge of inner springs had risen to 500 l/s before the installation of concrete revetments.

### 2.3. The problems of dams and reservoirs in karst

Several dams have been built in karst canyons, especially on the Verdon river. These include the Castillon and Chaudanne dams upstream of the great canyon, Sainte-Croix, Quinson and Greoux dams, as well as the Ceyrac dam in Languedoc (AVIAS, 1968). The location of such dams in karst has necessitated the injection of concrete on the valley sides. In he case of the 78 m high Sainte-Croix dam, the most severe problem proceed to be the presence of Miocene paleokarst, into wich the Verdon has deeply incised (THEROND, 1973). Despite massive injections of concrete, a lateral leakage still persists. Sainte-Croix lake, wich has a volume of 760 millions cubic meters, also probably loses water southwards into the Bresque spring, as suggested by a dye tracer study whose results are howewer not conclusive.

## 3 - THE EXPLOITATION OF SPRINGS AND KARST AQUIFERS

3.1. The Roman epoch save the beginning of large scale exploitation of springs, whose waters were collected and transfered by aqueducts over great distances. Examples include the Uzès spring to Nîmes via the "Pont du Gard", the Traconnade spring to Aix (*Aquae-Sextiae*) the spring of "la Siagnole de Mons" to Fréjus (*Forum Julii*). During the latter Empire period, the springs of the Alpilles group feed both the milling house of Barbegal and the city of Arles (*Arelate*).

3.2. During the Middle Ages, more mills were opened up near the main springs (Vaucluse major spring, along the Sorgues river), especially also the bounds of monasteries and upon the staircase sinter benches (Barjols, Cotignac and others in the centrum of Var Department) or along brooks and rivers across which were often erected derivation dams (VAUDOUR et al., 1988).

3.3. The first large historical catchment was at the "Source du Lez" and was destinated for supply in water to city of Montpellier, via a monumental aqueduc ("Promenade du Peyrou" at the centrum of the city), built in the middle of the 18$^{th}$ century.

Prior to recent "Canal de Provence", the city of Toulon derived its water supply successively from two karst springs: the "Foux de Dardennes" (at the beginning of the 20$^{th}$ century anf after the survey of E.A.Martel) and between the two world Wars, the more distant "Fontaine d'Ajonc" in the Caramy valley.

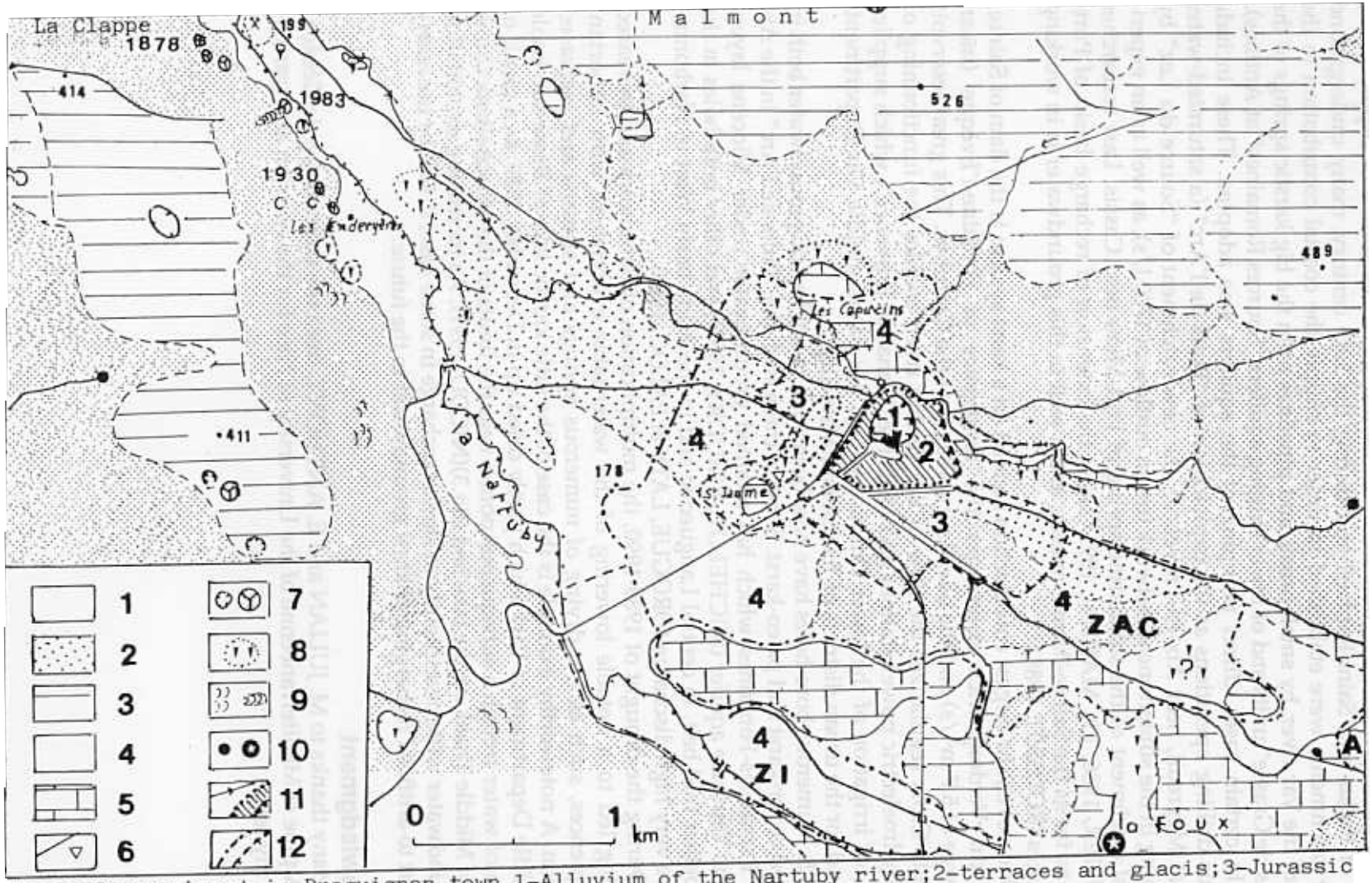



Fig.2-Gypsum karst in Draguignan town.1-Alluvium of the Nartuby river;2-terraces and glacis;3-Jurassic limestone and dolomite;4-Keuper(gypsum clay);5-Muschelkalk;6-fault,shaft;7-dolines;8-collapses; 9-landslides,10-spring,salt spring;11-canal,old city(1.medieval,2.18th century);12-urban extension (3.19th century,4.actual);ZI industrial zone,A-Artillery school.

3.4. Similarly, the "Siagnole de Mons" again served as source of supply to the cities of Fréjus and Saint-Raphaël and during the 20$^{th}$ century, many underground water catchments were etablished in order to supply the coastal conurbation to the West of the Var river, by small canals and pipelines from the big karstic springs of the "Plans de Grasse" units and of lower surging aquifers "Sources Romaines" at Antibes).

In certain cases, direct pumping of the aquifers was adopted. These include various drilling operations as the exploitation of "Puits de l'Arc" (a saturated-water zone at Meyreuil, near Aix-en-Provence), the new catchment of "Source du Lez" by pumping in the subterranean network (mean outflow of 1700 l/s), as well as an experimental catchment of the submarine spring of Port-Miou near Cassis. Last researches (COULIER, 1986; Ph. MARTIN, 1991) show the extension of recharge basin of Port-Miou as far as the Sainte-Baume massiv, and a well in this groundwater is in working for Cuges (ROUSSET, 1988).

However, the largest construction created on a karst system is the dam of Sainte-Croix du Verdon, wich submerges the resurgence of Fontaine-l'Evèque (mean discharge of 5.7 $m^3/s$) and the overflow spillages of the Garrubys. This great reservoir of Sainte-Croix regularizes the flow of the Verdon river, enables the functionning of three hydroelectric power stations and feeds the "Canal de Provence", which supplies water for irrigation of the lower Durance valley, Aix basin, middle Var Department, etc... and for the urban districts of Toulon and Marseilles.

3.5. Numerous bore-holes have now been sunk to top karstic groundwater both in confined cover-karst and paleo-karst. Some of these such the "Puits de l'Arc" in the Aix basin, Pernes-les-Fontaines which has attained groundwater under Miocène layers from the Vaucluse aquifer (MICHELOT et MUDRY, 1985), and other bore-holes in the Montpellier fold belt, in central Languedoc and in the Aude basin West of Narbonne; all have very high discharge (DROGUE, LATY et PALOC, 1983).

During the drought of 1989-1990, the multiplication of bore-holes and increased pumping led to a notable lowering of the water-table everywhere with important consequences, such as the drying of numerous springs and streams and increased pollution. A noteworthy example is the case of the little karstic lake of Besse-sur-Issole (in middle Department of Var) which partly dried up in December 1989, as a result of suction of water trough a subaqueous ponor, near the limits of the Muschelkalk (limestone of Middle Trias), on the lake bed (fig.3)(NICOD, 1991). As increasing exploitation of groundwater will consequently in slower recharge in some case, it will be necessary to resort to artificial recharging of karst groundwater in the future.

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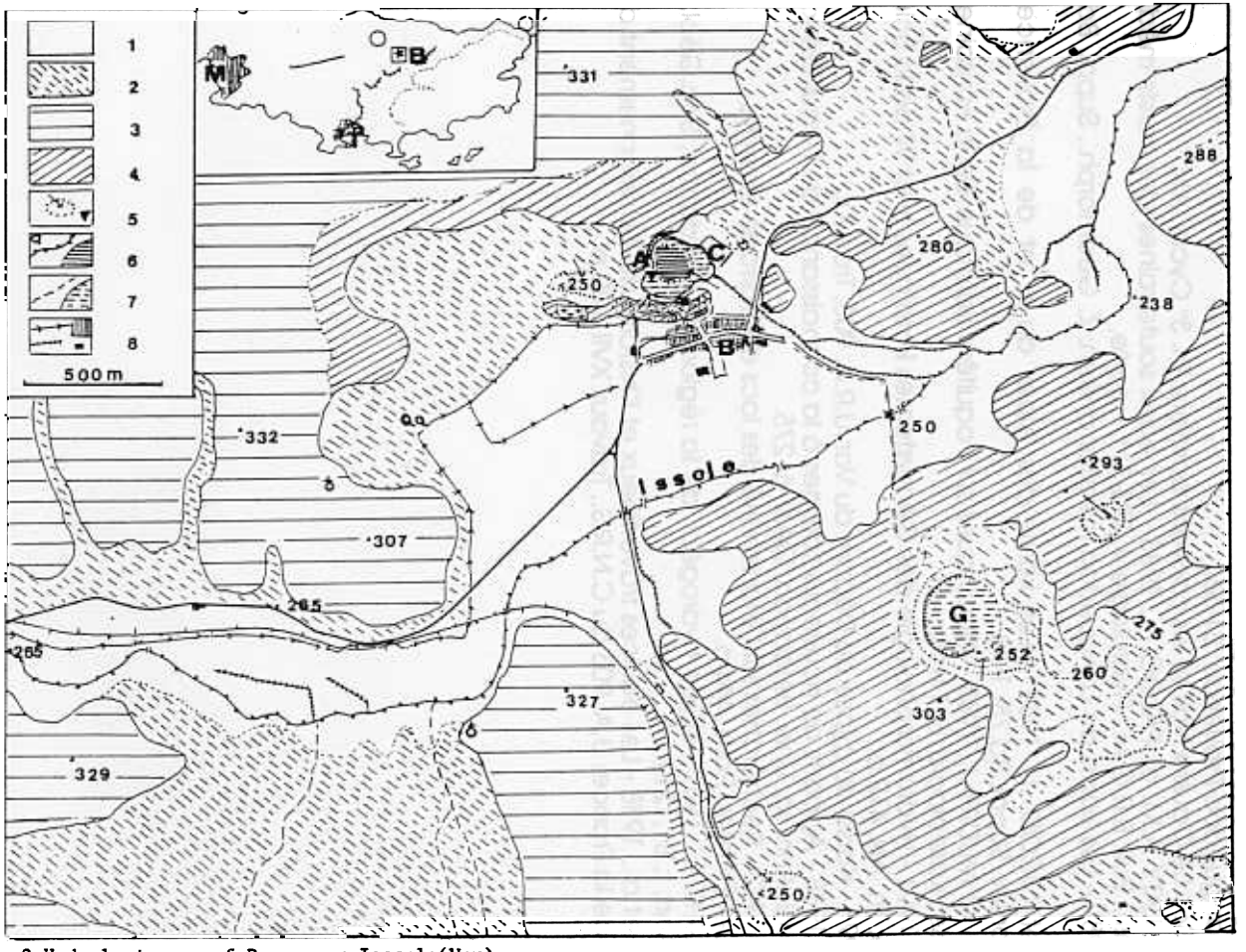


Fig.3-Hydrologic map of Besse-sur-Isssole(Var).

1-Alluvial bottom of valley,2-glacis and colluvial deposits,3-liasic limestones plateau,4-Muschelkalk,5-uvala, 6-permanent spring,river,lake,7-intermittent stream "vallat" ,8-irrigation,draining canal,town,landmark house. A-ponor,B-town of Besse,C-camping,G-Gavoty marsh.

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# A NEW METHOD FOR DATING OF NATURAL MATHERIALS WITH PERIODICAL MACROSTRUCTURE BY AUTHOCALIBRATION AND IST APPLICATION FOR STUDY OF THE SOLAR ACTIVITY IN THE PAST

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## ABSTRACT

*G. K. W.: environmental changes, cave deposits, global changes in the past. Geogr. K. W.: Bulgaria, Karst Areas in general.*

A New Method for perfect dating of natural materials with periodical macrostructure and with annual or daily cyclicity in their formation (like trees, bottom sediments, fossils, corals speleothems and others) by autocalibration is proposed. The base of this "Autocalibration dating" is the determination of the growth rate of the sample by power spectral analysis of time seria of given property of the sample having periodical cyclic recurrence. This time seria are obtained by scanning of a cross section of the investigated material. Advantages of the proposed method are its high precision independent of the age of the sample and its applicability for dating of all natural materials with periodical macrostructure having characterizing values, displaying annual of daily cyclic recurrence.

Some typical properties of the solar cycle are determined in the luminescent time seria of cave flowstones from Bulgaria.

To clarify the cyclic recurrence of the short-time variations of the climate and solar activity (SA) was proposed the method Laser Luminescent Micro Zonal Analysis (LLMZA) (SHOPOV, 19887. Some of its applications are given in (SHOPOV, 1988; SHOPOV &alii, 1988, 89, 90a, 90b, DERMENDJIEV & alii, 1990a).

Preparation of time seria with very different resolution (which can vary more than 1000 times) and different periods become available with the elaboration of this method, which allows research of either long or short time minima and maxima of the SA and general statistical conformities of the cyclic recurrence of the SA (DERMENDJIEV & alii, 1990a). The experimental set-up used is presented in (SHOPOV, 1988).

Up to now exists information for cycles of solar activity from direct measurements for 240 years, data from dendrochronology of tree rings for 7400 years ago with resolution 1 yr, and $^{14}C$ data for the last 10000 yrs. After calibration with these data, the LLMZA method can be used for obtaining such information with higher resolution

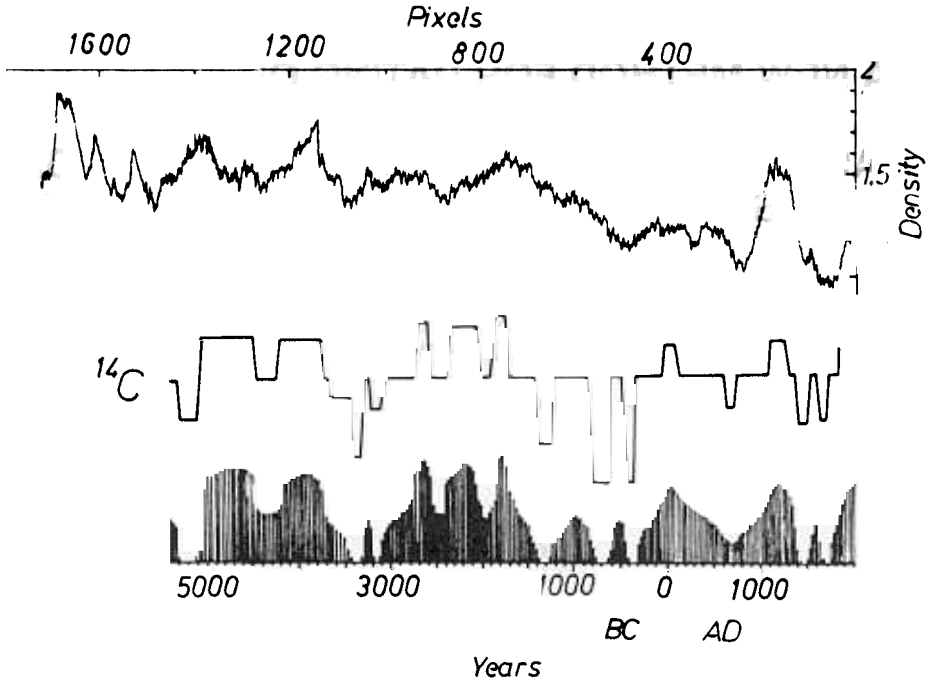


FIG. 1 Comparison of LLMZA with $^{14}C$ data: a) Luminescence time seria of cave flowstone with resolution 5 yrs/px. obtained by SHOPOV method (1988); b) Inverse curve of $^{14}C$ data and its interpolation c) as a long-term solar activity 18 envelope (of possible sunspot cycles) by EDDY (1978).

(up to 3 days) from up to several millions years ago (the age of the oldest flowstones).

The aim of this work is to develop an useful method for calibration of high resolution time seria by ages on the example of the time seria of a new indirect solar activity index: "Intensity of Luminescence of the Microzones of Cave Flowstones".

The main cycle of the SA, is 11 annual cycle. It is named solar cycle,because it is habitual for all phenomena and indexes of the solar activity (SA)(WALDMEIER, 1935). In SHOPOV & alii (1990a) and DERMENDJIEV & alii (1990b) we study the properties of the SA by the Intensity of Luminescence of the Cave Flowstone Microzones. This index is in anticorrelation with the index "deposition rate" of $^{14}C$ (fig.1) and in direct correlation with the solar activity as the thermoluminescent time series of 26 sediment cores (SHOPOV & alii, 1988; DERMENDJIEV & alii 1990a).

The luminescence of the calcite cave flowstones at Laser irradiation activates usually by organic admixtures (GILSON & MACARTNEY, 1953; WHITE & BRENNAN, 1989).

The luminescent centres in cave flowstones are organic molecules (like humic and fulvic acids, WHITE & BRENNAN, 1989) of penetrated in cave products of life processes of plants, growing over caves. The quantity of this products in result of photosynthesis strongly depends on the solar irradiation (DOUGLASS, 1919). Therefore intensity of luminescence of cave flowstones have revealed a strong annual cyclicrecourrence (independently of that cave flowstones usually have no visible annual rings; SHOPOV &alii, 1988,89,90b). Its allows to calculate the mean annual growth rate of the flowstone, by determination of the linear length of the mean annual period in the cross section by power spectral analysis.

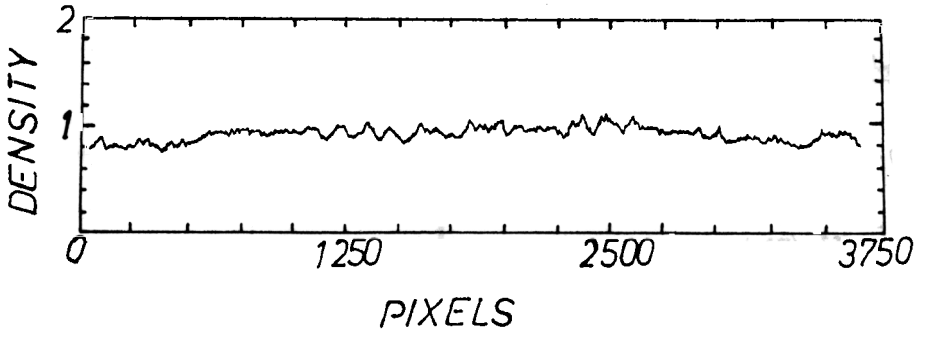


FIG. 2 LLMZA curve of the season climatic variations with, resolution 3 days (125 px/yr)(SHOPOVC &alii, 1988).

The intensity of luminescence of the microzones in cave flowstones is determined mainly by the SA during the formation of corresponding zone. This way the curve of intensity of its luminescence in dependence of the distance from the speleothem surface will present a time series of the changes of the past SA versus the age of rings in the flowstone. The paleoclimate can have only a feeble influence over the width of the zones (LUNGERSHAUZEN, 1963). After formation of the corresponding zone it is safe from further actions and saves information for the SA during its formation. It is conformed by the series which show well pronounced 11-yrs cycles by which form can be obtained general properties of the Solar Activity (SHOPOV & alii, 1989, 90b; DERMENDJIEV & alii, 1990a).

Luminescent time seria was obtained by irradiation of a polished cross section of cave flowstone with $N_2$- Laser and photography of its luminescence through a microscope. The obtained negative was developed with a scanning microdesitometer with automatical transformation of the density of blacking of the emulsion in digital form with recording on magnetic type and drawing on plotter.

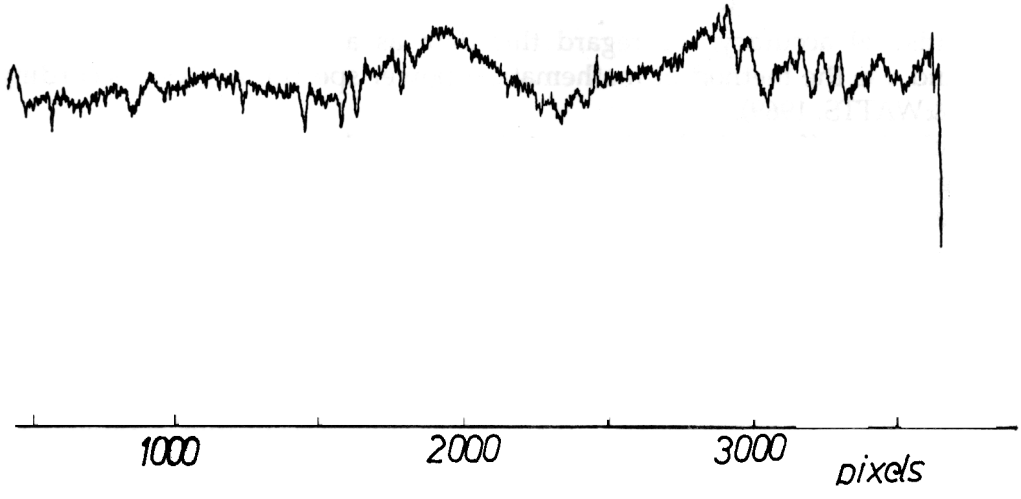


Fig.3 LLMZA curve with resolution 2,4 months, (4,74 px/yr).

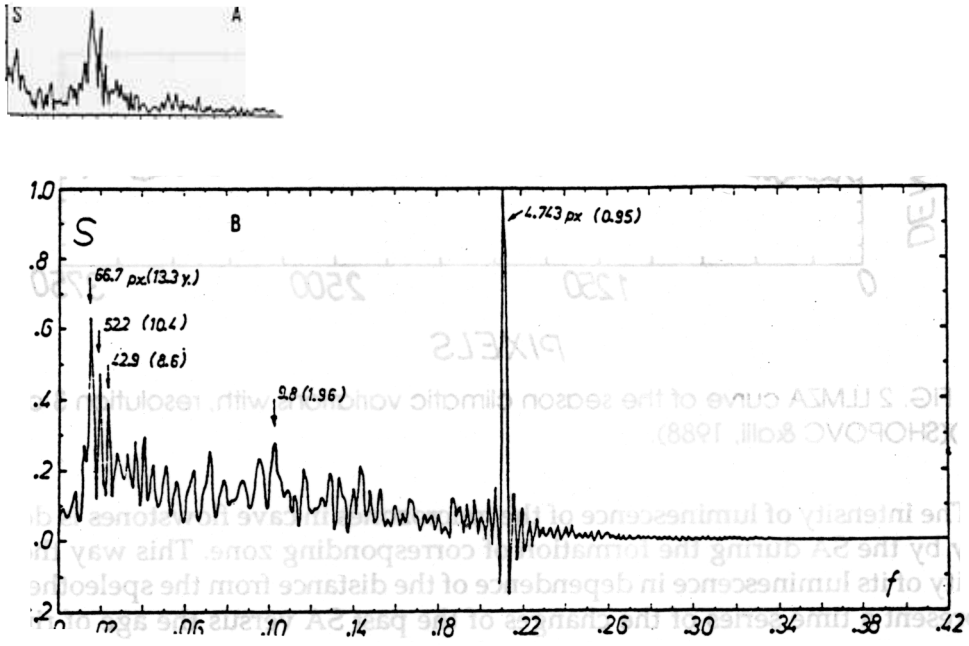


FIG.4 -A-. Highfrequency filtered spectra of LLMZA time series for 720 yrs from fig.3; B-power spectrum of the Wolf numbers time seria obtained from direct measurements of the Sun spots (RIVIN, 1989).

An example of a luminescent time seria with resolution of 125 px/yr is shown in fig.2. Density of blacking of the emulsion of the negative, which is proportional to the concentration of luminescent organic molecules is placed on the axis of ordinates, and the number of the measurements (pixels, which number is proportional to the age of the flowstones and 1 pixel is a time step of the series) is placed on the abscissa axis. The annual cycle is good visible in this 33 yrs long time series. All shown time seria are obtained from a cave flowstone from Bulgaria.

To study the periods of the periodical macrostructures of the sample with a proper statistical accuracy, we regard this data as a time series (time dependent process) and use the method of mathematical power spectral analysis accordingly to JENKINS &WATTS, 1969).

The obtained (from the luminescent time series shown in fig.3) power spectrum after using of high frequency filter is shown in Fig.4. It shows that by this way we can reliably determine the annual growth rate of the sample. This spectrum shows that during 750 yrs (length of developed time series) the annual growth rate of the speleothem were constant, because the annual peak in the power spectrum of this time seria is single and very narrow. Therefore power analysis of the luminescent time series can be used for perfect dating of the sample. If we know approximately the average annual growth rate of the speleothem (obtained from its absolute dating) we can indentified the annual peak in the power spectra of its luminescent time seria and we can determine the perfect annual growth rate of the sample from the position of this peak. If we know the linear dimensions of the developed time seria we can determine the perfect relative age of each part of this piece of the sample. If the speleothem grew without interruptions up to the time of getting the sample we can determine absolute age of the sample.

In our case we know from previous ESR dating that the average growth rate of investigated flowstone is about 1,70±0,2 micrometers/yr but from the position of the annual peak we determine the perfect annual growth rate of 1,58 micrometers/year.

The splittings of the 11-annual SA peak, observed in Fig. 4.a, are due to the availability of binary, singular, three- and four- cyclic 11 years cycles with different lengths (VEKLICH, 1987). The intensity and position of this peaks are indentical to that obtained from RIVIN (RIVIN, 1989) from the power spectrum (fig.4.b) of the Wolf numbers time seria (obtained from direct measurements of the Sun spots).

Periods of 11 (13,3; 10,4 and 8,8), 1 and 2 yrs were determined by power spectra (fig.4.a) of time seria with resolution 4,743 px/yr.

We named this dating approach as "Autocalibration Dating". The advantage of the proposed method is its high precision independent of the age of the sample. Our opinion is that it is applicable for relative dating of all natural materials with periodical macro-structure having characterizing values (like extinction, intensity of luminescence or thermoluminescence, concentration of given ion or others), displaying annual of daily cyclic recourrence (including samples without visible annual rings) like rhytmites, see and lake cores, plant fossiles, cave flowstones, trees and others, and for absolute dating if it grew till now.

ACKNOWLEDGEMENTS. This work is one of the bases of the International Program of Research of "Luminescence of Cave Minerals" of the Commission of Physical Chemistry and Hydrogeology of Karst of the International Speleological Union of UNESCO (15), and part of a grant with Bulgarian Ministry of Science.

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# KARST AS BASIS OF GREEK URBANIZATION

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## ABSTRACT

*G.K.W.: human impact, historical landuse, urban development, springs, changes in human ecology*
*Geogr.K.W.:Italy, Sicily, Syracuse*

Ancient Greek cities (example: Syracuse) relied on karst for water. Urban form reflected constraints of climate and geology. Urban institutions developed to optimize use of resources. Hydrogeology and hydraulic engineering contribute to the urban history of this period.

## INTRODUCTION

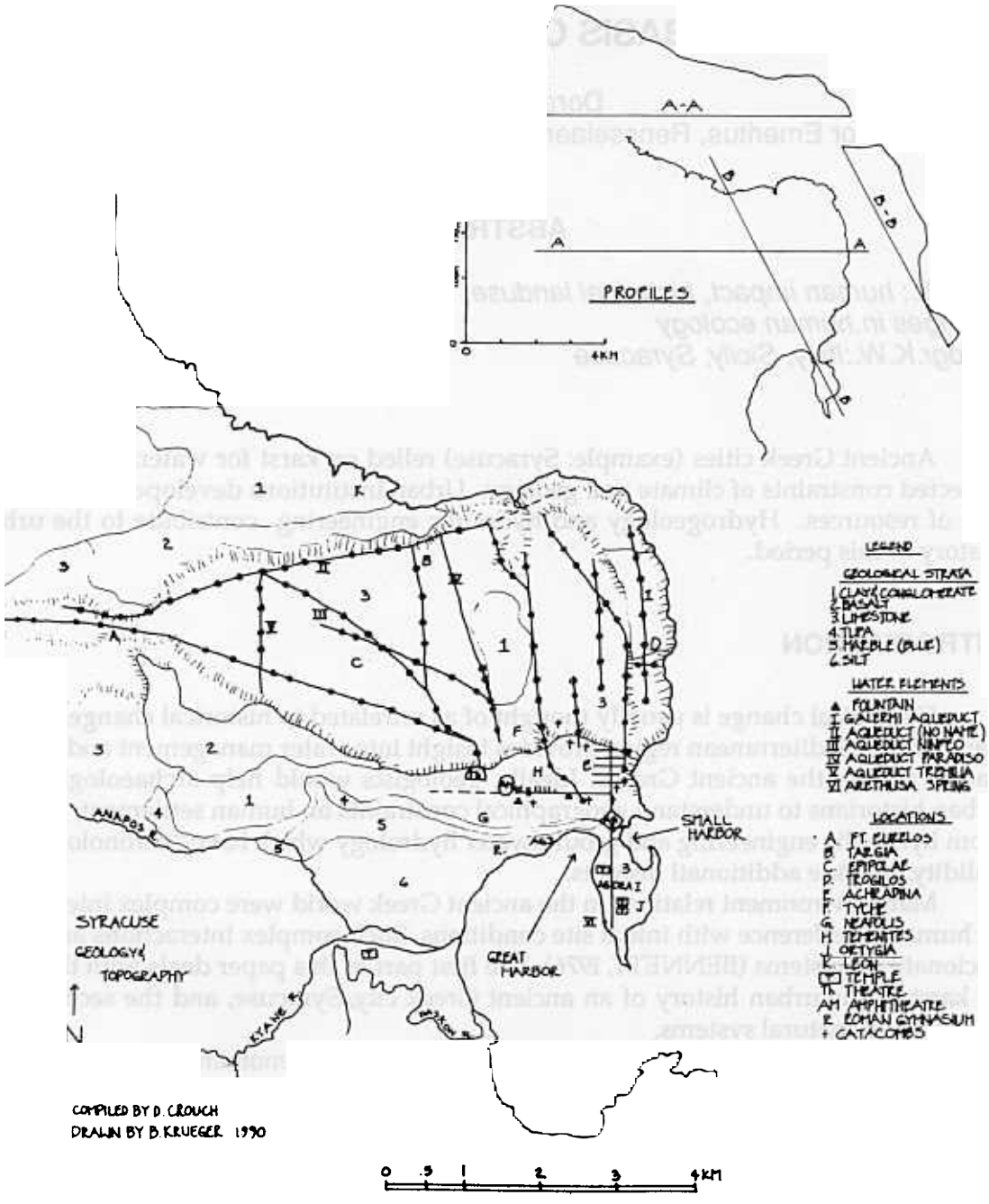
Geological change is usually thought of as unrelated to historical change. Yet the karst of the Mediterranean region provides insight into water management and urbanization among the ancient Greeks. Ideally, geologists would help archaeologists and urban historians to understand geographical constraints on human settlement. Insights from hydraulic engineering and groundwater hydrology which have "chronology free" validity, provide additionatl insights.

Man-environment relations in the ancient Greek world were complex interactions of human interference with initial site conditions. Such complex interactions are called socionatural systems (BENNETT, 1976). The first part of this paper deals with the place of karst in the urban history of an ancient Greek city, Syracuse, and the second part with its socionatural systems.

In Greek lands of the $8^{th}$ to $1^{st}$ centuries B.C., karst phenomena are widely distributed: continental Greece, Crete and the Aegean islands, Italy, Sicily, and Turkey (BELLONI et al; OZIS, 1985, fig 1, p. 96). In these places, limestone occurs as a rocky mantle with block faults (HUNTINGTON, 1911), steep slopes with few trees, densely wooded on terraces and plateaus (LEGRAND,1977). The slopes concentrate runoff into underground shaft-and-channel systems, water flowing underground as aquifers and appearing downhill in surface springs. Yield of water varies greatly from place to place.

Karst is an excellent reservoir for drinking water, owing to its joint networks, caves, shafts, and dolines (JENNINGS,1971; PICARD, 1957). Output of these karst systems is most useful to humans as springs and perennial rivers. Collecting water from a large watershed, a karst system is often out of phase with local rain events, exhibiting a dampened curve in outflow, which is to the advantage of humans who need water year round (DI CASTRI and MOONEY, 1973; MIJATOVIC, 1977). Springs that appear at the bases of mountains, where the soluable layer of limestone abuts an imper-

**Fig. 1. Geology and waterlines of Syracuse.**



meable layer of stone or clay (BOGLI, 1980) were most useful to Greek city builders.

The number of archaeological sites shows that people lived in twice as many places then, but not (contra FURON, 1952-3) that the population was twice as numerous. By the second millennium B.C. the Greeks had water technology (cisterns, wells, dams, and pipelines) that widened their choices among and control over local environments. Having learned to manage water in the karst terranes of their homelands, the Greek colonizers of the $8^{th}$ to $4^{th}$ centuries B.C. looked for similar rock formations at new sites. Thus they could be confident that they would find water and that their technology could manage it. The ancient Greeks did not, of course, call their geological environment "karst terrane" nor did they manage its water supply in the consciously mathematical way that a modern hydraulic engineer does. However, the sophistication of their water management indicates conceptual understanding of their resource base.

To sense the relationship between karst geology and Greek settlement, we will look at Syracuse in Sicily, selected to show how karst water potential played an important role in site selection and development.

## KARST AT SYRACUSE (Fig.1)

The karst areas of the Italian peninsula and of Sicily drew Greek colonists in the archaic period. Italian karst has been studied by BELLONI, MARTINIS, and OROMBELLI, among others, (1972) Sicilian karst by M. DALL'AGLIO and C. TEDESCO (1968). We will examine Syracuse as representing the Greek cities of the region.

Corinthian settlers selected the site of Syracuse because it had geological features analogous to Corinth. Syracuse is located on the southeast coast of Sicily, where two major layers of limestone are interstriated with narrow terraces of marl and conglomerate, tipping upward and inland to the northwest. Within these terraces, karst process has cut channels that slope toward the sea, and were used to deliver water to the growing city in Greek times. The inland waters flowing down the great dish of limestone and under the sea floor escape upward in wells and springs on the land or in submarine springs in the harbors. The island or penninsula of Ortygia was the first site of settlement, a notable source of water the spring Arethusa, at the edge of the sea, one of a series that used to be visible in the harbors flanking the island. A karst origin is likely for the submarine and coastal springs at Syracuse. Originally fresh water, these springs have been salty since an earthquake in the $12^{th}$ century (SCHUBRING, 1865, with map; SWEETING, 1973). Travelers saw smooth circles of fresh water in the choppy salt water of these bays. Modern studies of similar circles off the Greek and Yugoslavian coasts explain these springs: the water in the karstified limestone formation tries to come up to the surface through shafts that form along upright cracks in the rock. When the top of one of these shafts collapses, the fresh water flows out under pressure, forming an artesian spring. These springs are not now flowing. Perhaps the shaft collapsed and was plugged up, preventing the water from flowing out. Or, given the recent surge of urban developement at Syracuse, perhaps the groundwater table on the slope was reduced by many demands, lowering the pressure that had previously forced the spring water out to the surface.

The earliest temples were built on Ortygia, still the focus of urban life. They needed public fountains, drains, etc., but these have not been systematically located. To tap for public use the water flowing along bedding planes near the surface, there were several water lines crossing the island, as reported by SCHUBRING, one waterline near

the cathedral, one in the cloister of S. Lucia, two near the spring of Arethusa, and one on the coast of the Great Harbor. One plaza on Ortygia is still called "Ronco del Pozzo" (area around the well).

Other features of the water system at Syracuse are located on the mainland, in the suburbs: Acradina, Neapolis, Tyche, and Epipolae. A major focus was the grottoes above the theater, where water still collects. Water forms caverns in limestone and is pressure-driven into the open where caverns intersect the surface. Over several centuries, the water that had supplied these grottos found a new path farther down the hill, but the increase of population increased demand for water at this level. It was decided to resupply the grottoes via long-distance lines. The Ninfeo Aqueduct from the northwest (uphill) and the Galermi Aqueduct from the west converge at these grottoes.

By the $7^{th}$ century or early $6^{th}$ century B.C., long distance water supply lines were known in East Greek cities and on the mainland at Megara where the famous fountainhouse was built. Similar water lines occur a century or so later at Syracuse-imported water technology developed originally in the kingdom of Urartu (modern Armenia), then adopted by the Persians, and used in Greek lands initially on islands like Samos and Lemnos very near to western Asia Minor. The physical and documentary evidence enables us to assert that Syracuse had a mixed system of water supply, in which the oldest methods of wells, cisterns and springs were gradually supplemented by methods relying on more advanced technology (see in more detail D.P. CROUCH, Water Management in Ancient Greek Cities, Oxford University Press, in press). All were based on behavior of water in karst terrane. The engineers of the city provided amplification of a spring by directing to it flows and seepages from farther uphill, and also built completely artificial fountains.

## WATER HISTORY AT SYRACUSE

Water with $CO_2$ in solution carves channels in the limestone, beginning eons ago and still continuing.

Natural springs in caves draw settlers during Neolithic times or earlier.

Greeks of the archaic and classical periods utilize the caves and channels as aqueducts, enlarging them as necessary, by the early 5th century.

Earliest aqueduct dates from 491-477 B.C.

Water table drops because of large demand; supply by is increased by waterproofing tunnels, diverting streams, using tunnels as reservoirs.

Dwindling flow of water at the grottos while population increases requires additional long-distance water supply no later than $3^{rd}$ century B.C.

Reduction of population parallels down-cutting and draw-down of underground water. Population condenses downhill to utilize lower outlets closer to continuing commercial center.

New water system elements are added to compensate for old ones going out of use, and to provide bath-gymnasiums etc. for the new Roman population.

After long use as waterlines, abandoned grottoes and tunnels (originally karst passages) are re-used for tombs from the last century B.C., increasingly in the $3^{rd}$ and $4^{th}$ centuries A.D.

After a 15 century gap, the modern population begins deep pumping in the plains southwest of the city, renovating the old Galermi waterline.

Thus with the grottos above the theater and the lines that supplied them, the continuum spring-fountain-waterline exhibits all the complexity that is possible, given centuries of change in both the location of the vein of water and preferences of human users. So strong is the correlation of the history of Syracuse with karst phenomena that it is impossible to understand the form of the city without including this information. A city is complex; no single discipline can hope to account for all its features. By adding hydrogeological and hydraulic engineering information to our study of the urbanization of Syracuse, we achieve not only a more accurate perception of how the city worked and why the residential areas were placed as they were on the landscape, but also greater respect for Greek accomplishments. Contributions of the geological and engineering disciplines to a more complete and satisfying account of particular urban history are evident, though few in any discipline are trained to ask what the information and working methods from another discipline can do to help them understand the urban data they are working with.

Equally illuminating would be examination of the sites of Agrigento, Gela, Selinus, Morgantina in Sicily and Paestum, Pompeii, and Rome in Italy, but this format precludes that. Instead, we will consider the interaction between water necessities and social control.

## SOCIONATURAL SYSTEMS

From the $8^{th}$ through the $4^{th}$ centuries B.C. the Greeks founded colonies all over the Mediterranean. The 50 or so sites that I have visited are alike in being beautiful, but also alike in being almost exclusively located on karst geology. Like the beauty, this geological feature might be termed an accident, until we realize that karst provides a recognizable and manageable supply of water. A site was selected for resources including water supply. Then buildings were placed according to customs of daily life and availability of water. The geology guaranteed an abundance of water. At many sites water was so ample that the ancient engineers had rather to manage the water than to find or import it during the $8^{th}$ to $5^{th}$ centuries B.C.

## ALLOCATION OF WATER

Ancient use of three qualities of water was the complement to intelligent manipulation of karst water. The redundancy in water supply at these settlements was deliberate, an intelligent response to local climate and geology. Multiplicity of supply sources, re-use, and extended use provided safeguards against failure of any one source. Every potential water decision, such as locating bathing establishments near waterlines, was evaluated as to cost in effort and wealth. Water management tradition evolved in response to the real risks of urbanization in this climatological niche. What grim necessity forces certain modern cities to arrange for their survival, similar pressing necessity induced the ancients to organize some 2500 years ago.

When we see cities that endured upwards of 450 years, we ask how it was done. What would we have to do to sustain a settlement here? The constraints dictate the solutions. Sophisticated observation and analysis of geological potential for water supply had enabled them to tap and use natural flow in karst terrane. A site was selected for its spring which was sufficient for not only the first people but also the

increased population as the settlement became a town. The spring was dignified with a fountain house whose nymph guarded the water from casual pollution. As the town grew, one spring/fountainhouse was no longer enough. By sometime in the 7th century B.C., the Greeks were building long-distance water supply lines and drainage channels. By means of this technology, the town could grow to quite a large city with many fountains and adequate sewers.

In the ancient world hydraulic engineering played a major role in urban design and politics. In Athens during the 6th century B.C. the tyrants built an underground waterline that won them lasting popularity, and that continued to supply karst waters to the city until Hadrian's aqueduct was built 800 years later. Such features demonstrate motivation on the part of the rulers to win the favor of the people by supplying this basic necessity as a benefit of urban living.

An aspect of the relationship between geological setting and settlement not apparent in one or even several human lifetimes is that urbanization itself greatly increases runoff, and thus displaces the point of entry of the ground-water into the ground. Instead of gradual seepage through tree and plant roots into the soil, the urbanized area pours torrents of waters gathered from roofs and pavements onto the immediately surrounding unpaved surfaces, overloading their capacity to absorb, and promoting flooding. Conversely, the action of karst waters in cutting deeper into the limestone may leave high and dry a city that was depending upon them for its water supply MELHORN and FLEMAL, 1975; dissolution rates were studied in 1990 by DREYBRODT, just as wells may lower the water table. The dangers are exacerbated with scarce rainfall, intense evaporation, and infertile soil - none under human control. The condition of the watersheds of hinterlands is pertinent to the ability of the ancient engineer to extract water and transport it to municipal users. In the islands, whose bare rocky surfaces excite photographers and poets, but make settlement difficult,

"most of the island soils are barren from structural causes, while the sediment systems seem also to have led a fairly independent life. The best areas of land were so before man's arrival and in most respects have continued to be so until the present... The present dangers for the islands from human misuse are palpable but it is anachronistic to transfer present conditions of human ecology... uncritically into the past..." (BINTLIFF, 1977, p. 537).

As the last 200 years have shown, changes induced by human activity, plus minor climatic fluctuations, can cause local ecological systems permanent danger (GAGE, 1978). Such events took place in antiquity also, but they do not account for the whole story. Erratic climate has been a major factor in karst development, and consequently in managing the resulting water supply. Re-use of waste waters not only produced food, but also replenished the water table so that the wells and springs continued to flow for their children and grandchildren. This is resource management on a 50-100 year cycle, revealing their cultural values. Plurality of supply, not relying on only one source for so crucial a resource as water, insured the community. Flowing water was preferred for drinking, but cistern water could be drunk if necessary and used for a wide range of activities. Well water was allocated depending on palatability - at Delos for drinking, at Pompeii for sub-potable uses. Water was conserved by storing it as close at the point of use, covering channels, and diverting the excess from fountains to flushing and irrigating. Since every drop of water is an important resource, our distinction between "good" unused water and "bad" used water is irrelevant. All water in the ancient Greek world was potentially valuable since there were defined uses for every quality.

The work of modern engineers and geologists in such countries as Yugoslavia

makes us aware that karst waters can be harnessed. Many of their solutions are dependant not on advanced technology, but rather on careful observation and clever manipulation. The ancient Greeks were fully capable of both. The famous pinecone experiment in the sinkhole of the Tripoli plain during the 6th century B.C. is indicates that the ancient engineers were collecting data to manipulate karst for human purposes.

## CONCLUSIONS

As is the case with so often, relevant knowledge about settlement on karst terrane is in the hands of different disciplines which rarely perceive that they have any questions or answers in common. Karst has been studied by hydrogeologists and ancient Greek settlements by classicists, with an impenetrable membrane separating the two fields of knowledge. Yet my study has conclusively demonstrated that one cannot understand either the choice of an ancient Greek site or the subsequent history of the settlement without factoring in the geological base and water resources.

Karst terrane tends to self-destruct. This is a fact. What societies do about this fact varies considerably. A community can decide, "There's no use being careful, since the terrane self-destructs". Or they can decide, "We need to be gentle and keenly aware of the results of all our actions, since this terrane is delicate and tends to self-destruct". Many communities understood "reinvestment" into the natural environment to keep it in long-term balance. Certainly the long droughts of the 8th and 4th centuries B.C. forcefully reminded the Greeks of their precarious standing in the natural world.

This study has revealed what the ancient engineers and city founders had to know about water to make viable plans for new or expanded human settlements. It also reveals how adaptable the Greeks were in social arrangements for water. Founders of these settlements used traditional knowledge to find and develop water resources. Their methods were positive for long term water resource management. "Only 6% of water supply is used for drinking" is a truism in modern hydraulic engineering, but still is not common knowledge among humanists and classicists. To supply "only 6%" a single karst spring could suffice for an expanded urban population. House and city form reveal the society's means of collecting and using water, as well as constrain use. In the absence of written records, careful study of the geological base, of archaeological remains and of visual representations of water system elements can tell us much about how the ancient Greeks managed water to make settlement possible, sustainable, and amenable. Water management in Greek times was nicely balanced between elements that people could build, maintain and use privately, and those that required communal effort and provided communal rewards. Understanding this requires us to re-evaluate what we know about the ancient Greeks from purely literary remains which are of course skewed towards upper class male views of the Greek urban experience. It takes more thought than money or physical force to live well - comfortably, graciously, non-exploitatively. In spite of marked differences between the roles, functions, and powers of men and women, free persons and slaves, daily life among the ancient Greeks was pegged at a level of equity and comfort rarely equaled in human history. Both the daily routine and the built containers for that routine were pleasant for most people. Water arrangements played an important role in making this so. In so doing, the study indicates additional reason for respecting the accomplishments of our forebears.

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# RESOURCE USE IN RURAL TROPICAL KARSTLANDS: THE HUMMINGBIRD KARST, BELIZE.

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## ABSTRACT

*G. K. W.: landuse, resources, human impact*
*Geogr. K. W.: humid tropics, Belize*

Rural tropical karstlands are subject to a wide variety of traditional landuses which employ the natural karst resources of rock, water, soil, vegetation and wildlife. Although individual resource pressures are subtle, their combined impact can precipitate instability in the fragile karst environment, potentially resulting in inadequate supplies of food, water, and fuel. In the Hummingbird karst of central Belize resource use is accelerating as population pressures increase. Although much of the karst remains in secondary forest, there is increasing clearance for agricultural uses, including cattle grazing, citrus and cacao cultivation and small-scale mixed agriculture. Some soil depletion problems have already been noted and some wildlife species are becoming scarcer as a result of habitat destruction and increased hunting. Increased lime production for the citrus industry requires greater quarrying, water extraction and fuelwood use. Presently environmental stresses are below the threshold of instability, but the rapidly developing rural economy warrants careful monitoring of resource pressures.

## INTRODUCTION

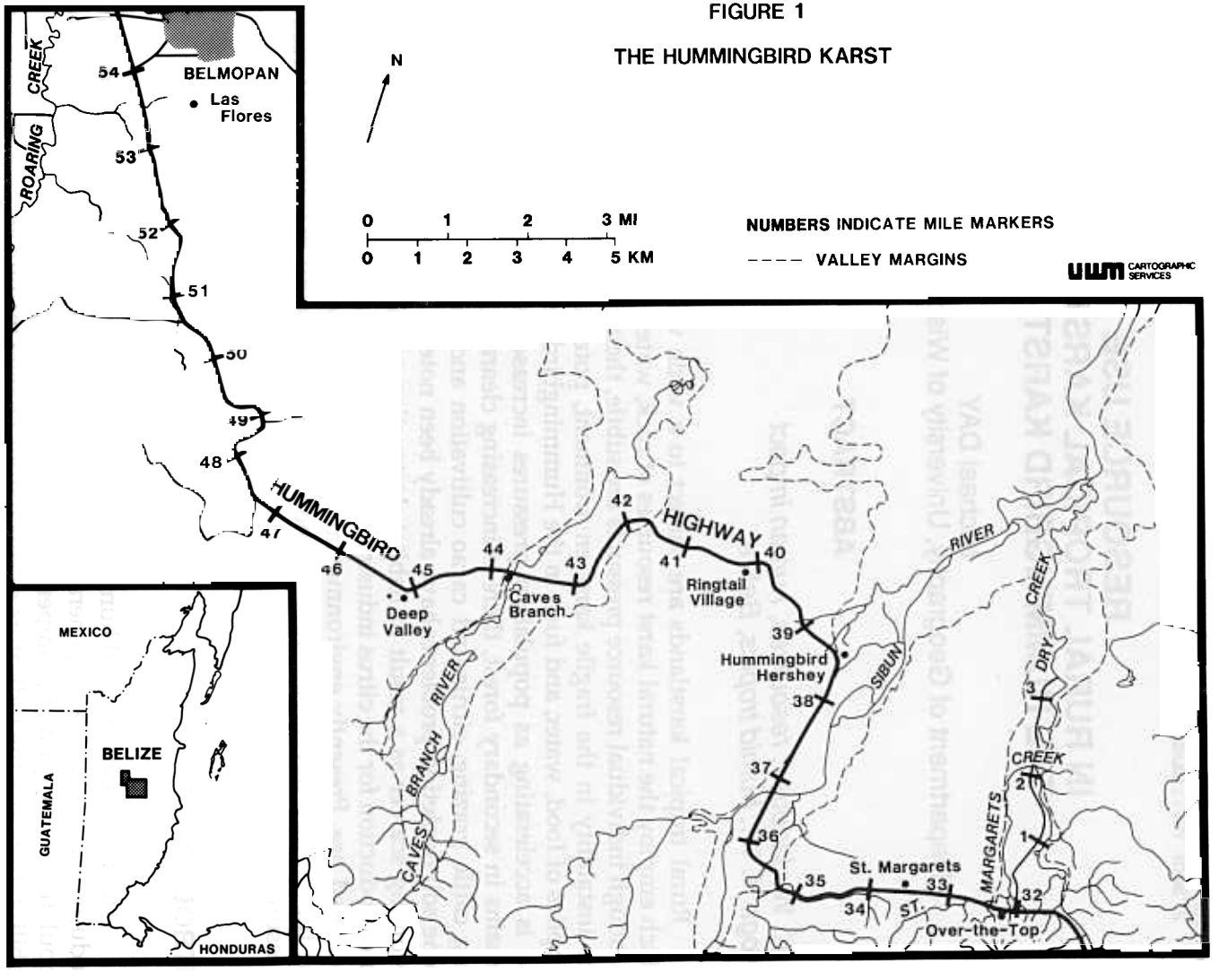
Although many tropical humid karst areas are still dominated by traditional rural landuse practices which are generally in harmony with the karst environment, growing populations and economic imperatives are steadily impinging upon environmental stability. Typically the indicators of precipitous change include accelerated forest clearance, increased agricultural investment, and the rapid construction of new buildings, settlements and infrastructure. In turn these are often reflected in diminished floral and faunal reservoirs, deteriorating soil and water conditions, and other problems in meeting the needs of traditional resource uses.

## THE HUMMINGBIRD KARST

The Hummingbird karst is 40 $km^2$ of the karst of central Belize north of the Maya Mountains and south of the Belize River Valley which straddles the Hummingbird

FIGURE 1

THE HUMMINGBIRD KARST



Highway for 35.5 km southeast of Belmopan (Figure 1). Roaring River, the Sibun River, Caves Branch and Dry Creek drain from the non-karst rocks of the Maya Mountains and dissect the karst into three blocks of rugged upland terrain comprised of enclosed depressions, residual hills, and valley systems (DAY, 1986a, 1987b; ROSEN, 1987). The intervening river valleys have alluvial floors and cliffed margins.

Soils on the limestones are patchy, calcareous mollisols or vertisols. Most soil profiles are less than 30 cm thick and steeper slopes may have little or no soil cover (FURLEY and NEWEY, 1979). In the main valleys the alluvial soils are mostly red-brown acidic sands and clays.

Annual rainfall averages 2000 to 2400 mm, with a marked dry period from January to May and a wet season from July through October (WALKER, 1973; FURLEY and NEWEY, 1979). Dry season aridity may be extreme, but intense wet season storms, including hurricanes, result in flooding and severe erosion (DAY, 1986b). Mean annual temperature is about 25 degrees C.

Natural vegetation is humid and wet-dry tropical forest (FROST, 1980). Over the limestone is a species-rich, broadleaved, deciduous seasonal forest (FURLEY and NEWEY, 1979) which contains a wide variety of wildlife.

## HISTORICAL AND CONTEMPORARY LANDUSE: AN OVERVIEW

Human use of the limestone area began with the pre- Hispanic Maya, who constructed at least five ceremonial or organizational sites and used at least fifteen cave sites in the Hummingbird karst. Most of these date to the Late Classic period (700-900 A.D.) when the Hummingbird area was significant as a trade and communication route between the Belize River Valley and areas east of the Maya Mountains (DAVIS, 1980).

The Late Classic Maya initiated significant landuse changes, clearing forest for shifting agriculture and practicing intensive farming around settlements. The river valleys and limestone uplands both were farmed employing a variety of agricultural strategies including terracing, flood water impoundment and irrigation.

The precise impact of this early landuse in the Hummingbird karst is difficult to assess, but in general Maya occupation had a marked impact on the tropical karst environment (DEEVEY et al, 1979). Forest clearance resulted in accelerated soil erosion, and Maya landuse had a lasting impact on forest composition (FURLEY and NEWEY, 1979). Environmental stress, as a result of agricultural and other pressures brought about by rapid population growth, may have contributed to Late Classic cultural upheavals (HARRISON and TURNER, 1978).

European impact on the Hummingbird landscape began with cutting of mahogany by the British in the late nineteenth century. By 1900 most of the Sibun River Valley was being logged and by the 1940s there were several temporary settlements. Completion of the Hummingbird Highway in 1954 spurred timber extraction, but Hurricane Hattie in 1961 destroyed most of the forest and commercial logging never recovered.

Previously-logged areas were first used for agriculture in the early twentieth century. In 1939 there were milpa clearings in the Roaring River area (FROST, 1979a) and by 1954 there were subsistence plantations around Roaring Creek (WRIGHT et al,1959).

Commercial agriculture was stimulated by the completion in 1954 of the Hummingbird Highway, which is the lifeline for residential, agricultural and industrial

activities in the Hummingbird area. Over 80% of the population lives within 1km of the road, and some 75% of all the land in agricultural use is adjacent to the road.

A second spur to agriculture was the construction of Belmopan in the late 1960s. Although the new capital has grown slowly, it has exerted considerable influence on agriculture and population, particularly in the 1980s. In addition to residents from within Belize, Belmopan has also attracted Salvadoran and Guatemalan refugees, who have arrived in increasing numbers since about 1980.

In 1975 total population in the Hummingbird karst was less than 100. By 1983 at least 155 immigrant families had moved into the area (BENNETT and FURLEY, 1983), and by early 1986 the total population was about 900 (BLISS, 1987). By 1987 the total population was about 1100, of whom 750 were Salvadoran or Guatemalan (DAY, 1987b).

The 1980s population influx accelerated development of small-scale mixed agriculture, while the expansion of commercial enterprises caused other landuse changes. The Hummingbird karst was almost entirely forest-covered in 1975, but by 1986 some 2500 hectares, mostly adjacent to the highway, was in agricultural use. Between 1979 and 1983 forest declined from 58% to 46% of the area adjacent to the highway. By 1983 pasture occupied 18% of the area, cacao and citrus 12%, milpa plots 12%, and residential areas 9% (DAY, 1987b; DAY and ROSEN, 1989).

## CONTEMPORARY RESOURCE USE

Recent increases in population, agriculture and commerce are beginning to have a marked impact upon the karst landscape and particularly on the area's resource base. Over 2000 hectares of forest were cleared between 1980 and 1986, and this has been accompanied by increased farming, loss of wildlife habitat, accelerated soil erosion, increased water extraction and contamination, increased hunting, increased use of fuelwood and quarrying of limestone.

Although many of these resource uses are focussed on private land they also have an impact on adjacent public land. Much of the Hummingbird karst is part of the 430 $km^2$ Sibun Forest Reserve, which is primarily dedicated to permanent forestry through sustained tree growth and regeneration, but which also serves to prevent soil erosion, retain water and provide wildlife habitat. Unfortunately, management of the Forest Reserve is minimal and landuse regulations are not enforced strictly.

### Agriculture

Farming is the dominant resource use in the Hummingbird karst, involving about 2500 hectares of land and almost 100% of the population. The agricultural pattern was established in the 1950s, following construction of the Hummingbird Highway, and agriculture has increased since 1970 as a result of government policy, private enterprise, the construction of Belmopan and the influx of population.

Agricultural activities in the Hummingbird area have a broadly similar history of introduction from adjacent districts, slow initial growth and rapid recent expansion (URICH, 1987). For example, cattle from the Belize River Valley were introduced to Caves Branch in the 1970s, and the Hummingbird area now has about 1000 head of cattle on 575 hectares of pasture (DAY, 1987b).

Cacao (*Theobroma cacao*) has been grown commercially in the Hummingbird area since the 1950s, but Hurricane Hattie in 1961 caused extensive damage to the pl

antations. In the Sibun valley commercial production resumed in 1977 under the auspices of the Hershey Foods Corporation. Hummingbird Hershey currently has 245 hectares in cacao production and is promoting a 230 hectare cacao project at Ringtail Village. In total 365 hectares were under cacao in 1986 (DAY, 1987b).

Citrus was introduced into the Hummingbird region from the Stann Creek Valley in the 1950s. By 1986 there were fourteen citrus groves in the Hummingbird area, covering some 165 hectares. Most of the citrus is oranges, grown on small farms as a primary or secondary cash crop. Citrus acreage is increasing rapidly and production should increase substantially in coming years.

Although commercial production of cattle, cacao and citrus, dominates the economy of the Hummingbird area, over 90% of the population practice small-scale mixed agriculture. Most individual landholdings are less than 10 hectares, and they are clustered in three localities: between Belmopan and Caves Branch, from the Sibun River to St. Margaret's Creek and within the Dry Creek Valley (Figure 1). In 1975 small-scale agricultural acreage was negligible, but by 1985 it had risen to about 300 hectares (DAY, 1986b), and by 1986 mixed agriculture occupied about 1395 hectares (DAY, 1987a; DAY and ROSEN, 1989).

Agriculture is beginning to have a marked impact upon resources within the Hummingbird karst. Forest clearance exerts pressure on wildlife populations and livestock watering renders some water sources unsuitable for human use. More significantly, soil erosion is an increasing problem, primarily as a consequence of milpa farming on steep karst slopes (HARTSHORN et al., 1984). Some 65% of present agricultural land is in valley or depression bases, but hillslopes are still being cleared and continued milpa agriculture is threatening the long term sustainability of the forest soils (FURLEY, 1987).

## Water resource use

Water resources in the karst are strongly limiting, and the demands of the growing population mandate careful management and conservation. Management strategies fall into two general categories: maximizing use of the intermittent surface water supplies, and tapping into the more reliable underground sources.

The increases in population, agriculture and industry have already had an impact on water supplies, particularly on surface sources in the upland karst. Springs, seepages, ephemeral streams and small reservoirs cannot meet demand in the dry season and water is brought from Belmopan or from the Sibun River by tanker or truck. Water for domestic use is provided regularly by Public Works Department tanker to households between Belmopan and mile 40 (Figure 1). In St. Margaret's village dependence switches totally to shallow public wells, which also supply the lime kilns. Caves Branch and Dry Creek dry season flow may be negligible also and water supply is a problem for farmers and other residents. The Sibun River usually flows throughout the dry season, but Hummingbird Hershey maintains and uses a 49 m well which was drilled in 1979.

Contamination of water supplies is not yet a serious problem, although this may be anticipated as human and livestock populations increase. When animals foul water in Caves Branch and Dry Creek alternative sources are used. There are reports of wells being contaminated and capped, but there are no reliable records of this.

## Limestone quarrying and lime production

In the Hummingbird karst there are over 30 quarries, some of which have been worked since the 1950s for construction of the highway itself and for cement and mortar used in the building of Belmopan. Quarrying has increased substantially since the establishment of lime kilns in the 1980s, but the manual removal of limestone has yet had few damaging effects. Any relaxation of explosives restrictions may pose greater problems.

Powdered slaked lime is used particularly in the Stann Creek citrus groves to increase acidic soil pH and magnesium content, and there is a thriving local business in lime production, with high magnesium content lime being in particular demand. Between 1979 and 1987, Salvadoran immigrants built six lime kilns along the Hummingbird Highway. By 1990 the number had risen to twelve, all located in St. Margaret's Village close to the wells.

Lime production requires limestone blocks or boulders, about 15 $m^3$ for an average kiln; firewood, up to five cords for a firing; and water, up to 12,000 liters for each firing. Peak demand for lime is in the dry season, especially in March and April, when kilns may be fired every week. To date the supply of raw materials has been adequate, although operators are now beginning to experience difficulty in meeting firewood demands, and the recent concentration of kilns in St. Margaret's is a direct response to the availability of water from the village wells.

## Use of forest products

Although there is little commercial timber extraction, residents use increasing amounts of wood for domestic purposes, primarily for cooking and construction. Domestic fuelwood consumption ranges from about ten to twenty cords per household per year. Approximately 100 cords of wood are used each year at Hummingbird Hershey for the furnaces employed in the drying of cacao beans. The operation of lime kilns has increased substantially the demand for firewood. A single kiln firing may use five cords of wood, and each of the twelve kilns may be fired four times a month during the dry season. As lime production expands the demand for fuelwood and the potential for local deforestation and usurping of forest reserves increases. This threat to the forest reserves has been recognized by the Forest Department (G.O.B., 1985a) but enforcement of regulations is difficult because of low staffing and financing levels.

Additionally some local residents make use of forest plants for herbal and medicinal purposes, and isolated forest plots are used for the illicit cultivation of marijuana (DAY, 1987b).

## Hunting and wildlife habitat use

Hunting and forest clearance are beginning to affect wildlife populations, endangering some species and causing others to retreat into the interior forest of the karst uplands, but encouraging those favoring open and agricultural land (FROST, 1979a,b, 1980; DAY, 1987b). Legal hunting pressures appear to be taking a toll on game species, particularly the gibnut or paca (*Agouti paca*), which is highly prized for its meat and is hunted extensively (G.O.B., 1985b). Other game species whose populations appear to be in decline include the Collared and White-lipped peccary (*Tayassu tajaca* and *Dicotyles pecari*), the White-tailed deer (*Odocoileus virginianus*) and the red brocket deer (*Mazama americana*). Among the common game bird species the picture is broadly similar (DAY, 1989). Illegal hunting is also rampant in the Hummingbird area, affecting a variety of protected species (DAY, 1987b).

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# STRESS ON TROPICAL KARST RESOURCES EXPLOITED FOR THE CULTIVATION OF WET RICE

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## ABSTRACT

*G.K.W. : human impact, environmental changes, resources*
*Geogr. K.W. : Bohol, Philippines*

By examining the type, development and management of karst resources exploited for the cultivation of wet rice a compendium of those vital to sustained cultivation has been developed (Urich, this volume). Some resources are more critical to the sustained operation of the agricultural system than others. In this case the quantity and quality of groundwater is paramount. Landforms and landuse are discussed. Changes in resource exploitation and landuse patterns are explored and impacts on the resources and particularly groundwater is investigated. Intimate relationships exist between a changing cultural ecological situation and agricultural and non-agricultural economic activities. The changes in karst resource exploitation and associated environmental impacts emphasize the need for comprehensive monitoring and remedial action strategies which integrate physical and social phenomena.

## INTRODUCTION

Investigations of karst-based agricultural systems, whether in harmony or disharmony with the environment, should logically begin with "an objective assessment of the resources in question" (Ford and Williams, 1989; Urich, this volume). The municipality of Batuan in the karst upland of the central Philippine island of Bohol exhibits a highly specialized wet rice agricultural system developed over millenia in relative isolation from external colonizing and often ecologically degrading forces (Urich, 1990) (Figures 1 and 2). However, since World War II, multi-faceted and complex external and internal forces have altered traditional community resource allocation and management practices. These changes have had widespread impacts. Most notable is a changing hydrology in reaction to specific changes in cultural ecology.

The desire for change has to some degree been sought by the indigenous folk in recognition of increased pressure to become more productive. More importantly however is a rising population density and an armed insurgency and counter-insurgency which has fostered intensified and degrading exploitation of karst resources.

This paper explores the causes and effects of this rapidly changing pattern of resource exploitation. It emphasizes the complexity of the relationship between the population and the resource base and its effect on the wet rice economy. Recognition of

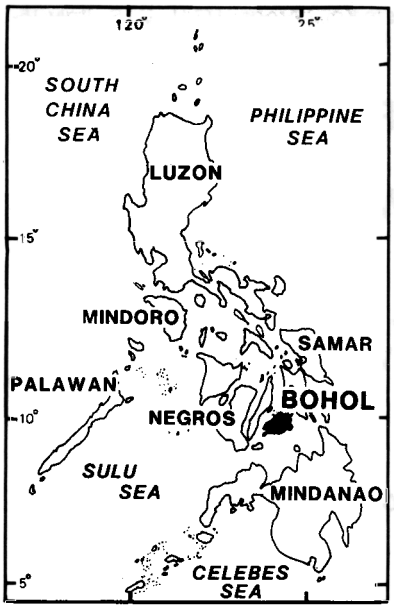


Figure 1: The position of Bohol island in the Philippine archipelago.

interrelationships between seemingly unrelated economic and social activities and agriculture may require a reassessment of development projects which could further compromise agricultural viability.

## LANDFORMS

Landforms typically asssociated with tropical karst are found throughout the study municipality of Batuan. They are formed predominantly in the Maribojoc Formation, but landform development in the Maribojoc is influenced by its proximity to the underlying Carmen Formation. Landforms include cone-shaped, isolated residuals (mogotes) which are also termed "haycock" hills owing to their resemblance to stacks of harvested rice (Smith, 1925; Faustino, 1932). Elongated interfluvial residuals and massive metamorphosed limestone blocks may reflect the influence of magmatic upwelling.

Karst depressions, though occasionally closed, are usually elongated in discontinuous valleys. In some areas they are narrow and elevated, opening to wide, polje-like flat valleys. Individual karst features include caves, swallets, sinkholes, springs, and tufa dams. Slopes are highly variable, with the majority being less than 3 percent (Table 1). Steeper slopes and vertical cliffs are generally associated with the limestone residuals.

In Batuan the greatest expanse of relatively flat land surrounds the Poblacion (municipal administrative center). From this point the density of limestone residuals increases to the east and west (Figure 3). To the north a 7.5 km long ridge locally known as Camanayon Mountain forms a natural and cultural barrier between Batuan and the Municipality of Carmen. A flat polje-like valley narrows to the south and stretches about 7 kilometers toward the municipality of Bilar.

## LANDUSE

Fifty-six percent of the land area of Batuan slopes at less than 3.0 percent. About half of this 56 percent possesses saturated bedrock or access to a spring water irrigation

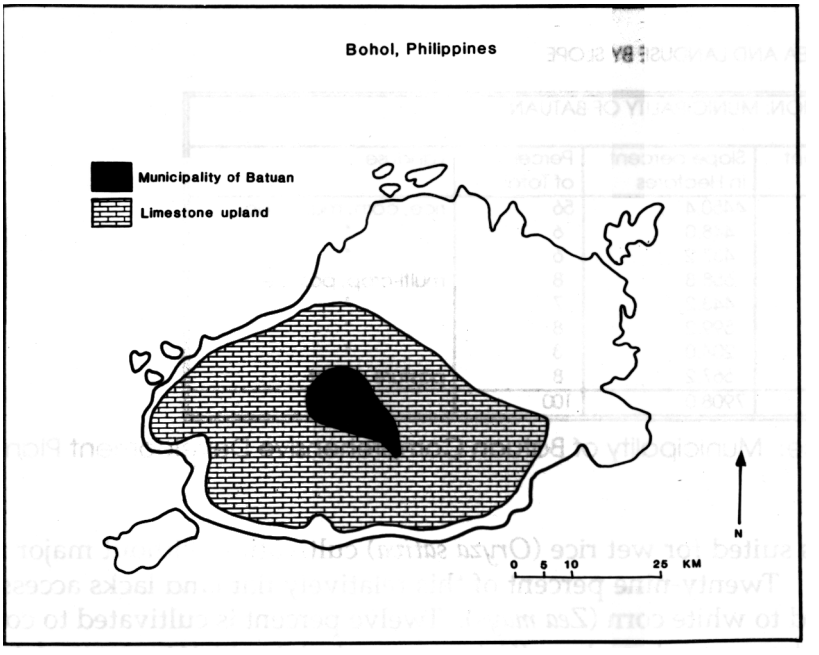


Figure 2: The location of the municipality of Batuan within the limestone upland of Bohol.

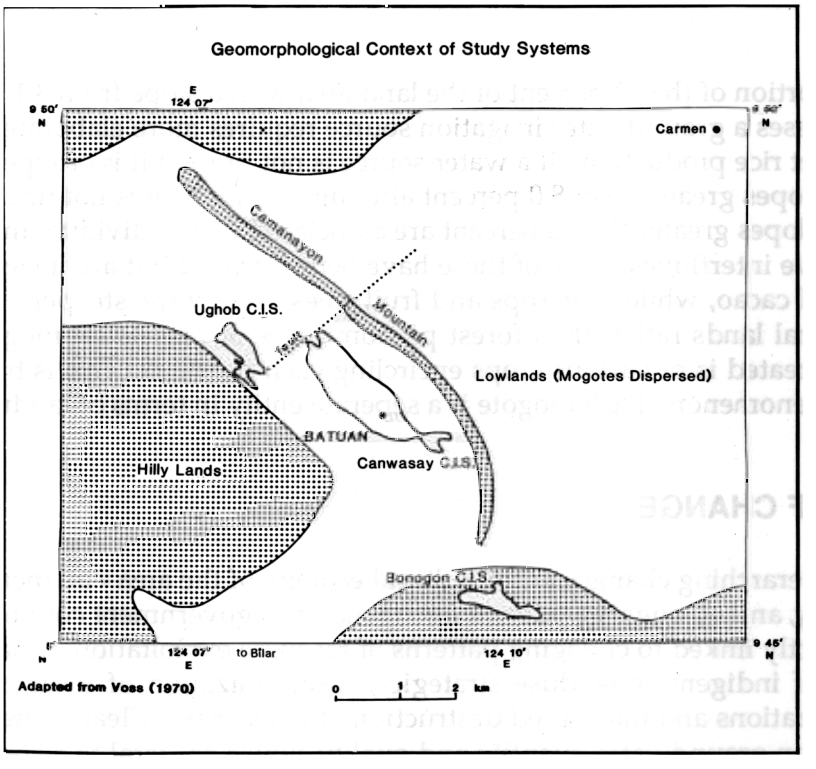


Figure 3

TABLE 1
PERCENT AREA AND LANDUSE BY SLOPE

| CLASSIFICATION: MUNICIPALITY OF BATUAN | | | |
|---|---|---|---|
| Slope percent | Slope percent In Hectares | Percent of Total | Landuse |
| 0.0 - 3.0 | 4450.4 | 56 | rice, corn, multi-crop |
| 3.1 - 5.0 | 448.0 | 6 | " |
| 5.1 - 8.0 | 437.2 | 6 | " |
| 8.1 - 15.0 | 658.8 | 8 | multi-crop, pasture |
| 15.1 - 18.0 | 443.2 | 7 | " |
| 18.1 - 25.0 | 599.2 | 8 | " |
| 25.1 - 50.0 | 204.0 | 3 | " |
| 50.1 - > | 667.2 | 8 | pasture, forest |
| | 7908.0 | 100 | |

Source: Municipality of Batuan Comprehensive Development Plan (1982)

source and is suited for wet rice (*Oryza sativa*) cultivation without major technological intervention. Twenty-nine percent of this relatively flat land lacks access to irrigation and is planted to white corn (*Zea mays*). Twelve percent is cultivated to coconuts (*Cocos nucifera*), rootcrops such as taro (*Colocasia escalenta*), ubi (*Dioscorea alata*), and sweet potato (*Ipomea batatas*), legumes such as peanuts, bananas (*Musa sapientum*), vegetables including tomatoes (*Lycopersicon esculentum*), fruits including mango (*Mangifera indica*), jackfruit (*Artocarpus heterophylla*), star apple (*Chrysophyllum cainito*), coffee (*Coffea arabica*), and cacao (*Theombroma cacao*). The nine percent of relatively flat land remaining is either in pasture, developed for settlement, or in isolated instances remains forested.

That portion of the 12 percent of the land area with a slope from 3.1 to 8.0 percent which possesses a groundwater irrigation source requires more elaborate terracing for sustained wet rice production. If a water source is not present it is cropped in a similar manner as slopes greater than 8.0 percent although white corn is not uncommon. The majority of slopes greater than 8 percent are associated with individual mogotes rather than extensive interfluves. Few of these have been terraced but are instead cultivated to coffee and cacao, while rootcrops and fruit trees occupy the steeper slopes. Increasingly pastoral lands rather than forest predominates on the flatter mogote summits. The image created is of various crops encircling each residual. This is by no means a universal phenomenon. Each mogote is a seperate entity in terms of landuse history.

## AGENTS OF CHANGE

Two overarching changes in the cultural ecology of the area - an increasing population density, and an ongoing peasant insurgency and government counter-insurgency - can be directly linked to changing patterns of resource exploitation. Changes include disruption of indigenous landuse strategies, disorganization of indigenous peasant labor organizations and intensified destruction of landforms. Clearly, the most critical impact is upon groundwater quantity and quality, which are vital to a sustained population and agricultural economy. Thus, this discussion will focus on the catalysts of change noted above and the affect these changes have had on resources and their

management, particularly groundwater.

## Population

In the study municipality of Batuan, centrally located in the upland of Bohol, the rate of population growth has outpaced local government projections. The 1970 municipal population stood at 8,712 (0.90 person per hectare). By 1975 it had risen to 9,940 but declined to 9,835 by 1980. In 1980 the municipal development council projected a population of nearly 10,000 by 1989, but by 1989 this was exceeded by almost 2,000 (Virador, 1989). In 1980 (the most recent published data available) the municipal fertility rate was 3.3% or 332 births for a population of 9,835 (Republic of the Philippines, 1980). While the fertility rate is high the overall growth rate in 1989 is estimated to be 1.85%, a factor of continued out-migration of primarily young men.

Batuan's population of 11,729 in 1989 (1.48 persons per hectare), consisted of 1,948 farm families and 480 non-farm families. The largest segment is married females (over and under the age of 21) and unmarried females over the age of 21 (41.2%). Males over 21 constitute 28.2% of the population, and youth of both sexes between the ages of 10 and 20 constitute 20.8%. The smallest percentage is comprised of those under the age of 10 (9.8%)(Virador, 1989). The imbalance in sex ratio as noted above can be attributed to migration of young men. The small percentage under the age of ten is the result of population growth control programs.

Growing population pressures have initiated a correspondingly rapid expansion in caingin (slash and burn) agriculture in the uplands. This expansion has resulted mainly from increased population pressures and to a lesser degree by a relative slowing of the above emigration concurrent with increasing return migration. However, most of the new caingin plots are not used for annual crop production, but have been developed for carabao (water buffalo) pasture. Requirements for local pasture have increased as traditional pastures, located to the north in the cogonal grass (Imperata cylindrica) lands of the municipality of Carmen, have been returned to cultivation under similar population pressures.

## Insurgency and Counter-Insurgency

Batuan's population is presently experiencing an extremely high level of stress associated with armed insurgency and counter-insurgency. Military policies have focused heavily on population re-location and infrastructure development. Historical settlement patterns involve dispersion of housesites. A typically situatation being on the toeslope of a residual. Highly diversified dooryard gardens and small livestock enterprises are common.

A wide array of informal self-help organizations also exist which aid families during periods of financial or psychological stress and include Gala (marriage) and Dayong (death) organization. The hongos is most closely associated with agricultural landuse. Traditionally it has been composed of from 14 to 20 members with a rotating "manager." A hongos may be called by any member, who in effect becomes the "manager" of the hongos for that particular day. A hongos if often called in association with irrigation system development and maintenance or hillslope stabilization including terrace contruction and tree planting. These are all activities which because of time, skill and energy require a pool of labor.

Impacts of the insurgency and counter-insurgency are evident in the rapid and widespread movement of families and clan groups from traditional, highly decentralized ancestral house sites to "strategic hamlets" at the request of the military. Reloca-

tion follows military counter-insurgency movements through the countryside (Jones, 1989). As a result virtually every family of the traditional uplands has been recently relocated adjacent to lowland paddy, close to village cores, or along a road. Historical communication, support network, dooryard garden and small livestock enterprises are altered. The hongos has come under unprecedented pressure as the military fears its use as a tool for infilitration and indoctrination of the peasant membership by Maoist rebels. This undermines the maintenance of already implemented indigenous remedial action strategies such as terracing and stone lined irrigation canals. However, it may have future ramifications as it militates against the design and implementation of new, indigenous conservation strategies.

Historically, changes in resource exploitation patterns have been met with a host of indigenous remedial measures such as terracing and field bunding. Destruction of traditional labor patterns disassociates the culture from planning and implementing its own remedial actions. In response the population requests increasing inputs of money and technology from the government and outside development agencies. An increasing relience on outside agencies for assistance is flawed in this case by the government's fear of karst from an engineering perspective.

Some remedial actions taken by the government (road building, irrigation development) can be linked to its attempt to "develop" and thus affect areas sympathetic to its overthrow. Unfortunately development practioners acknowledge that they are ill prepared for development of limestone environments and where attempted success has been limited (Seroje, per. comm, 1989). The government concedes that their typical development strategies such as irrigation dams do not work, and when attempted, repayment is difficult (Reeder, 1990).

Thus development in the fragile karst upland must be prepared to confront complex technical, economic and social elements.

## THE CHANGING RESOURCE BASE

Increasing population densities, and insurgency and counter-insurgency issues have resulted in an imbalance in the long evolved cultural ecology of the region. In reaction karst occupants and development agents feel compelled to alter the cultural use of the karst environment in hopes of "developing." This development has introduced inappropriate technologies and over-exploitation of specific landforms resulting in quantitative and qualitative changes in groundwater. Importantly, water resource degradation is just part of a vortex of physical and cultural decomposition as declining irrigation water supplies apply pressure on allocation procedures, which stress conflict resolution mechanisms, which put further stress on resources.

## THE GROUNDWATER BUDGET

### Quantity

Informal interviews indicate that all parties (farmers, politicians, business persons, journalists) see a hydrological calamity occurring in Bohol's karst upland (Bohol Chronicle, 1990a). Anecdotal evidence postulates a spring flow decline of 40.0 percent over the last 20 years (Apolonio Virador, personal communication, 1989). Climatic records do not corroborate with the steep decline. Shifts in landuse and

resource allocation are the more likely culprits.

Some controversy surrounds the role of deforestation in reducing spring flow in limestone terrains; however, a solid case is found in Batuan. In this case deforestation as a result of caingen agricultural activities has intensified in area and frequency with an expanding population and the presence of a finite lowland resource base. Meanwhile economic stress has intensified the rate of illegal forestry (Bohol Chronicle, 1990a).

Farmers state that small rock-carved cisterns located on the flanks of mogotes which were once forested completely dried upon forest clearance. It appears that more water penetrates and enters the hydrologic cycle of the marly, poorly consolidated, Maribojoc Formation when well forested, rather than when virtually barren or only colonized by patchy grasses (Imperata cylindrica, I. exaltata, Saccharum spontaneum subs. indicum, Themeda spp. and Robettboellia spp.). In such conditions water moves rapidly on the surface, resulting in reduced groundwater recharge and severe erosion.

A second cause of reduced agricultural spring flow is the development of piped domestic water systems. The first systems were constructed in the late 1960's and early 1970's and new systems are being developed as the population becomes more agglomerated. Spring water vital to irrigation is diverted to households where it is used inefficiently because of severe leakage in conveyance and wastage in the home.

A third and more insidious form of resource degradation involves the quarrying of mogotes for road building materials. A primary method of initiating local development is to construct farm to market roads. These projects are designed and implemented by private contractors and military engineering detachments. While press reports remark on the illegality of such operations due to the designation of the distinct karst upland as a national geologic monument, nothing has been said about the irreparable hydrologic damage (Bohol Chronicle, 1990b). This activity began in earnest with the road building program initiated by the American colonial regime in the 1920's. The soft, marly limestone (locally termed "anapog") of the mogotes, is cheap, easily quarried, accessible and an excellent road building material. It is used increasingly in construction of light duty farm to market roads who's extent has expanded dramatically with the outbreak of civil war.

The cumulative effects of change in resource exploitation for agricultural (slash and burn) and non-agricultural (road building materials) activities has resulted in destabilization of groundwater. For example, an abandoned concrete aqueduct is found near the terminus of the one irrigation system. Water resources have declined to the point that irrigating land this far from the spring water source is no longer feasible. Productivity of rice lands has also been reduced due to a lack of irrigation water during the dry season. The municipality of Batuan has not experienced a widespread and devastating drought since 1983. In the subsequent 8 years deforestation has continued unabated resulting in less than adequate irrigation water supplies in 1985 and 1988 when precipitation was only slightly deficient. Thus it appears that the irrigation systems are becoming increasingly sensitive to minor fluctuations in precipitation.

## Water Quality

Like most tropical, less-developed rice growing regions, Batuan remained relatively "pristine" in an indigenous agricultural sense up to the end of WW II. Widespread penetration by outside development forces was marked by the introduction of the "Masagana 99" program in January, 1973. Spearheaded by the International Rice Research Institute and the Central Government, Masagana 99 was presented as a

package to small farmers which included low interest loans with no collateral, High Yielding Varieties (HYV's), fertilizers, pesticides, and herbicides. Initial local acceptance of the program was strong, but the tide swiftly turned after environmental problems appeared.

## Agro-chemicals

Indiscriminate application of pesticides decimated the tabon (egret) population. Prior to the introduction of pesticides Batuan was abundantly supplied with the tabon, which accompanied carabao in their daily activities. The tabon consumed ticks and other insects associated with the carabao. Farmers estimated that at least three tabon used to accompany each carabao, but during the study period, there were only about 18 in the entire municipality. Informants believe the population is recovering slowly.

Farmers also fish in irrigation canals using the crushed leaves of the tigao shrub (Callicarpa paloensis) which when mixed with soil and water forms a natural stunning agent. With the introduction of pesticides farmers began pouring them directly into the canals to stun fish. Unfortunately, carabao also wallow in and drink water from canals, and cases of severe dysentery, which is often fatal, were linked to pesticides. Use and abuse of chemicals is also linked to extinction of fish and crustaceans in cave systems accepting water from agricultural lands. No accounts of human illness were related to herbicide and pesticide abuse during this period, but given the nature of the karst landscape and the inability to diagnose environmentally related sickness accurately, such cases probably occurred.

The highly toxic rat poison, zinc phosphide, is applied by many farmers especially near settlements where rats find excellent habitats during the rice fallow. Two tablespoons are mixed with a kilo of corn grits, and a tablespoon of the mixture is placed in 30 to 40 small plastic packets. The packets are then torn slightly and distributed along paddy field bunds. Rats feeding on the poison disperse the toxic mixture. Unconsumed packets are not collected after distribution.

Today, pesticide and herbicide use has been curbed to a large degree, but development agencies continue to introduce new chemicals that are equally if not more toxic than the ones used previously. They include "brestan," a non-specific pesticide recommended for the control of the "kuhol" snail, and "thiodan" and "parapest" for insect control in seedbeds. Previously, a host of indigenous treatments derived from plant extracts served as pesticides.

## Domestic Chemicals

The other major non-organic pollutants are laundry soap and bleach. Since WW II, packaged laundry products have swamped the market and are widely used. Water for laundry is generally from the larger agricultural springs, since it is perceived to be "pristine." Impacts of detergent use are most apparent at the end of the hot, dry fallow of April and May. As irrigation begins, the combination of heat, water and phosphates leads to extensive algae blooms, some of which completely envelop paddies. Algae are not inherently degrading, however competition with other high quality nitrogen fixing aquatic plants such as azolla (pinneta fern) may have severe impacts.

## Organic Wastes

Disposing of human and animal wastes in the Bataun environment has caused numerous problems. Crude population densities average about 1.48 persons per hectare. However, when the feces of the municipalities 2556 pigs is incorporated the

TABLE 2
Diarrhoea Cases Treated In Batuan 1982-1988 - Reported Treatments

| Year | J | F | M | A | M | J | J | A | S | O | N | D | Total | Total Deaths |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 34 | 27 | 22 | 40 | 29 | 28 | 27 | 52 | 37 | 23 | 29 | 42 | 390 | 1 |
| 1987 | 77 | 3 | 8 | 14 | 14 | 32 | 80 | 54 | 26 | 43 | 33 | 44 | 358 | 5 |
| 1986 | 10 | 23 | 18 | 38 | 39 | 21 | 35 | 13 | 2 | 8 | 8 | 5 | 220 | 8 |
| 1985 | 14 | 22 | 26 | 27 | 20 | 10 | 15 | 18 | 17 | 26 | 11 | 13 | 219 | 4 |
| 1984 | 24 | 17 | 17 | 17 | 17 | 17 | 14 | 5 | 13 | 30 | 17 | 51 | 239 | 7 |
| 1983 | 27 | 57 | 51 | 45 | 36 | 58 | 69 | 85 | 74 | 39 | 15 | 33 | 589 | 4 |
| 1982 | 27 | 39 | 21 | 11 | 17 | 34 | 40 | 55 | 35 | 25 | 13 | 18 | 335 | 2 |
| 143 | 188 | 163 | 192 | 172 | 200 | 280 | 282 | 204 | 194 | 126 | 206 | 31 | | 31 |

Source: Monthly report on the program for control of diarrheal disease (Oral Rehyc Therapy), Batuan, Bohol. Dr. Allw S. Calamba (Municipal Health Officer).

equivalent crude population density rises to 2.43 person per hectare. This is given that the feces output of one pig can be equivalent to three humans (Kiernan, 1989). Potability tests indicate severly contaminated water. Local water-borne diseases include gastroenteritis, typhoid and internal parasites. Malaria and schistosomiasis, which are commonly related to lowland rice environments with poor sanitary facilities, are not found in the limestone upland. The lack of these common diseases is due to the lack of intermediate hosts and is a function of ecological conditions.

A monthly review of diarrheal diseases was conducted by the municipality for the years 1982 to 1988 (Table 2). The statistics show a steady case load of diarrhea with very little fluctuation by month. But 1983 stands out as an exceptionally severe year, which corresponds to a severe drought that concentrated contaminants.

The incidence of intestinal disease among residents of Bataun is included in this study to emphasize the interrelationship between water used agriculturally and domestically. Due to the permeability of the karst, biological wastes, chemical fertilizer, inorganic pesticides and laundry effluents rapidly enter the drinking water.

## DISCUSSION

The highly developed irrigation systems of Batuan appear on the surface to be operating smoothly and efficiently. Deeper examination, however, reveals that cultural disturbances may be undermining their physical and chemical sustainability. "Sick irrigated lands" are to be found in Batuan. Specific reasons for degradation include one of, or a combination of, the following: introduction of inappropriate HYV (High Yielding Variety) technologies, decline of group labor organizations (hongos) as a result of the military's forced resettlement of non-combatants in non-traditional environments, changes in upland landuse, quarrying of mogotes, and shifts in water resource allocation from agricultural to domestic concerns. Of greatest consequence both now and in the future is the continued physical destruction of the uplands, which has already had widespread impacts on regional hydrology. It appears that these pressures of both external and internal origin have stressed the physical resource base possibly further than it has been pushed before.

## CONCLUSION

This paper exposes the relationships between human activity and karst resource degradation. If these changes are to be countered with rehabilitation or at the very least mitigation, monitoring and remedial strategies for critical karst resources must be developed. Unfortunately a dichotomy has developed between indigenous peoples needs and the governments will and capacity to respond. Attention must be increasingly focused on indigenous technologies and implementing institutions.

Resource management strategies must have several complementary characteristics. If they are to be designed, implemented and administered by governments they must be both efficient and cost-effective as they will be financed by agencies with tight fiscal policies. Furthermore, they must be easily understood in regards to accrued benefits. If goals are to be attained indigenous knowledge and labor must be used. Clearly, a thorough monitoring of the groundwater budget from a quanitative and qualitative perspective must take precedent. Furthermore, the social activities associated with resource manipulation and allocation must be recognized and acknowledged as formidable barriers to technological intervention.

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