CITY OF
PUERTO PRINCESA

United Nations
Educational, Scientific and
Cultural Organization

Puerto Princesa Subterranean River
National Park,
Puerto Princesa City, Palawan
Inscribed on the World Heritage List in 1999

The River of Swallows

A brief guide to the environmental features of the Puerto Princesa Underground River - Philippines

LA VENTA

The outflow of the Puerto Princesa Underground River

Giant cave entrances open on the walls of the St. Paul range

The River of Swallows. A brief guide to the environmental features of the Puerto Princesa Underground River - Philippines
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Foreword

In 1971, when the St. Paul Subterranean River (now popularly known as Puerto Princesa Underground River) was declared a National Park, only a small part of the cave was known, no map was available and no one knew what unique and amazing scientific discoveries were hidden inside this natural gift from the Creator.
Since then, many changes have occurred that transformed this once virtually undiscovered and unknown marvel into what it is today: a fully-accredited UNESCO World Heritage Site (1999), a highly protected National Geological Monument (2003), a treasured ASEAN Heritage Site (2005) and, recently, voted by millions as one of the New Seven Wonders of Nature (2012) in a worldwide marketing and PR campaign!
None of these titles, however, would have had real significance and credibility were it not for the discoveries of the Italian Speleological Society and the geographical association called La Venta, a group of dedicated explorers who brought experts in mineralogy, biology, hydrology and paleontology to map out the various chambers and tributaries of the cave, document their scientific findings and provide irrefutable proof that the Puerto Princesa Underground River contains unique features that can be enjoyed by millions over many generations due to its being naturally sustainable!
More explorations have been planned by the La Venta group, together with our own scientists and experts in various fields, to further unearth still undiscovered parts of the karstic or cave system, to search for more unique minerals that might contribute to the betterment of mankind and to ascertain the geologic age of the entire cave where perhaps, other fossils, such as the recently discovered 20million year old Sirenia, might still be buried deep inside the walls of the entire cave system.
We thank the La Venta Group for completing this book, The River of Swallows, as their contribution to the people of our beloved Puerto Princesa City. This book serves as an invaluable testament for the world to appreciate the beauty, the scientific findings and the wonders that make the entire cave system around the Puerto Princesa Underground River, now measuring over 32 kilometers and still counting, together with its astounding living organisms that co-exist within a well-balanced eco-system and its high energy level that can absorb high impact tourism, a True Wonder of Nature, definitely, God's gift to mankind throughout future generations!
We welcome you all to visit our City in the Forest, the cleanest and greenest city in the Philippines today!

Mabuhay!

Hon. Edward Hagedorn
Mayor
Puerto Princesa City
1992 to 2013

The PPUR outflow at night time

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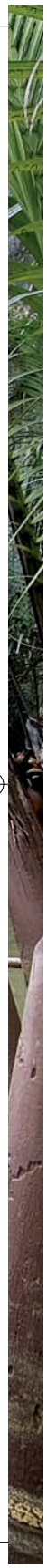


Introduction

Twenty-seven years have passed since we visited the St. Paul Underground River for the first time. It was 1986, no roads reached the area, the total known length of the cave was just a few kilometres and very few people were aware of this incredible jewel of our planet.
Since that time, hundreds of cavers have explored its huge galleries and thrown light on its mysteries, its alien fauna, and its unique speleothems. In the meantime the name of the cave and its park has changed, and the Puerto Princesa Underground River has entered the Unesco World Heritage List. In this quarter of a century hundreds of thousands of visitors have felt the fantastic feeling of navigating its giant-size galleries amongst flocks of swallows and bats. Today a cement road connects Puerto Princesa to Sabang, hotels welcome the visitors, and tens of *bancas* take them to the cave entrance.
There is however one thing that has remained the same: the respect of the cave and its dwellers, the awareness that tourism is not always in conflict with conservation, and the capacity to leave the environment and the cave absolutely untouched. Despite the huge number of tourists visiting the cave and the possibility they had to mystify the change in name of progress and development, the authorities have not built a single cement step, hung a single steel footbridge, or set up an electric line to light up the cave.
Among the unique features of this underground world, which you will discover in the following pages, the ecological approach to the cave is probably the most amazing one: the Puerto Princesa Underground River is one of the most visited caves in the world and yet, at the same time, the least damaged. This is absolutely exceptional, and represents the true point of force of this tourist site: while entering the cave, every visitor feels the same, powerful, unique feelings of the first explorers.
In a world led by mere economic interests, the international community can never thank enough the authorities and the park personnel for this far-sighted policy.
We have entered the cave hundreds of times, explored and mapped tens of kilometres of galleries. Many of the sites we have seen inside may not be reachable by tourists, due to technical difficulties or environmental sensitiveness. This book represents an opportunity to communicate, by words and images, this fascinating secret world.

Antonio De Vivo, Leonardo Piccini

Left: The entrance of the Puerto Princesa Underground River is a magical passage from the green environment of the bay to the dark galleries of a hidden world

The outflow of the cave represents the main underground estuary in the world

The Puerto Princesa Subterranean River National Park

James A. Mendoza

History of the Puerto Princesa Subterranean River National Park (PPSRNP)

Amid calls to protect national patrimony, the Park was established on March 26, 1971 by virtue of Proclamation n° 835 signed by President Ferdinand E. Marcos. Formerly known as the St. Paul Subterranean National Park, it initially comprised an area of 3,901 ha. Experts later concluded that the size of the Park was inadequate to protect the outstanding natural values of the area. To ensure long term viability, President Joseph E. Estrada issued Proclamation n° 212 on November 16, 1999 expanding the area of the Park to 22,202 ha and renaming it Puerto Princesa Subterranean River National Park to properly identify it with the place.

In recognition of its scientific importance as a permanent laboratory for studies on geological processes, uniqueness and high scenic value, the National Committee on Geological Sciences declared the St. Paul limestone formation a National Geological Monument on December 4, 2003.

Management of the Park falls under the scope of Republic Act n° 7586 or the National Integrated Protected Area Systems Act and Republic Act n° 7160 or the Local Government Code of the Philippines Act.

Management history

Management of the Park began in 1979 under the Ministry of Natural Resources. In 1986, the Park was placed under the newly formed Department of Environment and Natural Resources (DENR) Region IV Office. In 1988, the Philippine Government signed an Agreement with the World Wildlife Fund for the Debt-for-Nature-Swap Program. Under the agreement, that eventually involved the Haribon Foundation, the WWF assumed a portion of the Philippines external obligations. In exchange, the Government invested a similar amount for the protection of the environment. The Park was fortunate to become one of the areas to benefit from this program.

Management responsibilities of the Park were transferred from the DENR to the Local Government of Puerto Princesa based on a Memorandum of Agreement signed between DENR Sec. Angel C. Alcala and City Mayor Edward S. Hagedorn on December 3, 1992. It is managed by the City Government on a program centred on environmental conservation and sustainable development. It has the distinction of being the first National Park devolved and successfully managed by a local government unit.

Currently, the Park is managed by the City Government through a Protected Area Management Board (PAMB), a multi-sector body that provides policy directions and other oversight functions. The PAMB has 17 members, it is chaired by the City Mayor and members are composed of representatives from the City Government, DENR, Palawan Council for Sustainable Development Staff, Bgys.Cabayugan, Marufinas, New Panggangan, Tagabinet, Tribal Chieftains of Cabayugan and Kayasan Ancestral Domains, Haribon Palawan and Tagbalay Foundation from Non-Government Organization, and Peoples Organization.

Management is classified at two levels; the core zone that benefits from complete protection, and the buffer zone that is divided into sub-zones intended to minimize the impact on the core zone. A Management Plan sets out the programs and objectives to ensure the long-term management of the PPSRNP. Funds raised from tourism are deposited into a trust fund with disbursements made exclusively for the protection, maintenance, administration and management of the PPSRNP.

A park guide indicates the location of a cave in the Saint Paul karst

The giant entrance of Binang Bangan cave in the southern sector of the National Park

World Heritage inscription

The Philippine Government nominated the Park with an area of 5,753 ha for inscription to the World Heritage List in 1992. The nomination was deferred based on a 1993 International Union for Conservation of Nature Technical Evaluation that noted that the site was suitable for world heritage listing, but the area was too small to adequately protect its underground river water shed and to ensure the long term viability of its significant biodiversity.

An expanded nomination of 38,753 ha that included 8 barangays was submitted for consideration in 1998. In its 1999 Field Inspection Report, the IUCN noted that "the underground river and all its tributaries are within Bgy. Cabayugan and is the critical area for protecting any potential World Heritage values in the nomination, particularly those related to water quality and quantity of the underground river". The adjoining Bgy. Marufinas also has important values particularly for forest conservation. It noted that the natural values of the other barangays, while still important, are less significant in the context of potential World Heritage.

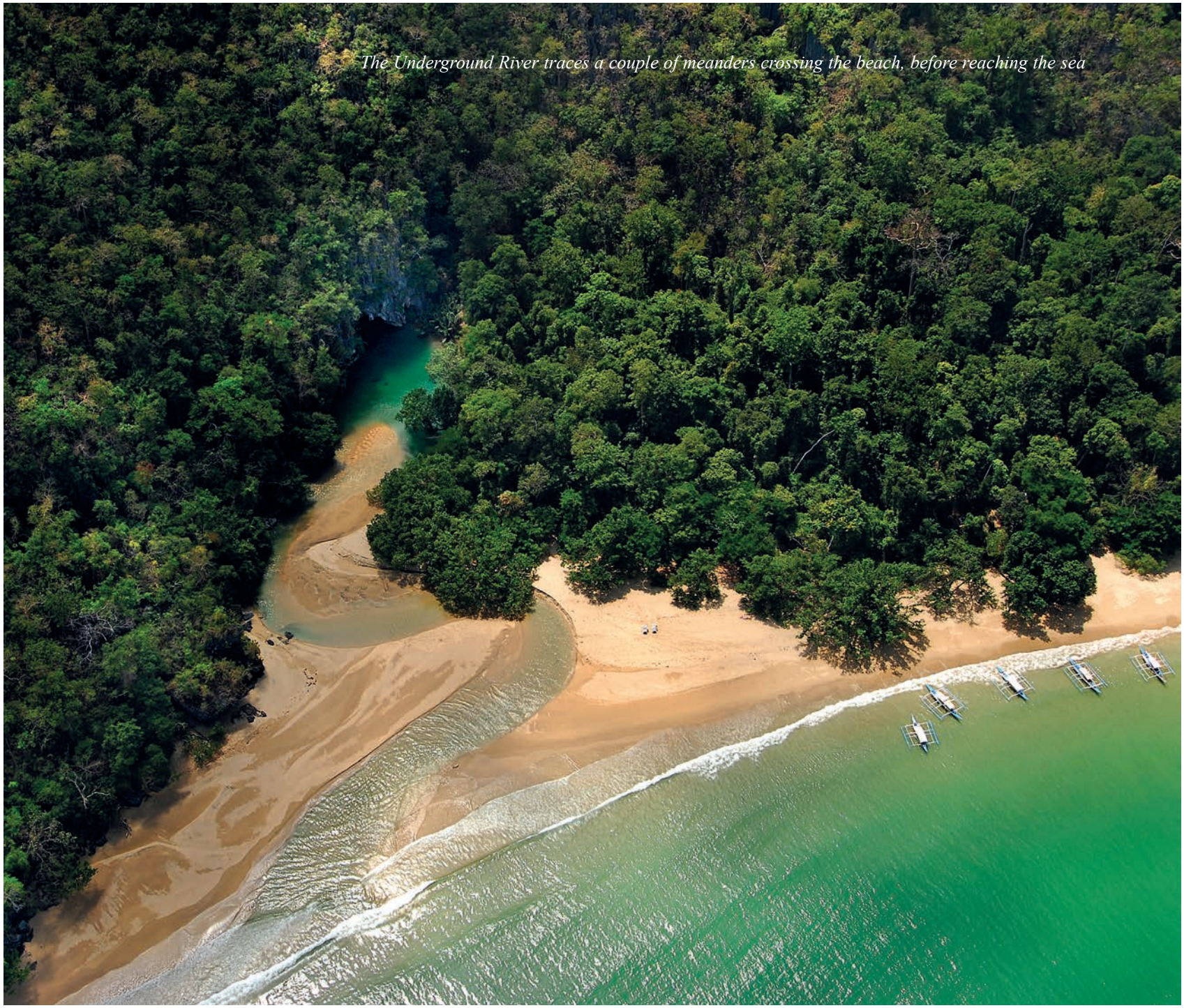
It recommended that the nomination be referred back to the Philippine authorities for amendment and legal definition of boundaries to include only the areas noted as most

important for protection of the catchment of the underground river and for biodiversity conservation. It further recommended that the proposed World Heritage nomination boundary be agreed upon by the relevant communities and this should be confirmed in writing.
Agreements between the City Government and relevant Communities were negotiated and formal resolutions were passed noting their agreement to include their respective areas within the revised nomination.
During the World Heritage Committee's December 4, 1999 Meeting, the Park was inscribed on the list of natural World Heritage Sites under two natural criteria.

Criterion (iii) Superlative natural phenomena, scenic beauty
The PPSRNP features a spectacular limestone karst landscape. The underground river flowing into the sea and the associated tidal influence make it a significant natural phenomenon.

Criterion (iv) Biodiversity and threatened species
PPSRNP represents a significant habitat for biodiversity conservation. It contains a full mountain to sea ecosystem and protects the most significant forest area within the Palawan biogeographic Province.

The long branches of the bitaog (Calophyllum inophyllum) stretch over the beach of the Saint Paul Bay



The Underground River traces a couple of meanders crossing the beach, before reaching the sea

The base camp at the entrance of Tagusan Cave, during a survey of the 2007 expedition

History of the explorations

Antonio De Vivo

"Fourteen or fifteen leagues south-west of Luban are the Calamines, a Province made up of seventeen Islands subdu'd, besides many others not yet reached, among the first of which is the great one called Paragua, partly belonging to the Spaniards, and partly to the King of Borneo.
This island of Paragua is the third in bigness among the Philippines. Its shape is long like a strait arm, by means whereof Manila and Mindoro seem to shake hands with the great island of Borneo. The compass of it is 250 leagues, the length 100, but the breadth not above twelve in some places, and fourteen in others. The middle of it lies between nine and ten degrees of latitude; its furthest cape called Tagufao, towards the south west, is fifty leagues distant from the island of Borneo, in which interval there are many low islands that almost join the two lands. The inhabitants of the coasts of these islands, and of Tagufao, are subject to the Mahometan King of Borneo; but up the inland there are wild Indians unconquered, barbarous, lawless and subject to no King; and therefore all their care is not to be subdued to the King of Borneo, or the Spaniards. Two parts of the island are in their possession. The Spaniards have in it about 1200 Tributary Indians, black like those of Africa, who range from place to place, without any certain place of abode. They are very faithful to the Spaniards, who keep a garrison there of 200 men, part Spaniards and part indians, with an Alcaide, or Governor, whose residence is in Taytay, on the opposite point of Borneo, where there is an indifferent fort. The island is almost all over mountainous, and full of abundance of sorts of trees and wild beasts; and produces abundance of wax on the mountains, but very little rice..."

Giovanni Francesco Gemelli Careri
"Journey around the world
(Part V – Containing the most noteworthy
things seen in the Philippine Islands)", Naples, 1700

The outflow of the cave has always been known to local people, and for sure the first explorers would have been people living in the area, probably pushed to enter the cave searching for drinkable water and swallows' nests. Some well visible writings left by visitors in the first part of the cave bear the dates of April 13th, 1937 and June 20th, 1966; others, even older, dating back to 1930 and 1934, and bearing the word APO, may clearly be seen at the end of the final part of the navigable section, now called the Rockpile. At the moment there is no report on such old

A writing left by Alpha Phi Omega dating back to 1930

visits, but they were probably carried out by the US association Alpha Phi Omega, founded in 1925.
The following visits to the Underground River, though documented only by a direct interview in 2011, were carried out by Federico Celino in the mid 60's. Celino, born in 1927 and originally from Pangasinan, Luzon, moved to Cabayugan in 1950 with his wife and his four children. At that time there were no roads to the western coast (the first road was built from Baheli in 1983). In Cabayugan lived three families and in Sabang no more than seven. This gives an idea of how remote the area was at that time. Locals entered the caves eventually to collect guano or for hunting. Celino reports that in 1965, together with a friend from Mindanao, he entered the PPUR descending the Daylight Hole by means of lianas (!) and using flashlights. He did the same thing descending the Australians' Inlet, and the data he reports perfectly match with the geographical and topographical information in our hands. Celino did not visit only the PPUR but also the other caves of the area; together with a tourist from Malaysia, Na Tari Tu Sin, he entered Lion Cave, Tagusan Cave, Horror Cave, Memory Cave and one more probably now known with a different name, Sinohotan Cave.

As far as we know, the first documented exploration of the underground river was carried out by the Hungarian geologist Balázs and some Philippine friends (BALAZS, 1973), who compared the St. Paul karst to the "Yangshuo type karst" of southern China, characterized by extremely steep positive landforms known as "towers". On that occasion the navigable part of the cave all the way to the point later called 'Rockpile' was explored and 5 km survey carried out; a sketchy survey of the karst area and of the cave itself were also enclosed in the mentioned research.
Seven years later, in 1980, an Australian expedition was organized by Traditional Explorations and the Sydney Speleological Society. Led by Brad Warren, who had visited Palawan in 1979 with the World Wildlife Fund and had been amazed by the Underground River, the expedition was multi-disciplinary and numbered 35 members including cavers, entomologists, anthropologists, divers and technicians. The expedition was planned as the first step of a 5-year environmental project conceived as support for parks conservation and management.
The caving team covered the whole length of the active branch of the cave all the way to a second entrance placed in the ceiling of the gallery, the so-called 'Day-light Hole', that was eventually also reached from the forest. The cavers also discovered a side branch, approximately 500 m downstream from Rockpile, but did not push the exploration further. At the end of the expedition the total development of the cave was 6.9 km.
In 1982 a second expedition left from Australia. Led by Malcolm Calder, it was organized by the Environmental Studies Association of Victoria for Associated Research Exploration and Aid, and numbered 14 members. It was not a specific caving expedition but an environmental research project. Nevertheless, the team completed the exploration of the unexplored branch discovered in 1980 and reached a third entrance in the forest following the long affluent (Australians' Inlet). At the end of this expedition the total length of the cave was 8.2 km.
In 1986 the cave attracted the curiosity of some Italian cavers who, after the completion of an expedition to the karst of Sagada (Mountain Province, Luzon) aimed to

verify the caving potential of the island. The 8 cavers visited the Quezon karst in the South, the St. Paul and El Nido karsts in the North, and Coron Island in the Calamians.
Some of them went back three years later (February 1989) with the "Mactingal 89" expedition (11 members), after a period spent in the karst of Calbiga (Samar) which at the time was struck by intense cyclonic rains. In the short time at their disposal (20 days), the Italian cavers sighted and partially explored the huge galleries above the underground river and also some side branches to the river (Balingsasayao Galleries, Italians' Chamber, Halo-halo Galleries, Gypsum Galleries). The former, hydrologically inactive, are formed by one level of galleries subdivided by chokes and giant concretion masses into three important segments sub-parallel to the main branch. In the course of the expedition approx. 5.7 km of new passages were explored and the whole cave was re-surveyed except for the affluent leading to the third entrance. The development of the cave passed from 8.2 km to approx. 14 km. In the course of the expedition a short exploration and a sketchy survey of the Little Underground River (East of the St. Paul Bay) was carried out (approximate length 1100 m).
The following year (March 1990) a small team of Italians

Federico Celino with his wife (center), his nephew (right) and some members of La Venta, March 2011

Just beyond Rockpile, Italian Speleological Society, 1989

went back to St. Paul to continue the exploration of the fossil levels; the 4 cavers explored the Mud Galleries and the Crocodile Chamber, adding 2.6 km to the total length. The cave was now almost 17 km long.

In 1991 (February and March) a scientific expedition composed of 14 Italians and 3 French cavers continued the explorations and carried out in-depth studies on the cave fauna, the tide effects on the underground river level, and the consequent mixing of fresh and marine waters. Almost 3 km of new galleries were explored (Navigator's Chamber) and two tributaries (Cobra Gallery, Blades Creek, only explored in 1989) surveyed. Such surveys were further pushed in 1992, in the course of a short expedition composed of 2 cavers.

These last explorations brought the total development of the system to more than 20 km, to which almost 1 km of small explored but as yet unsurveyed side galleries should be added.

In May 2000 the geographical association La Venta supported the production of a documentary, ***The River of the Swallows***, co-produced by the Italian producer Paneikon together with the Italian network RAI 3 and the French La Cinquième. The documentary was awarded the first prize at the Film Festival of the International Speleological Congress of Brasilia 2001 and the Grand Prix at the Speleovision 2002 Film Festival at La Chapelle-en-Vercors, France. During the shooting further biological and hydrological studies were carried out by Prof. Valerio Sbordoni and Prof. Paolo Forti.

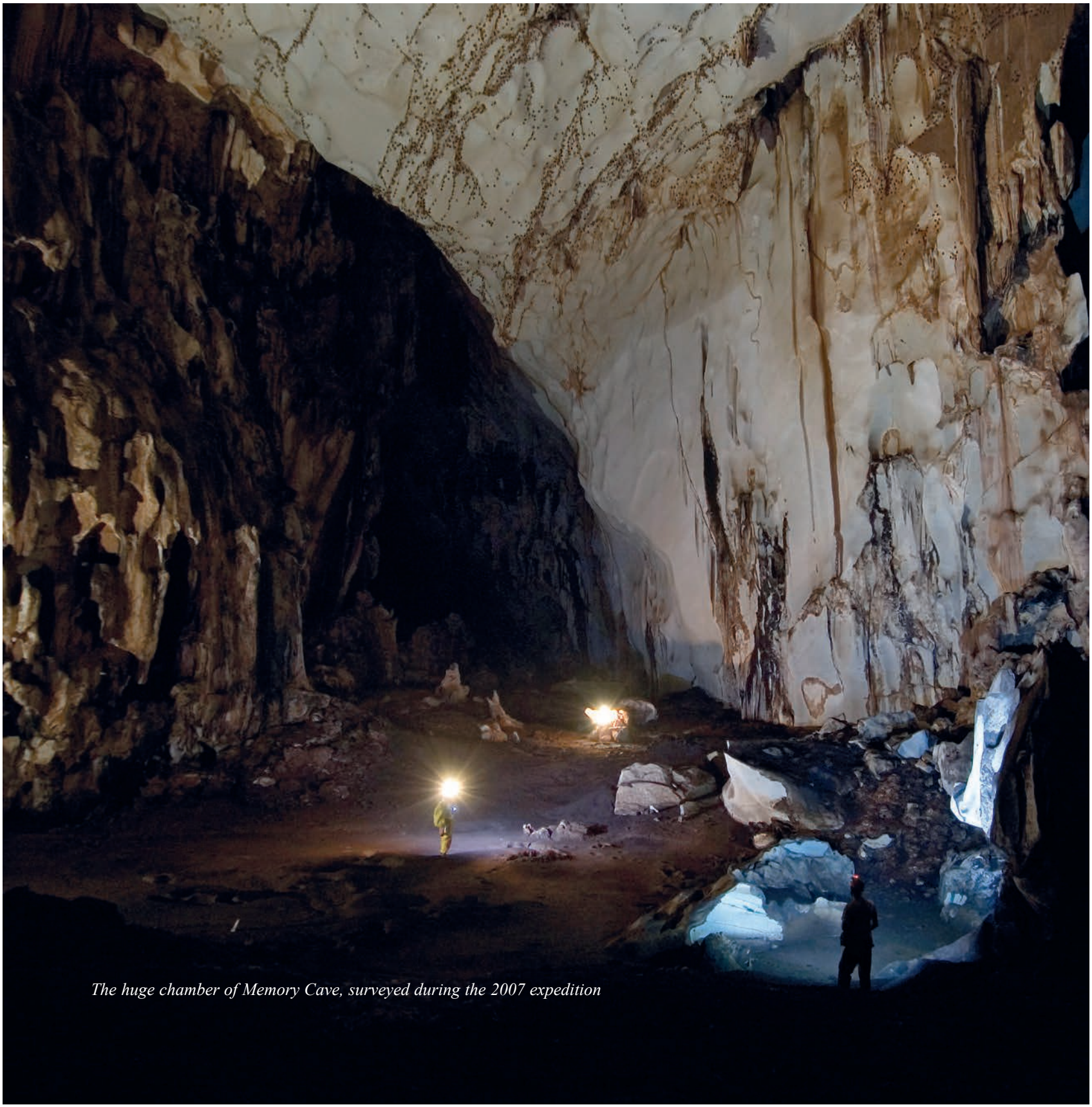
In 2001 the Philippine Gaia Exploring Club discovered the Gaia Passage and re-explored the Australians' Inlet.

In February 2007 exploration was boosted by a big expedition organized by the association La Venta in collaboration with the PPSR National Park and the City of Puerto Princesa. The 23 members of the team explored Cin Gallery, Frangose Branch, Old River Gallery and minor leads, bringing the development of the system to over 24 km. The expedition also explored and mapped some giant relict caves in the area of Cabayugan (Tagusan, Horror, Memory, Million Bird, Unnamed, and Lion) plus a vertical cave in the north of the karst, Nagbituka, to the depth of 95 m.

The semi-flooded gallery which allowed entering the Cin Galleries during the 2007 expedition

The Rockpile camp during the 1989 expedition, Italian Speleological Society

In the same year the explorations were continued by the Philippine Speleological Society, the Gaia Exploring Club and the Western Visayas Caving Association; the team explored the Gaia Passage, a right side branch with a large inactive gallery. The exploration stopped due to an accident during a climb to reach a gallery high in the ceiling.
The following year, between February and March, La Venta continued the research with a team composed of 14 Italian and 2 English cavers. The Mud Galleries and some minor branches were further explored and mapped. But the major result of the expedition was probably the survey in the north sector, where two deep caves were explored, Nagbituka 1 and 2. Nagbituka 1, partially seen the previous year, became and is now the deepest in the Philippines at -280 m. In 2009 another expedition was organized by the Gaia Exploring Club, with the aim to re-map the Australians' Inlet.
Two years later, between February and March 2011, a third expedition organized by La Venta took to the St. Paul karst a team composed of 30 Italians, 1 Spanish and 1 Belgian. Pushing the climb in the Gaia Branch the team discovered and explored almost 5 km of new giant galleries and chambers: Orient Express, 150 Years Gallery, Magellan Chamber, Grandfather Branch, and Helictites Chamber were now part of the great underground system. The team also explored side pathways in the first part and new leads in the Mud Galleries and the Australians' Inlet.



The huge chamber of Memory Cave, surveyed during the 2007 expedition

The expedition also carried out geochemical and geomorphologic research, and discovered the well preserved remains of a Sirenid fossil in the wall of God's Highway, along the main active branch. The fossil had been mentioned by the Australians in their 1980 report, but its importance had probably been underestimated. Beside the Puerto Princesa Underground River, the expedition also explored the Little Underground River (LUR), which had not been visited since 1989. Unexpectedly, over three kilometres of large beautiful galleries were explored and mapped. During the last days of the expedition a 12 person team (6 Italians and 6 Filipinos) reached the top of Mt. St. Paul and discovered interesting areas for further cave exploration.
The total length of the Puerto Princesa Underground River is now 32 km.

At the entrance of the Little Underground River, 2011

On top of Mount St. Paul, March 2011

The puzzled face of a Long Tailed Macaque

Biodiversity of the National Park

James A. Mendoza

Flora

The PPSRNP is one of the most important biodiversity conservation areas of the Philippines. As a major block of forest, it is designated a core area for the Palawan Biosphere Reserve. It is representative of the Palawan Moist Forest, noted by the World Wildlife Fund (WWF) Global 2000 report as having the richest tree flora in Asia, with high levels of regional and local endemism. Flora of the Park represents more than a third of the entire flora of Palawan. At least 800 species of plants from 300 genera and 100 families have been identified in the Park. These include at least 295 trees dominated by the *dipterocarp* species.

There are eight forest formations present: ***forest over limestone soils*** that grows in the St. Paul mountain range and scattered limestone outcrops. It is composed of species that have adapted to very thin soil such as the Queensland umbrella tree (schefflera) and begonia; ***montane forest*** grows in the uppermost slopes of Cleopatra Needle (800-1500 m asl) east of the Park, vegetation is characterised by the growth of mosses, lichens and ferns; ***forest over ultramafic soil*** occurs on Mt. Bloomfield west of the Park. Vegetation is composed mostly of shrubs and trees growing to a height of not more than 1.5 metres

Large trees are often covered by parassite plants

*Giant dao (*Dracontomelon dao*) is a common presence in the Saint Paul forest*

infested with a scrambling bamboo species (*Schizostachyum diffusum*); ***lowland evergreen forest*** is characterised by the presence of numerous large trees growing to 30 m or taller such as the *Dracontomelon dao, Intia bijuga, Koordersiodendrum pinnatum,* and *Dipterocarpus gracilis*; ***riverine forest*** found in the sand bars along the Babuyan river. Plant species such as the *Homonoia riparia* are highly adapted to water inundation and do not occur in drier soils; ***freshwater swamp forest*** is composed of tree species adapted to being partly submerged in water for part or most of the year; ***beach forest*** grows on the sandy shores along coastal areas of the Park. Species include *Calophyllum inophyllum, Pongamia pinnata, Erynthia orientalis*, and *Pandamus sp*; and ***mangrove forest*** containing species that have adapted to the extreme conditions in the intertidal zones along the Sabang River. Species identified belong to the *Rhizophoraceae* family such as *Rhizophora spp*. and *Bruguiera spp*.

The diverse species of flora in and around the Park represent a very important gene pool of economically important plant species including rattans (*Calamus sp*), almaciga (*Agathis philippinensis*), and rambutan (*Nephelium ramboutan-ake*).

The conservation significance of the Park forest at the international level is heightened when considered in the context of the high levels of past and current deforestation in the Philippines and in the region. The role of the Puerto Princesa Subterranean River National Park takes a special urgency in this perspective.

Giant lizards (Varanus) do not seem disturbed by people visiting the National Park

A hermit crab on a bitaog (Calophyllum inophyllum) along the shore of the Saint Paul Bay

Fauna

The faunal diversity in the PPSRNP is moderate with a total of 269 terrestrial vertebrate species recorded. Birds comprise the largest group of vertebrates found in the Park which incidentally has been identified as an Important Bird Area (IBA) and Endemic Bird Area (EBA) of the Philippines by Birdlife International (BI). A total of 195 species of birds was recorded representing 67% of the total bird species and all of the 15 endemic bird species of Palawan. Internationally threatened bird species include the Philippine Cockatoo (*Cacatua haematuropygia*), Chinese Egret (*Egretta eulophotes*), and Nordmann's Greenshank (*Tringa guttifer*). Endemic species are the Palawan Peacock-pheasant (*Polyplectron emphanum*), Blue-headed Racquet-tail (*Prioniturus platenae*), and Palawan Hornbill (*Anthracoceros marchei*).

There are also 30 species of mammals present in the Park. Most common is the Long Tailed Macaque often observed feeding in the forest canopy and along the shoreline during

low tide. Other prominent species are the Oriental Small-clawed Otter (*Amblonyx cinereus*), Palawan Stink Badger (*Mydaus marchei*), Palawan Arrow-tailed Flying Squirrel (*Hylopetes nigripes*), and the Palawan Porcupine (*Hystrix pumilus*). Also notable are 8 species of bats that inhabit the cave. 19 species of reptiles have been recorded in the Park, of which 8 species are endemic. Species include large predators like the reticulated python (*Python reticulates*) and the monitor lizards that are large enough to be mistaken for crocodile; also the rare fresh water turtle (*Caura ambionensis*) is present.

Amphibians are the smallest group of vertebrates with only 10 species identified. The Philippine Woodland Frog (*Rana acanthi*) is the most dominant and frequently encountered.

Invertebrate species are principally represented by insect fauna. Of the surveyed insects, the Lepidoptera group that include species like *Trojana* are the most commonly observed being at flight most of the time.

The subterranean river is home to creatures that include the Megalomorph Spider, *Thereupoda*, and *Amblypygius* or tailless whip scorpion.

In the marine component, sea grass beds are dominated by tropical eelgrass (*Enhalus acoroides*). Commonly seen species are the Horned Starfish, Spotted Sea Cucumber, and Cigar Wrasse.

The condition of coral reefs in St. Paul bay is considered good with more than 57% cover. They are composed primarily of branching table corals with the presence of tabulated, encrusting and massive corals. Colourful fish species include Humbug Damselfish, Regal Angelfish, and the Blue Barred Parrot fish. Marine species include Blue Starfish, Green Lobster, and giant clams.

The Green Sea Turtle (*Chelonia mydas*) and Hawksbill Turtle (*Eretmochelys imbricate*), both internationally endangered species, are also observed to feed in the sea grass beds and nest in the white sand beaches of the St. Paul bay.

Spectacular butterflies are a pleasant company all over the National Park

The physical environment of the Saint Paul karst

Leonardo Piccini

Palawan is the fifth largest of the more than 7,100 Philippine Islands and covers an area of 12,000 km^2. It is located in the south-western part of the archipelago, not far from Borneo, and together with Balabac and the Calamians forms a NE-SW line of islands spreading for about 600 km.

Palawan is a narrow, elongated and mostly mountainous island and is located between 11°50' and 12°20' latitude N, and 117°00’ and 120°20' longitude E. The highest peaks are: Cleopatra Needle (1593 m) and Mount St. Paul (1028 m) in the northern sector; Victoria Peak (1727 m) in the central sector and Mt. Mantalingajan (2054 m) in the southern part. Two important N-S depressions, corresponding to valleys or lowlands, divide the island into three tectonic sectors. Along the depression which divides the northern from the central sector, we find the Saint Paul Dome karst ridge. More precisely, the St. Paul area is located east of Ulugan Bay, about 50 km NE of Puerto Princesa. The length of the ridge, placed between the Babuyan River valley to the E and the Cabayugan River valley to the W, is about 10 km and its average width is 4 km.

Sharp blades and pinnacles of rock are the product of intensive corrosion on the limestone

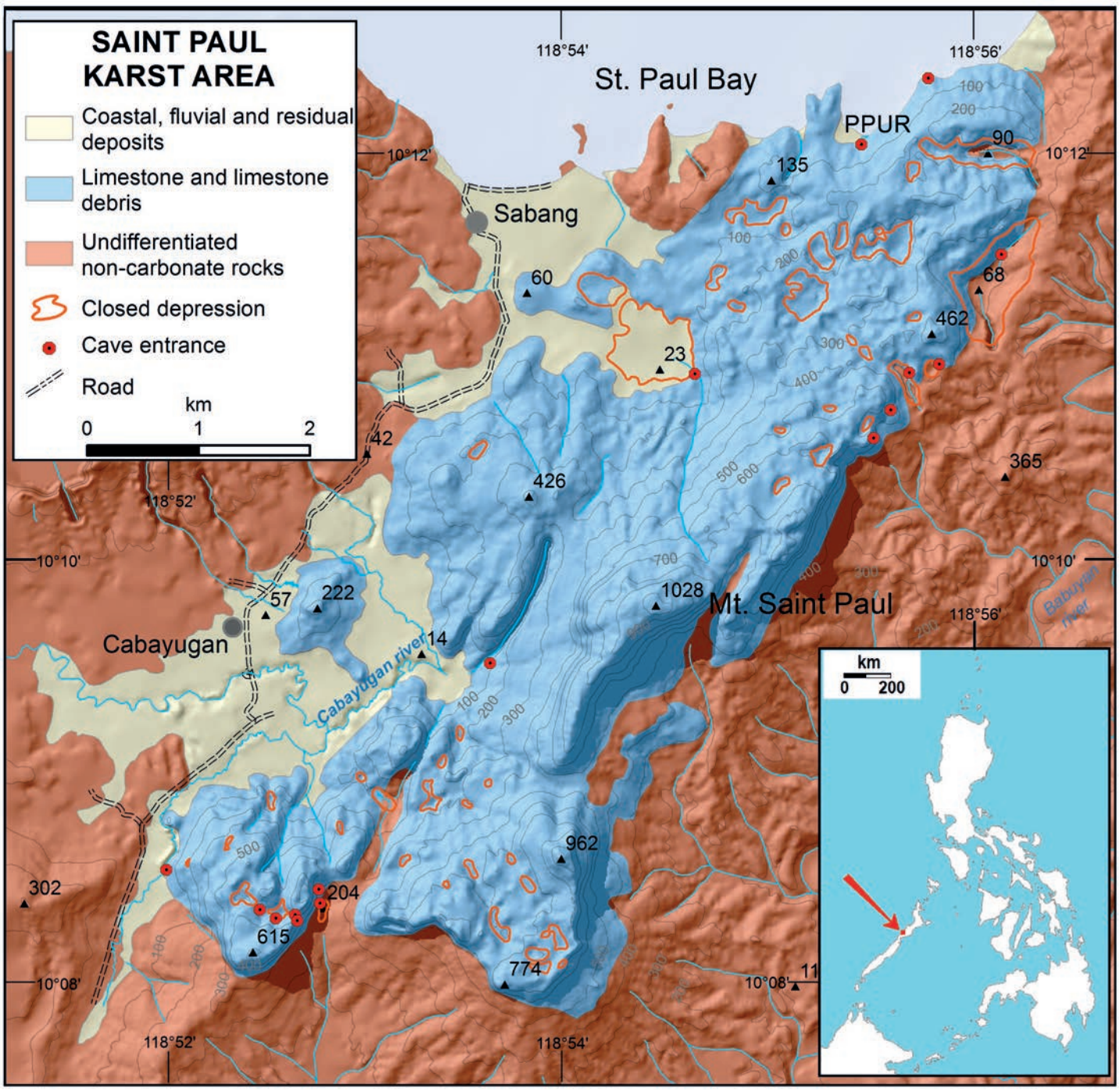
Geology

The St. Paul karst covers an area of about 35 km^2 and is made of massive to roughly bedded, light to dark grey, limestone showing levels rich in fossils. It represents the remains of an ancient coral reef, about 20-25 million years old.

Such rock formation, more than 400 m thick, lays over sedimentary (mudstones, sandstones and marls) and volcanic rocks, dating back to about 30-25 million years before present (Oligocene age) and laying on an older metamorphic basement.

The limestone outcrop is shaped as a NNE-SSW elongated, asymmetric ridge sloping down to the west. From a structural point of view it consists of a multiple NW dipping homoclinal relief limited by NE-SW oriented faults. Such lineaments have controlled both the general shape of the mountain and the karst landforms, determining the lining up of dolines and the development of the major caves. One of these faults may be seen along the coast, near the Manlipien park station, where it puts the limestone and the basement rocks in contact.

The formation of the mountain is relatively recent. After having been drowned and covered by terrigenous sediments, the limestone reef gradually rose up and was


SAINT PAUL
KARST AREA
Coastal, fluvial and residual deposits
Limestone and limestone debris
Undifferentiated non-carbonate rocks
Closed depression
Cave entrance
Road
km
0 1 2
St. Paul Bay
PPUR
Sabang
Cabayugan
Mt. Saint Paul
Cabayugan river
Babuyan river
118°54'
118°56'
10°12'
10°10'
10°08'
118°52'
90
135
60
68
462
23
42
426
365
57
222
1028
14
962
302
204
615
774
km
0 200

exhumed again by erosion some millions of years ago. Erosion first removed the sediment covering it and whose weight had caused its transformation into a compact calcareous rock. This process probably led to the formation of a wide and regular limestone ridge less elevated than now about 6-5 million years ago (Late Miocene).
Rivers coming from the south crossed this mountain forming gorges and caves of spectacular dimension, nowadays preserved as ancient tunnels in the southern sector of the ridge.
Successively, a further tectonic uplift led to the present morphology and altitude.
At the present time, limestone makes up the upper part of the right (W) side of the Babuyan River valley as the water course has deeply eroded into the underlying impermeable formations. Such carbonate rocks form a continuous wall up to 500 m high, with the exception of the northern part of the outcrop where the limestone merges into the surrounding non-karstic landscape.
On the other side of the range, carbonate rocks descend to the Cabayugan valley and to Sabang with steep slopes cut by rectilinear NE-SW oriented steps.

An evident notch, due to corrosion, testifies the level of the sea during the last interglacial period, about 120,000 years ago

Hydrology

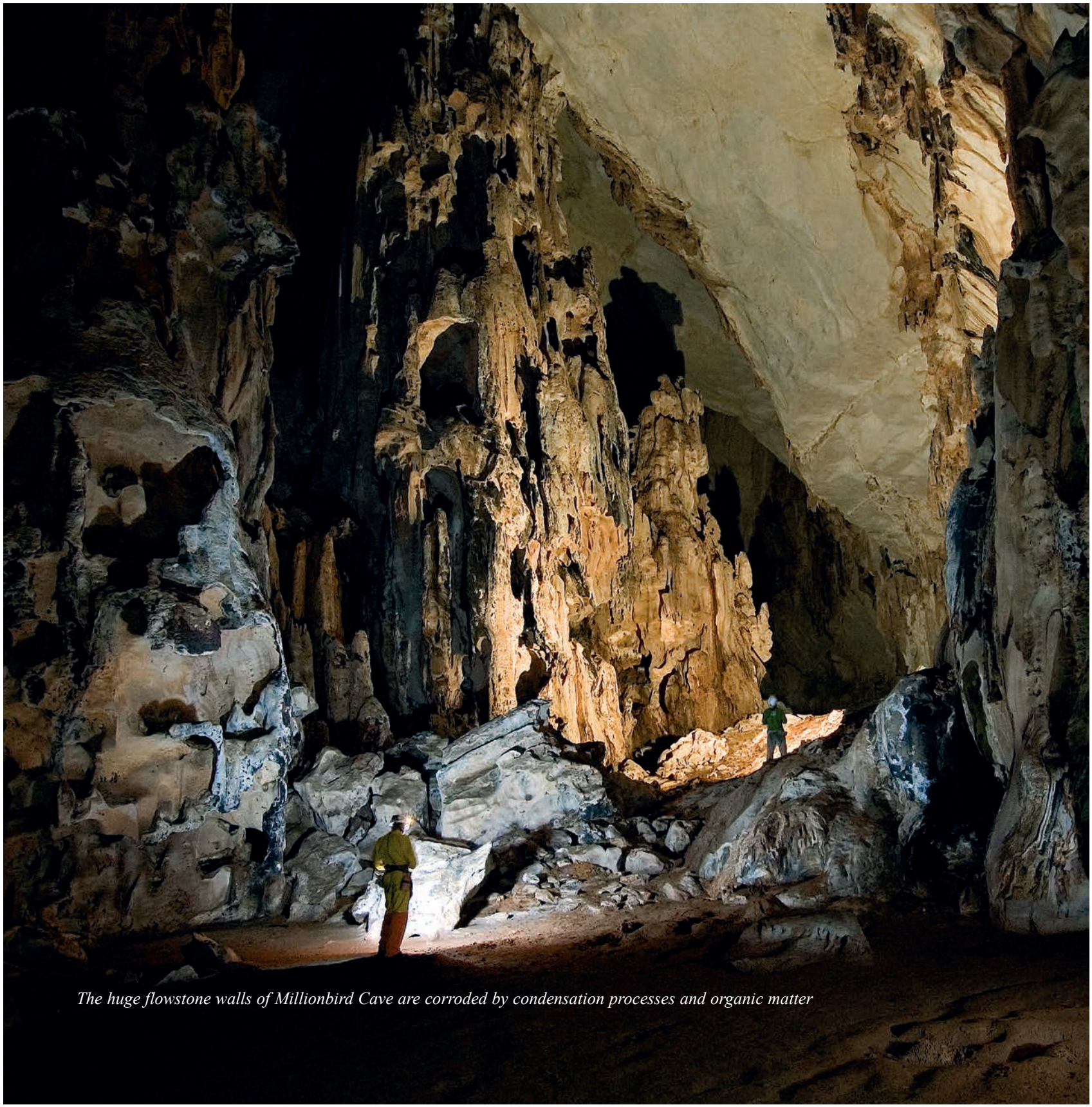
The hydrographical basin of the Cabayugan River extends for more than 30 km^2 in the impermeable rocks of the metamorphic basement and in the volcano-sedimentary formations on the western side. Just east of barrio Cabayugan the stream ends against the steep limestone slopes of Mount St. Paul and sinks under a rock fall of blocks at an altitude of approx. 25 m asl. Along the west side of the mountain, the karst system captures other surface streams from minor blind valleys.
The northern border of the karst corresponds to the coast of the St. Paul Bay for about 3 km. In the limestone cliff, protected by a sand bar, the main entrance or 'outflow' of the Underground River can be found.
This cave represents the main resurgence of the Cabayugan River, that dissappears into the limestone 7 km upstream.
Another marine spring cave is located a few hundred metres further E and collects the water sinking in the closed basins occurring along the east side of the karst in its northern sector. This cave is named the Little Underground River.
Basing upon the known hydrologic setting of the area at least two drainage systems can be identified, one drained by the Underground River and one by the Little Underground River. However, the occurrence of submarine and presently unknown springs cannot be excluded.
As the entrance of the Underground River on the coast is at sea level, the tides affect a large part of the cave up to about 6 km inside the mountain. Along the whole navigable part, the salt water lies under a thin sheet of fresh water, just a few centimetres thick. This condition is only found during the dry season and in absence of rain. During the floods the cave is cleared of salt water, which later returns slowly once the flood has passed. Mixing phenomena between fresh and salt waters take place inside the cave causing particular processes of rock corrosion, which lead to the formation of water level notches.

Karst geomorphology

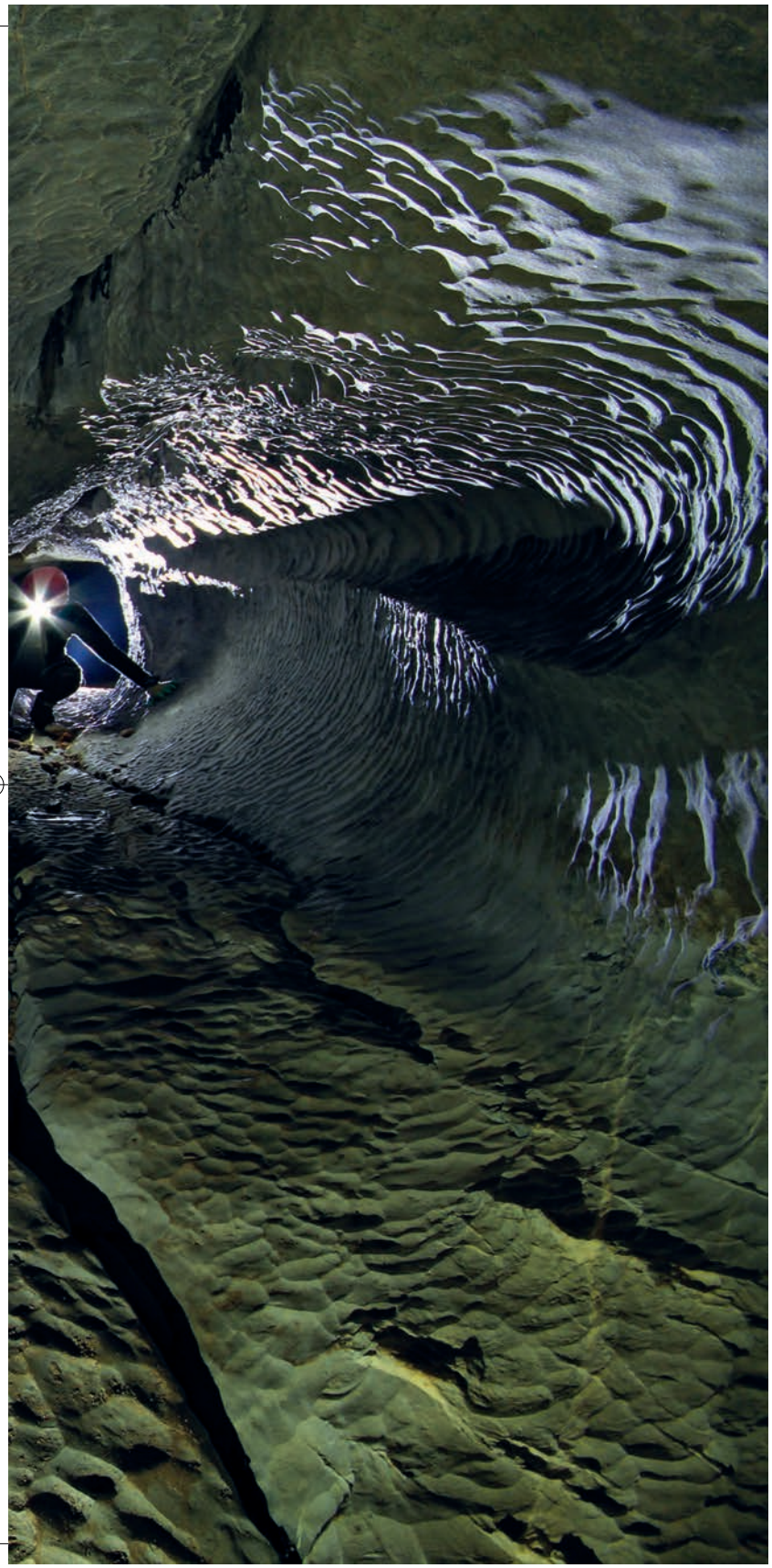
The landscape of the area is a typical tropical karst consisting of towers, cones, pinnacles, and large depressions, occurring mainly in the northern and southern sectors of the ridge. Large closed depressions (cockpits and dolines) cover about 10% of the total limestone surface. Major depressions occur in the form of elongated blind valleys on the east side of the northern zone, and are mainly developed on clastic rocks.

Steep slopes and calcareous cliffs characterise the central part of the St. Paul ridge, while to the north the landscape consists of an irregular plateau with several dolines. Large and deep depressions occur along the eastern limit of the limestone outcrop and can actually be considered as small blind valleys. These depressions, the largest of which is more than 2 km in length, have several swallow holes that are frequently active even during the dry season and feed minor karstic systems parallel to the PPUR, which flow directly to the sea (one of these systems is the Little Underground River).

An aerial view of the southern sector of the Saint Paul ridge



The huge flowstone walls of Millionbird Cave are corroded by condensation processes and organic matter



Some of the eastern sinking streams, located at 290 and 250 m asl, feed two active caves, named Nagbituka 1 and Nagbituka 2 respectively. These caves consist of large tunnels, mainly vadose in origin, descending to the north along the contact between limestone and sandstone. At present, Nagbituka 1 is the deepest cave in the Philippines.
The southern part of the St. Paul ridge has a different morphology and is characterised by two mountains, which have some plain summit surfaces gently descending toward NW, intersected by large and deep elongated depressions and large sinkholes. Their average altitude is around 450 m for the western one, and 700 m for the eastern one. The eastern area has many sinkholes and cave entrances, but the extremely rugged surface, shaped by sharp blades of limestone up to 10-15 m high, do not facilitate easy field investigation.
Six caves have been surveyed in the western mountain. One of these contains an active sinking stream with a small catchment basin. The other five caves have similar morphological features and consist of large tunnels, developing between 300 and 400 m asl, that connect some of the deep depressions in the centre of the mountain with the steep external slopes. In this sector, the widest caves have mostly developed horizontally and have functioned, in the past, as collectors of large rivers coming from the internal zones of the island. These caves are fragments of an ancient and maybe unique system which was functioning as an underground river.
Along the coastline, the presence of an ancient notch, located about 6-7 m above the present sea level, should be underlined. This notch refers to the sealevel highstand which occurred about 120,000 years before the present time, when the mountain glaciers and polar ice-sheets had a much smaller extension than the present ones. A similar notch can also be found inside the Underground River, up to 4 km from the entrance and at the same elevation.

The clean tubes inside the Little Underground River are washed by running water during the rainy season

The genesis of caves

A cave is usually described as a natural cavity, which can be accessed by humans. Commonly a minimum length of 5-10 m is required to consider a natural void as a proper cave.
Natural voids can be formed by many different processes and in very different kinds of rock. Their genesis can be related to fusion processes inside the ice of large mountain glaciers, or to subterranean flow of magma on volcano slopes. Caves can be formed by erosion in fine soft sediments, by gravitational collapses or by weathering in silicate rocks, such as granite. Subterranean removal of deep weathered rocks can create large caves in arenaceous rocks, such as quartzite.
Most explored caves however (probably more than 99%) are formed by subsurface dissolution of soluble rocks such as gypsum ($CaSO_4 \cdot 2H_2O$), and carbonate rock (limestone and dolostone) consisting in calcite ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$).
In carbonate rocks the formation of caves is due mainly to the dissolution processes of water infiltrating from the surface and passing through the rock. The effect of this process is generally named 'karst', from the name of a European region, shared by Italy and Slovenia, where these kind of phenomena have strongly affected the landscape.
The dissolution of limestone by water is boosted by the occurrence of carbon dioxide (CO_2) dissolved in the water, according to the following chemical equilibrium:

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca_2+ + 2HCO_3-$$

The amount of CO_2 is a very important factor and usually the higher its concentration the better the development of karst. In the last decades research has revealed that the formation of a cave in limestone and dolostone is a very complex phenomenon, which involves other kinds of processes.
Often, the dissolution is increased by the occurrence of strong acids produced by the oxidation process of minerals such as sulphides (e.g. pyrite FeS_2) or by the rising of deep waters enriched with CO_2. Where the dissolution processes have produced a network of subterranean streams, mechanical erosion can act as an important factor in widening the underground passages. Weathering due to condensation processes can have a relevant role in areas characterised by a strong seasonality and caves with high air fluxes. In practice, to form a karst landscape three ingredients are essential; soluble rock (usually of a carbonate type), water, and carbon dioxide.
These three ingredients co-exist in many places on Earth but it is especially in the intertropical zone that they are particularly abundant. In fact, the largest outcrops of shelf limestone rocks are found in South-East Asia, between China, Indonesia, and the Indonesian Archipelago, as well as in Mexico and in the entire Caribbean area.
Abundant precipitations are found in South-East Asia, with a strong seasonal regime influenced by the monsoons, and in the area of the Caribbean.
Carbon dioxide is a gas present in the atmosphere and the amount of which, beside being alterted by humans with massive inputs resulting from hydrocarbon combustion, is strongly tied to the biological activities of plants. The greater the biological activity, the more CO_2 is present in the environment, especially at ground level and in the uppermost soil layer. In humid intertropical zones the

The flooded gallery of the Little Underground River

This spectacular sector of the 150 Years Gallery, in PPUR, was formed by a subterranean river when the sea level was higher than present

vegetation grows abundantly, especially in Central America and South-East Asia, so all the conditions are met for the development of large karst systems, which is indeed what occurs. Compared to temperate areas, where karst is also well developed, tropical areas generally have more marked forms, especially regarding size.
The karst processes have even more effect mainly because of the low degree of seasonality. The lack of a cold season means that plants have a nearly continuous growth cycle, with a strong biomass production that, when it decomposes, releases CO_2 into the atmosphere and in the soil. This, for example, allows the formation of well-developed forms of surface corrosion with dolines and *karren* fields often reaching very large dimensions.
Furthermore, the high degree of infiltration and the common presence of closed basins, drain enormous amounts of water, which give rise to true underground rivers that transport large quantities of sediment. In these conditions, alongside the chemical dissolution processes, mechanical erosion processes become very important, leading to the formation of large corridors. Such large underground spaces are unstable, and sometimes the ceiling collapse creates an opening at the surface and form wide depressions and large, deep shafts which are also characteristic of tropical karsts.

The Daylight, the upper and inactive entrance of the Underground River

A brief description of the Underground River

Leonardo Piccini

The Underground (or Subterranean) River is a cave stream about 8 km long which collects the water from a wide surface basin, diverting it to the sea through huge galleries flooded by water.

The main access to this cave is from the sea. On the side of a wonderful tropical beach, a water stream carves a shallow canal through the coralline sand. Going upstream, after a few dozen metres you reach a small green lagoon which reflects a luxuriant vegetation. The lagoon is bounded by a calcareous cliff, at the foot of which a portal opens the way into the subterranean river.

The entrance, only a few metres wide, gives access to a low gallery with several lateral coalescent branches. It's a real subterranean estuary, the course of which is the result of the alternate succession of fresh water erosion acting mainly during floods, and the corrosion by salt water pushed into the cave by the tides and mixing with the fresh water.

After about 400 metres, suddenly the vault rises and the gallery reaches considerable dimensions. The first large chamber we meet is called The Cathedral: a wide and high room rich in flowstones and large stalagmites.

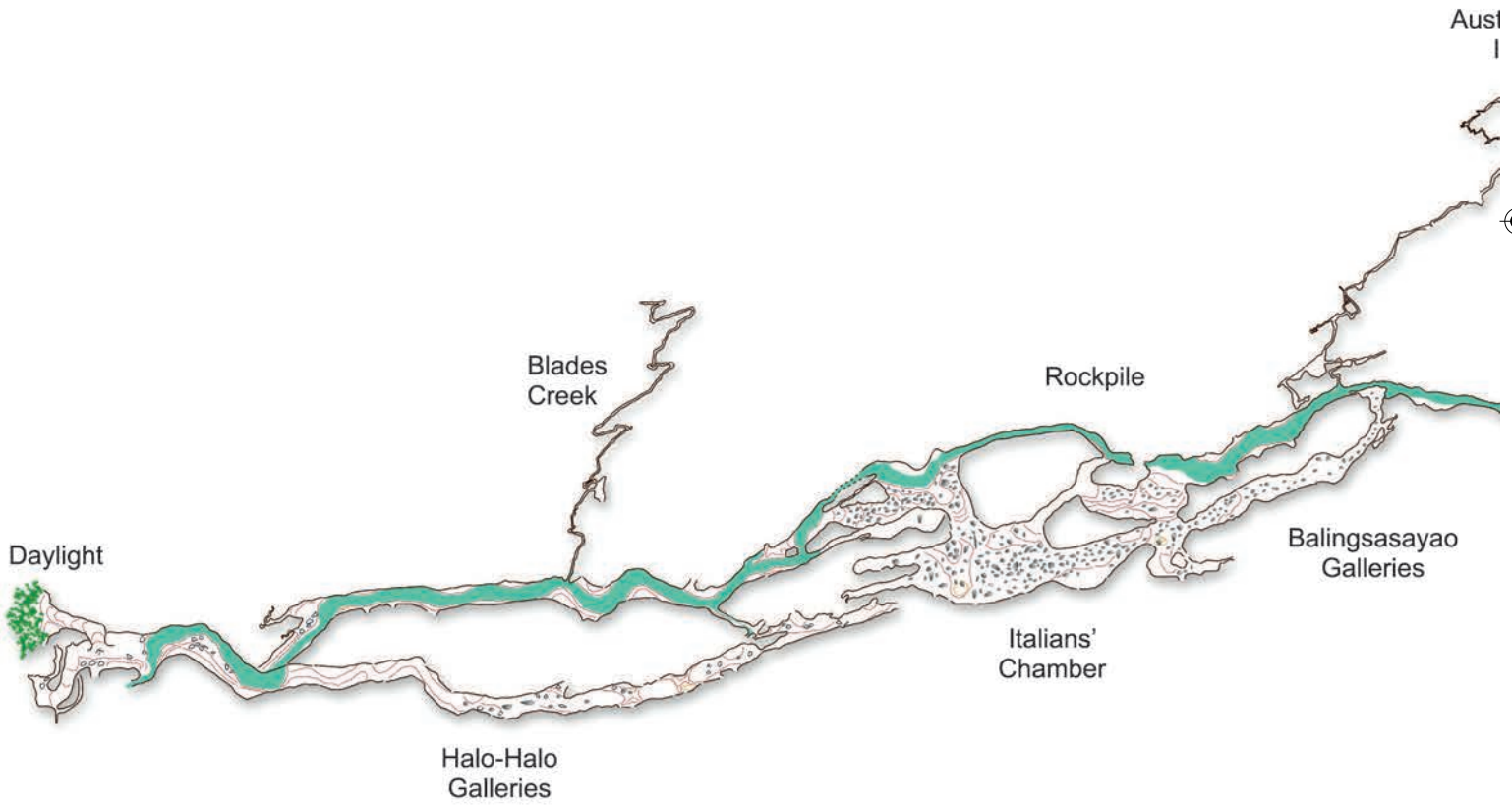
Further on, we enter a long rectilinear tract where the vault lowers to just a few metres above the surface of the water; then another vast hall, about one hundred metres high, is reached. This high chamber is the result of a huge collapse which connects the present river with the galleries through which it ran in the past, about 80 metres higher up. Here we can see that the present Underground River is only the last of a long series of subterranean rivers which over time have passed through the depths of this mountain.

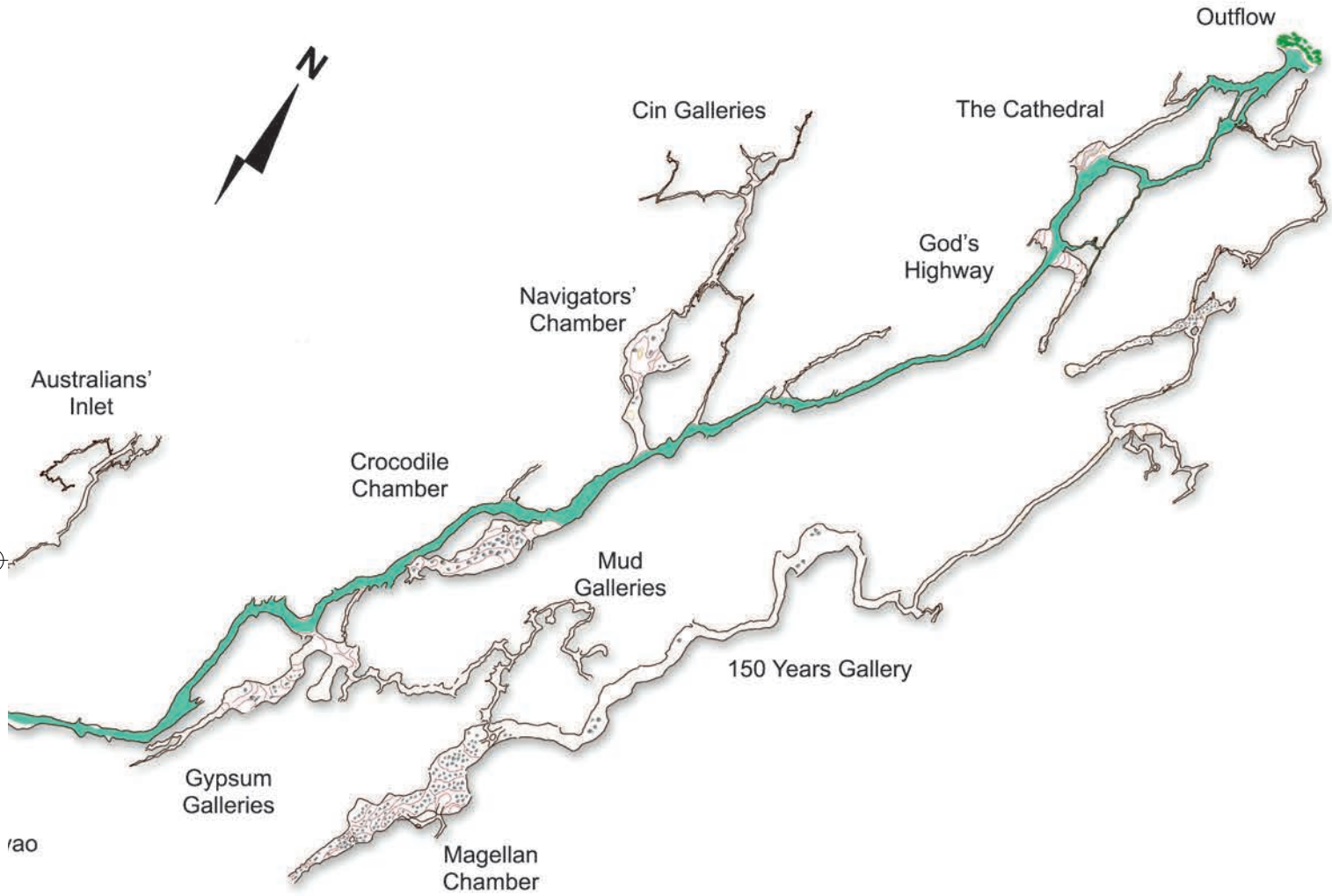
The tract that follows is one of the most extraordinary underground passages in the World, God's Highway. Almost 400 metres of a perfectly straight tunnel with a regular cross-section, 8-10 metres wide and a little less in height, with a completely flooded floor. Stalactites of irregular shapes hang from the ceiling, big enough to have survived the violent floods of the river. Upstream of this passage the gallery gains greater dimensions, mainly in width, and it begins to show several ramifications. Some of these lead to conduits parallel to the main one, which are active only during the rainy season.

On the right hand side there is first a long tunnel which leads to a parallel gallery (Cin Gallery), a tunnel acting as a diversion path during large floods. Just a few dozen metres upstream there is the access to the wide Navigator's Chamber, which also connects to the Cin Gallery.

PUERTO PRINCESA UNDERGROUND RIVER
Palawan - Philippines

PLAN VIEW





Survey:
1989 - T. Bernabei, A. Bonucci, N. Campion, A. De Vivo, F. Dal Cin, P. Iesu, M. Leonardi, L. Piccini, M. Topani, G. Rossi.
1990 - A. Diamanti, L. Piccini, J. Schmidtlein, M. Vianelli.
1991 - R. Beso, L. Delazzari, P. Ducerf, G. Ferret, C. Ferron, S. Meggiorini, S. Melotti, G. Rossi, R. Zorzin.
2003 - Gaia Exploring Club.
2007 - G. Boldrini, M. Frova, M. Liverani, F. Lo Mastro, L. Piccini, G. Savino.
2011 - S. Arrica, O. Belloni, C. Corongiu, J. De Waele, M. Liverani, V. Malcapi, G. Mariannelli, S. Merighetti, A. Mezzetti, D. Pani, S. Panichi, M. Pazzini, L. Piccini, F. Sauro, M. Taverniti, I. Tommasi, S. Zucchini.

Data elaboration and graphics: Leonardo Piccini.

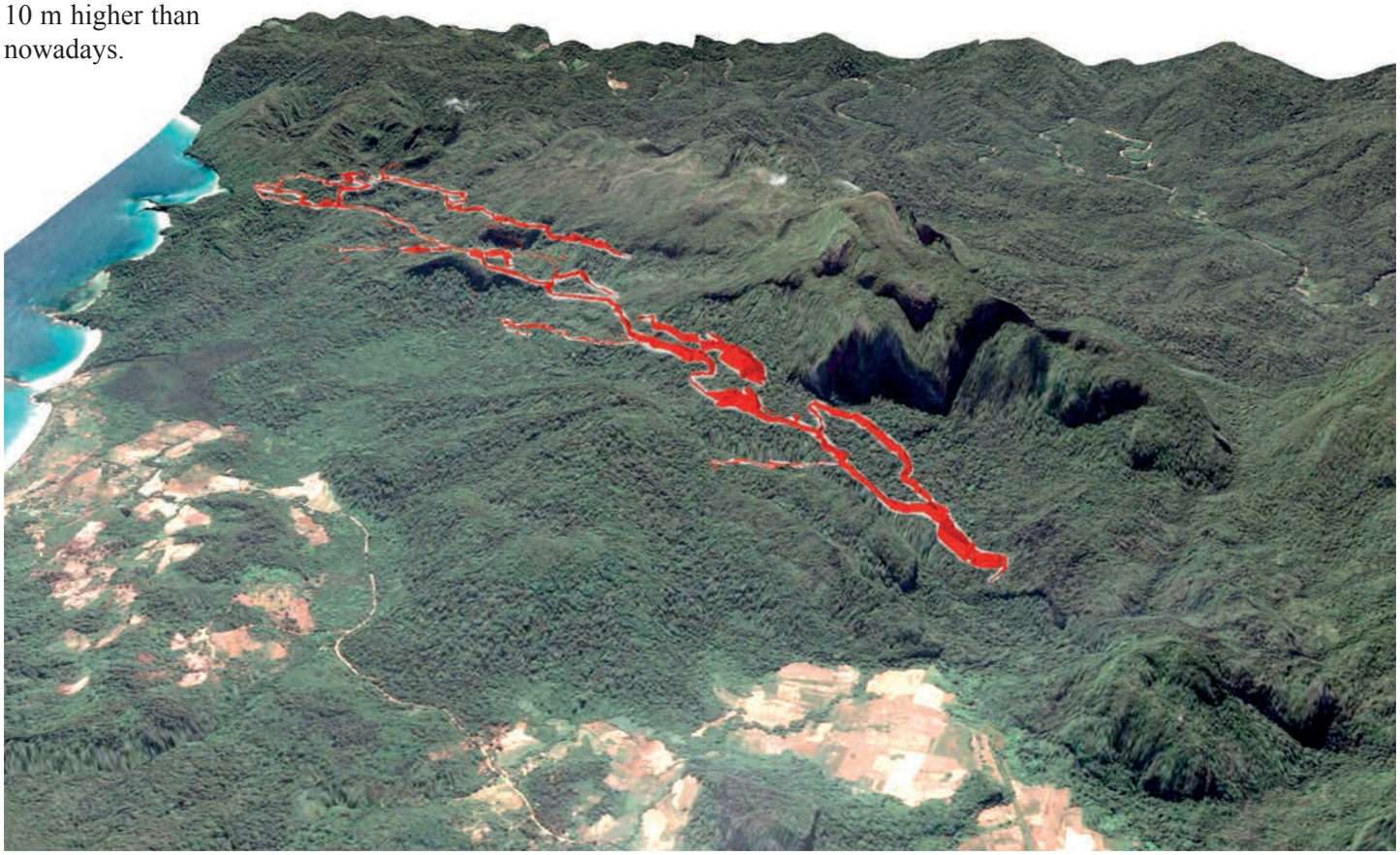
On the left-hand side and some hundreds of metres further on there is an important branch consisting of a large and elongated collapse hall (Crocodile Chamber) and a lateral tunnel named Mud Galleries. The Mud Galleries are about 1.8 km long and are a bit smaller compared to the main tunnel. The name comes from the large deposits of mud in the final part of the branch. Some lateral diversions contain very nice flowstones.

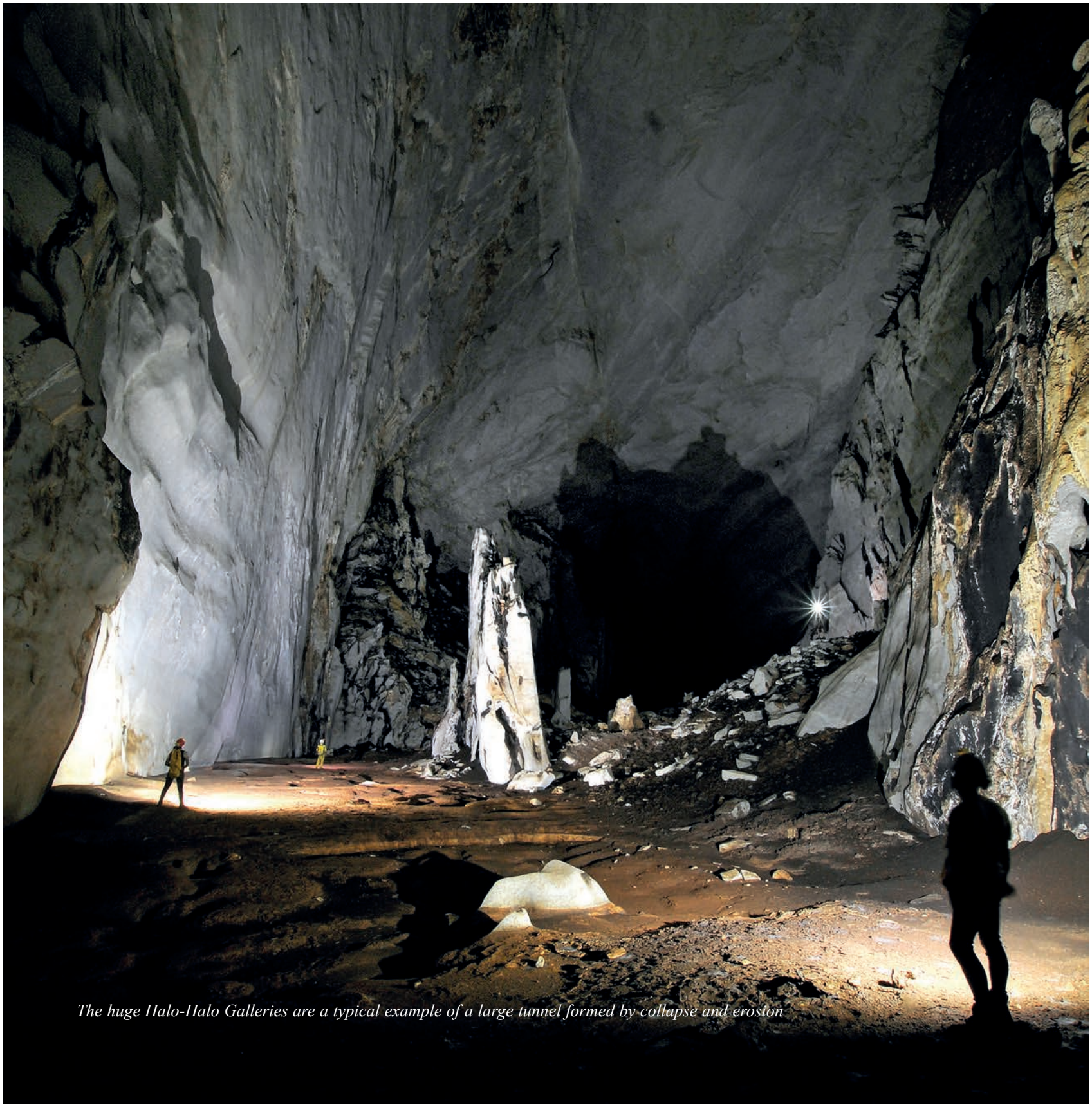
Here we are about 3.5 km from the sea-entrance. The gallery has a height of up to 20-25 metres. In some places, the side walls show the signs of ancient water levels. The most evident is a long regular notch that runs about 8 m above the present water level. This is the effect of corrosion during the last sea level high stand, which occurred about 120,000 years before the present time when the sea level was globally 6-10 m higher than nowadays.

On the right, where the gallery is wide and the river very shallow, an important tributary comes from the surface. This is the Australians' Inlet, coming from a wide closed basin just south of Sabang named Uran.

After 4.5 km, corresponding to less than one hour navigation, we arrive ashore on a riverbank of cobbles and mud. The gallery then continues submerged, whereas a wide hall, known as Rockpile, opens on the left. It is a huge place; it's difficult to appreciate it even with very powerful lights. An approximately 200 m long gallery

A 3D view of the Underground River (in red), which develops beneath the western slopes of the Saint Paul Dome





The huge Halo-Halo Galleries are a typical example of a large tunnel formed by collapse and erosion

allows us to go back to the river whereas, further up, a short climb opens into upper galleries of exceptional dimensions. In this higher zone, more than 100 metres above the present river level, there is an enormous hall, discovered in 1989 by Italian cavers (Italians' Chamber), 350 m long, 140 m wide and more than 80 m high. It represents one of the largest hypogean chambers in the World. Here, huge numbers of swiftlets find an ideal place to nest, and there are numerous spiders which hunt birds and their eggs.

To continue our way along the river we must now wear neoprene wet suits and swim in some sections. In this second part some regular round-section tunnels alternate with large halls, inside which we are at risk of losing our way among the chaos of large blocks.

Two kilometres further upstream of Rockpile, on the left-hand side, there is an important tributary, possibly the main one from the left side. The stream comes out from a small sump but, laterally, a climbing passage allows us to reach an upper large tunnel named Halo-halo Gallery. This is again a tract of an ancient path of the river. The gallery is often wider than 30 m and up to 50 m high.

The main tunnel continues for 1.5 kilometres after the Halo-halo branch, until we reach a hall with a very high vault, where daylight filters in. This place has a simple but appropriate name: Daylight. We are close to the sinking point of Cabayugan River but it is not possible to pass through the active path because a large rock choke closes the way. The light comes from a huge entrance that opens about 60 metres above the plain level, near barrio Cabayugan.

The main underground stream runs in a large tunnel, with lateral minor diverting passages and in some places upper old relict galleries joining with the active one through large chambers.

Upstream Rockpile, the Underground River flows along a large gallery affected by collapses. Note the sediments on the left bank showing the level of floods

The lower limit of dripstones along the PPUR probably indicates the level of water during major floods

A curious thing is that the cave runs all along the north-western side of the Saint Paul ridge; this means that most of the karst surface lies on the right-hand (eastern) side of the cave; despite this the Underground River has no consistent tributary from the right side. Why? Where does the water infiltrated all over the karst area flow up? How does it reach the sea?
These kinds of questions have tortured our minds during all these years since the first exploration. Now, finally, we have an answer. The first part of the cave, close to the seaward exit, presents a very complex pattern. Several branches divert from the main gallery. One of these lateral branches, just 150 m upstream of the outlet, was explored by the Filipino cavers of the Gaia Exploring Club in 2001. A large gallery, which they reached after a narrow flooded corridor, heads eastward and closes at a huge stalagmite formation, 15 m high.

Swimming in the flooded conduits approaching the Cin Gallery

A spectacular flowstone formed above the maximum level of floods, upstream Rockpile

Beyond this obstacle, which stopped the exploration of the Gaia Club, a second dry and huge system of galleries exists: like another cave, a parallel system of new amazing galleries. It is a 'hidden' river, which is flooded only during rainy seasons.
The first part consists of a high gallery, about 10 m wide and 40-50 m high. The floor is formed by a sand deposit. On the right an upper sector hosts a hall with very nice helictites. On the left we reach a part of the gallery where the floor is covered by extraordinary calcite crystals. It is really a fantastic underground place, like a coffer which hosts a 'pirate' treasure.
It is easy to guess that it is an extraordinary cave in many aspects and in particular from a biological point of view. The subterranean river and its numerous branches house, in fact, one of the world largest and most important underground ecosystems. There are hundreds of thousands of swiftlets (salanganes), and almost as many bats, that twice a day, at dawn and at sunset, perform a striking migration. Seemingly, salanganes and bats have reached an agreement about the timing of their entry and exit from the cave; in general, when the bats begin to exit, almost all the swallows are back on their nests. Because of the great amount of organic matter that swallows and bats bring daily into the cave, around this flying community many other animals are present, made up of reptiles (snakes), fishes, crustaceans, and insects whose dimensions are a bit scary.

Speleothems: the cave's treasure

Up to a few decades ago, caves were regarded as places with no mineralogical interest and this because many of them are depleted of any chemical deposits and, even where they exist, over 90% consist of a single mineral: calcite. Now it is generally accepted that natural cavities are perhaps the most important environment of the world for minerals genesis: in fact waters flowing inside them may deposit a lot of different minerals, some of which are extremely rare and, up to the present time, restricted to such an environment. Currently over 350 cave minerals have been observed and each year new ones are discovered around the world.

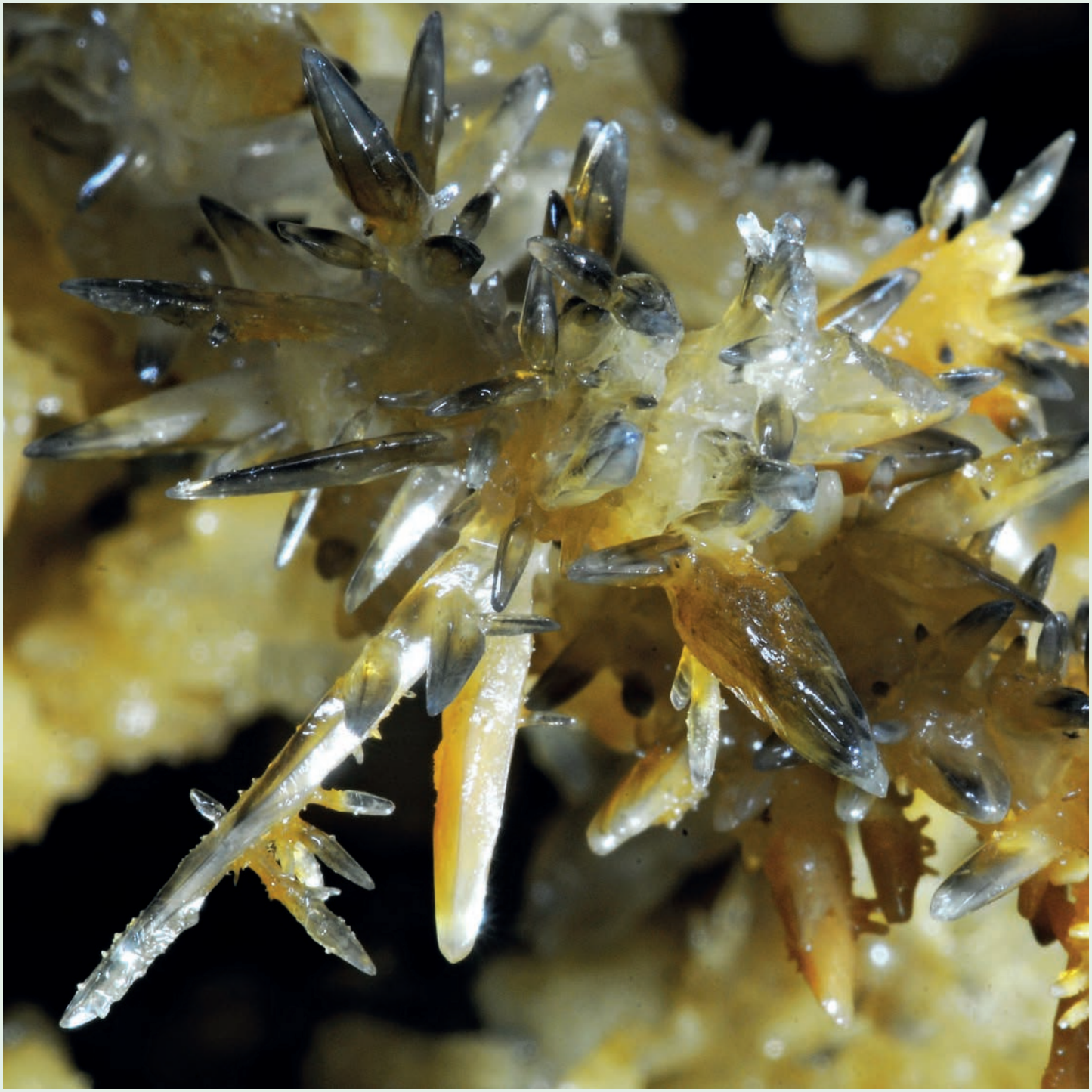
All chemical deposits in caves are generally named 'speleothems' (cave formations): they may exhibit very different textures (from perfect and very large crystals to completely amorphous compounds), dimensions (from tens of metres to fractions of millimetres) and colour (from transparent to dark black, from yellow to blue, from orange to green). But it is the speleothem shape that exhibits the largest variability: in fact, in a single cave it is possible to observe, close to each other, enormous stalagmites, extremely thin needles, crazy twisting helictites (which seem to refuse the law of gravity), incredible 'cave clouds' or even perfectly rounded 'cave pearls' and satin-petal cave flowers... This incredible variability is simply controlled by a single factor: the kind of motion of the feeding water.

Dripping induces the deposition of stalactites on the cave ceiling, but it develops stalagmites where it splashes on the floor; flowing water creates flowstones and draperies, capillary water is responsible for the development of helictites and flowers, while steady water produces cave clouds and pearls, just to mention the most common cave formations. For this reason speleothems represent the true cave treasure, transforming the darkness of the underground world into a sparkling enchanted castle worthy of visitation by hundreds of millions of tourists each year.

Anyway, if it is rather well known that the most important aesthetic value of a cave is represented by its speleothems, actually only a few are aware that cave deposits are far more important for science. In the last few years cave formations have become fundamental tools to study the past from different points of view like climate, environment, earthquakes, and allowing also

Right: Calcite crystals radially growing on a coralloid speleothem (total size about 30 mm)

A cave pearl, diameter about 18 mm



Left: Calcite crystals grown in a pool of clear water

A helictite "forest", formed by precipitation of calcite in a zone of evaporation

their absolute dating. Due to this, the chemical deposits in caves have become the most detailed available archive for the whole Quaternary (up to 1.8 million years from present). By far, the majority of this information is recorded within the growing layers, therefore cave formations may be regarded as 'stone books' in which any layer corresponds to a page in which all the events that occurred during its deposition have been written. But speleothems may be far older than 2 million years; thus, in the near future, when the analytic techniques will be improved, they will supply data on environmental changes over tens or even hundreds of million years.

It is therefore evident that cave formations must be protected: today many countries are aware of the touristic and/or scientific importance of cave deposits and therefore protect speleothems in general, or at least the caves in which their display is most abundant, by law. But a few countries still permit the trade of cave formations, consequently many natural cavities are actually exploited for this reason. Chemical deposits belong to and must stay inside caves: therefore no fragment, even already broken, of speleothem, should be extracted from caves for collection or, even worse, for trade. Even scientific sampling must always be reduced to a minimum to avoid an excessive depletion of the pristine beauty of the cave. Rules are fundamental, but not enough to avoid vandalism; it would be very important that all the people entering a cave voluntarily followed the caver's motto:

"Inside a cave, take only pictures and leave no evidence of your visit"

Paolo Forti

Dense colonies of bats live in the fossil areas of PPUR

Is there life in this cave?

Valerio Sbordoni

The organisms that live inside caves are kind of special, displaying peculiar morphological features such as elongated legs and appendices, extreme reduction or complete lack of eyes and pigmentation. In short, a series of features that bio-speleologists call 'troglomorphic' and that stress how closely those organisms are connected to the cave environment.

Natural selection has modelled these features in time, starting from the progenitors that lived, and sometimes live still now, in the external environment and show no trace of cave-adaptation.

Evolution towards cave life requires different factors that, to different extents, are active in the various types of caves. Such factors are: the actual size of the cave population, its degree of isolation from outside populations, the time spent inside the cave (expressed in terms of number of generations) and natural selection. As time goes by, troglomorphic features become more and more prominent, due to the continuous exposure of the population to the cave environmental selective pressure. Dominant factors are the lack of light and the scarcity of food (caves are usually poor in food resources).

This is definitely not the case in PPUR, where visitors are impressed by the remarkable availability of trophic energy. Indeed, PPUR is a typical tropical cave, with a rich fauna and large amounts of food available. In most cases, the former comprises poorly specialised animals, that is, with no obvious signs of adaptation to cave life, such as the large populations of bats and swiftlets

Thousands of small crabs habit the muddy banks of the Underground River

(*Collocalia genus*). These are the main producers of the huge amounts of guano that represent the main trophic resource of the cave, especially in its terrestrial environment.
So far there is nothing new: similar situations have been found in other areas of South-East Asia, especially in Borneo (that shares many zoological and botanical features with Palawan). What makes the difference in the Underground River is that this cave behaves like a classic estuary, in which tidal patterns affect a very long stretch of the cave. This means that high tide carries sea (or brackish) water up to 6 kilometres inside the cave, whereas the fresh water, flowing as a sheet on top of the salty one, is projected outside like a kind of resurgence, which in flood periods forms a large muddy plume on the blue surface of the sea, that can be easily seen from a plane. The two types of water don't mix much and at the interface there is an accumulation of large bacterial populations, as well as the rest of the biomass of the remaining trophic network.
The tidal pattern, together with the seasonal variation of rainfall, creates large spatiotemporal variations in the distribution and quantity of fauna in the water ecosystem. We were able to observe the most impressive evidence of the consequences of such a regime in May 2000, when we saw huge heaps of *Ocypodidae* larvae (ghost crab) at the magalopa stage. Their mass literally covered the walls for about half a metre from water level, for hundreds of metres. Many larvae could also be seen swimming in the water. It was an incredible resource, tons of biomass appealing to all sorts of predators.
The different distribution of the fauna during the day was instead documented by the fish captured by a net placed a few hundred metres from the entrance of the cave. In 24 hours, the net captured typical fresh water fish, such as a microphtalmic catfish (with clear signs of adaptation to cave life), as well as sea fish, like the indo-pacific blackmouth croaker *Atrobucca nibe*. Obviously, the catfish (still alive when captured) had descended towards the sea following the fresh water flow during low tide, whereas the blackmouth croakers (already dead at capture) had entered the cave following the salt water cone created by high tide.

Large Megalomorph spiders (Therapoda) are among the most dangerous predators living in the cave

A centipede (Scutigerimorph)

Right: The Amblipigious females carry their joeys with them to avoid they are predated by other animals

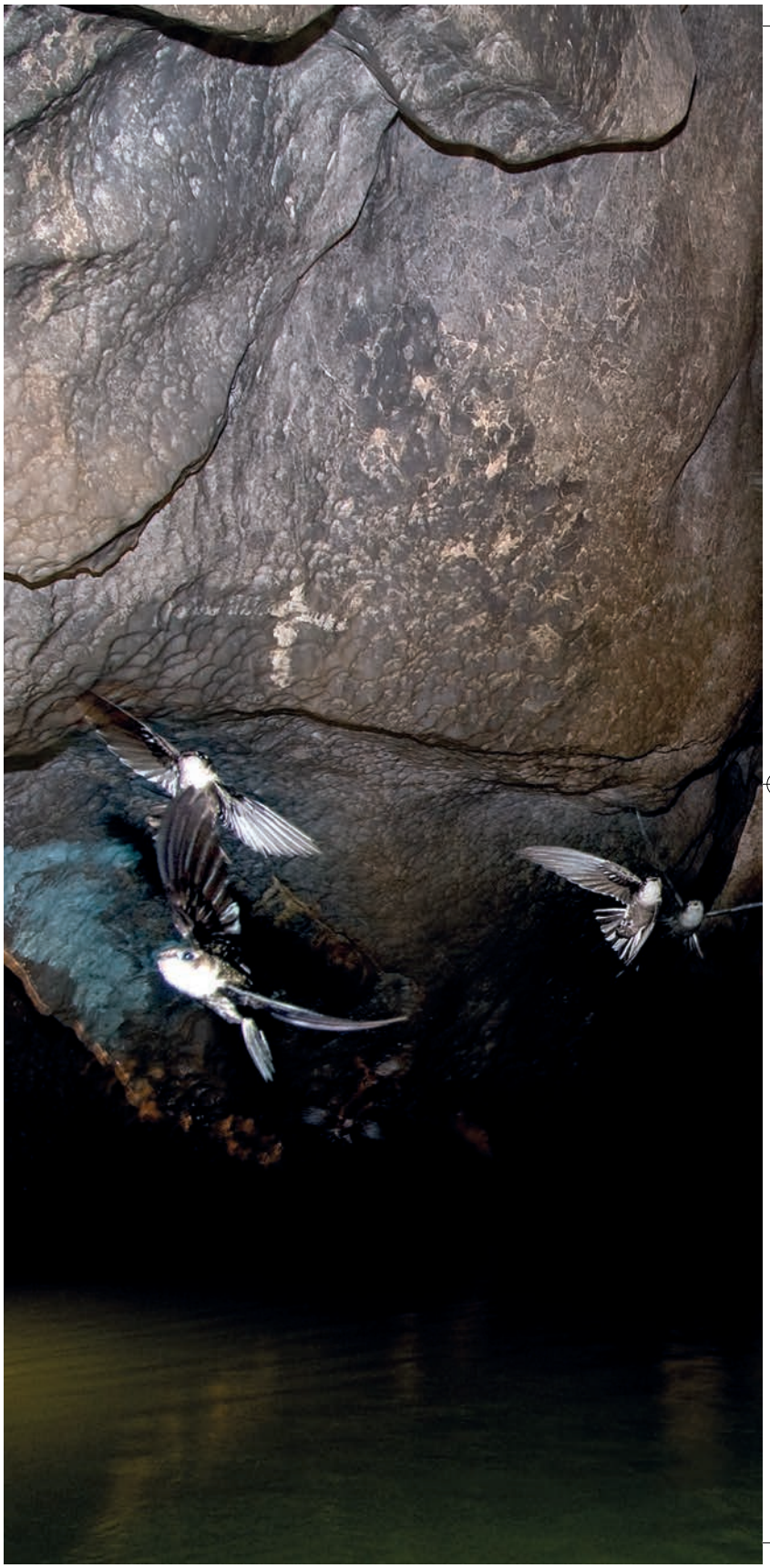
During the day bats hang on the roof of the lateral rooms of the Underground River

In most of the cave sectors terrestrial fauna is also quite rich, representing all the levels of the trophic network. The presence of at least three species of snakes is noteworthy; amongst them is the colubrid *Elaphe erythrura*, often found in the caves of South-East Asia where it feeds mostly on bats. Finding a cobra a few kilometres inside the underground river, though, was unexpected, as was the discovery of a flourishing population of pythons (*Python reticulatus*), well fed on bats and swiftlets. We also found many Thereuopoda individuals, large and voracious scutigeromorpha centipedes, whose presence is shared with the caves of Borneo. A huge population of large migalomorph spiders, probably from the *Masteria* genus, was also found. Meanwhile, the walls are home to *Amblypygi* and the large cave crickets of the *Rhaphidophora* genus. The guano community includes a new species of the Leiodidae beetle *Phomaphaginus*, as well as a small *Tineidae lepidopter*.

For sure one would not expect to find, in a cave with these features, troglobite organisms; yet, in a high branch of the cave, relatively removed from the areas where bats stay and swiftlets nest, we were very surprised to find a small terrestrial isopod crustacean and a pseudoscorpion that displayed clear troglomorphic features, both blind and de-pigmented.

From the ecological point of view then, the cave presents three distinct ecosystems, each characterised by the different nature and abundance of the trophic resources.

These features make the PPUR system an extraordinary natural laboratory to study the evolutionary processes and the ecology of hypogean environments.



Every day, at sunset and sunrise, the swallows (Collocalia Genus) *move in and out of the cave; it is a fascinating event taking place since immemorial times*

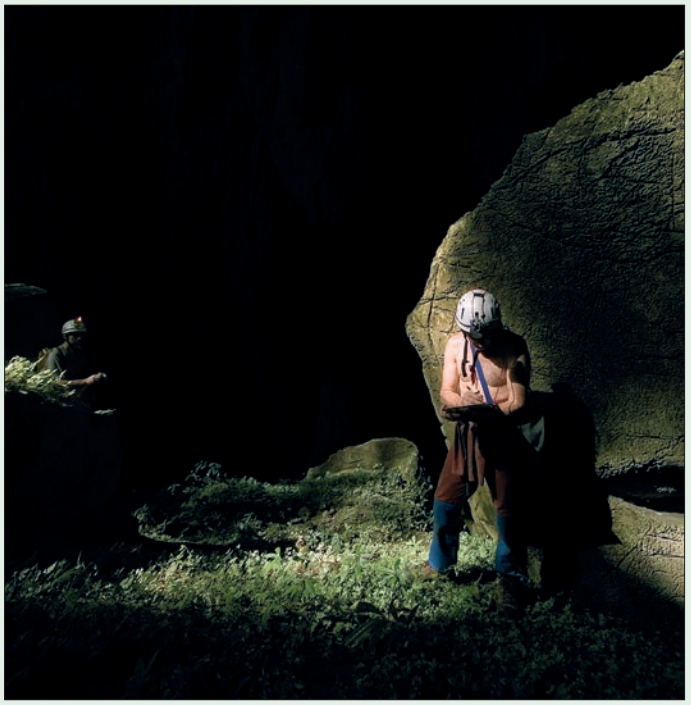
Cave climate

A visitor who passes a cave entrance has the feeling of having entered an unchanging place.
It's partly true, as the rock effectively isolates the cave from the outside world's changes, but not completely. Even underground, the laws of atmospheric physics sneak in and even in caves there are clouds, rain, wind, and seasonal cycles. It is just that everything there is more subdued, often noticeable only with instruments, and only now we are beginning to understand the subtleties of underground meteorology.
Outside, the climate varies from one place to the other: you can go from arid, very hot deserts to rainforests, from glacial plains to temperate gardens. The differences in precipitation and thermal excursion which cause these variations are however quite small; between an arid zone and a humid one, there is only a three or four-fold difference in annual precipitation, between a continental and a maritime climate, there is only a two or three factor difference in the thermal excursion. So, the outside is really hypersensitive, and small climatic differences cause important changes in landscapes.
Life is extremely sensitive to climatic variations and small variations, drawn out over centuries, are enough to radically modify entire environments.
In caves the situation is very different. We are discovering that the underground 'climate' is indeed apparently unchangeable, but varies from one cave to the other much more than is the case outside. In some caves the seasonal thermal excursions are of 1 or 2 °C, in others less than one-hundredth of a degree. Some caves are crossed by hundreds of cubic metres of air per second, in others there is no measurable airflow. One cave may expell hundreds of cubic metres of water per second, while another might only let rare drops fall here and there. One is whipped by continuous small underground storms, while another is perfectly calm. The differences among the underground 'climatic types' are factors on the scale of a hundred, a thousand, a million!
It is said that caves are warm in winter and cold in summer… this is not true: their temperature is simply constant and equal to the temperature of the rock in which they are formed. The rock itself has the average temperature of the waters that crossed it over the millennia and waters have approximately the average annual temperature of the area. Therefore, in practice, the temperature of a cave is very close to the average annual temperature of its location, so it is noticeably warmer than the external air in winter and noticeably cooler than the outside in the summer. Approaching the equator, average temperatures rise, and therefore cave temperatures do so as well. The maximum is found along the thermal equator, that is, along that tortuous line which runs around the planet, usually slightly to the north of the geographic equator, which separates the average annual temperatures which then diminish towards the poles. There, at sea level, caves are at their maximum possible temperature (around 26-30 °C),
In caves, relative humidity is also constant and generally always very high, because they are nearly closed spaces containing enormous exposed surfaces of water. In such conditions water evaporates until 'saturation'

Downloading of data from a meteorological station

occurs, that is to the point in which the air cannot hold any more water vapour. At that point we say that the relative humidity is 100%, but we will soon see that, as the temperature gets higher, a greater quantity of water needs to evaporate to saturate the air with humidity.
Many caves have wind blowing through them. The reason is simple: it's a 'chimney effect'. When we heat air in a chimney, it becomes less dense and therefore tends to rise, sucking air from the bottom and shooting it out from the top. The 'draught' is stronger as the chimney gets higher and wider.
Caves do the same: if the air inside is less dense than the outside air, it rises, entering the low entrances and exiting from the upper ones. Unlike chimneys, however, sometimes caves can contain air which is denser than the outside air, therefore the flow reverses: the air crossing the mountain exits the lower entrances after being swallowed by entrances higher up, whether known or unknown.
There's another factor which moves air in a cave: the fact that atmospheric pressure varies. Therefore the cave needs to suck in or blow out air to keep the internal pressure aligned with the external one. However, usually this is a significant factor only in particular situations, like when there are sudden pressure drops caused by large atmospheric disturbances, and usually doesn't continuously influence the movement of air inside mountains.

The topographic survey of caves needs a long and accurate field work



But why is the internal air sometimes denser than the external air and sometimes less dense?
For almost all the caves on this planet, the reason is the temperature difference between the inside and the outside. We have already seen that the inside temperature is approximately the average annual temperature of the location. When the outside is colder than the cave temperature (in winter or at night, for example) the internal air is relatively 'hot' and therefore rises, all the more violently as the difference in temperature increases. On the other hand (in summer or in daytime), the air is relatively 'cold' and denser, therefore causing it to fall.
Another cause of air density variation is the air own water content.
We have already mentioned that the amount of water vapour contained in humid air depends on the temperature. In a cubic metre of air at 100% relative humidity, at 0° C there are only 4.9 g of water, which takes up a volume of 6 litres. At 26 °C there are 24.4 g of water, which takes up 30 litres (3% of the cubic metre).
Humidity changes the density of air, because water vapour is nearly 40% less heavy than dry air. So, if the temperature is high, water vapour becomes a significant air component; therefore, if relative humidity varies greatly the weight of air can change significantly.
So in warm caves, in order to estimate the difference in air density between the inside and the outside, temperature differences aren't enough; you have to include also the variations in the external humidity.

Giovanni Badino

A large amount of moisture climbs up every day from the sea allowing the growth of a rain forest on the rocky slopes of the Saint Paul ridge

The scientific issues of interest of the Puerto Princesa Underground River

Giovanni Badino, Federico Fanti, Paolo Forti, Leonardo Piccini

Caves are often places of great interest for science. The main reason is that it is in caves that we can often find the remnants of the ancient environmental conditions which occurred on the Earth in the geological past.
Caves allow us to touch with our hands the internal structure of the Earth crust, even if only in its more superficial part.
Caves can also tell us much about the present environmental conditions, because they act as a 'filter' which smoothes the short-term effect of global changes showing their middle to long-term and most important effects.
Caves host unique ecological systems, where the fauna can evolve under slowly changing environmental factors. They are like biological laboratories that can help us to understand the evolution of life on Earth, from its origin to now.
Caves are all this and much more. They are like an old and mysterious book which can tell us something about the history of our planet.
The Puerto Princesa Underground River is one of the most extraordinary caves in the world and so it is undoubtedly a fascinating place for scientific research. An amazing scientific adventure that is just at the beginning.
Here we have summarised some of these issues of interest, but many more topics are waiting to be investigated, primarily the biological ones.
Without any doubt, these features make the St. Paul karst a unique place in many respects, even in the worldwide karstic panorama, and the creation of the National Park and its insertion in the UNESCO Heritage List is a great opportunity for study and research for many years to come.

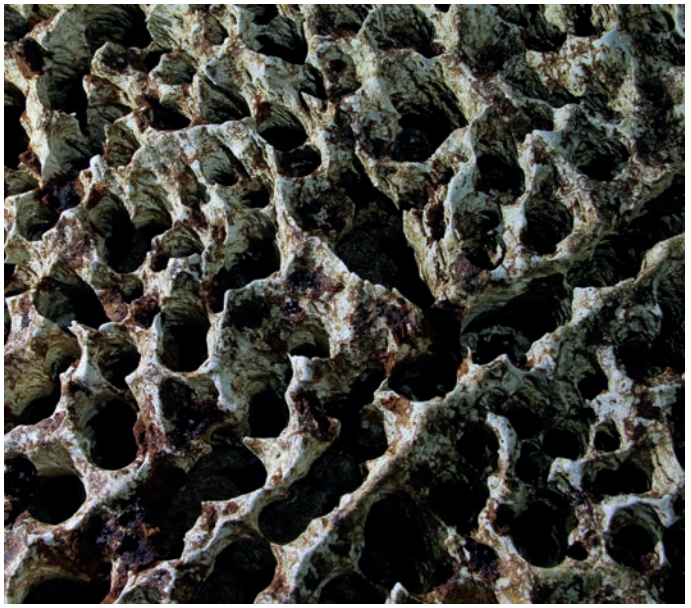
GPS surveying of geological features

Left: A few hundred metres downstream Rockpile, the wall of the main gallery shows the notches left by the previous levels of the water inside the cave

Geomorphology

L. P.

A cave is a natural void opening in rock and large enough to be accessible to humans. But how can we study a void? What kind of information can we get from something that "does not properly exist"?
Geomorphologists are used to interpreting the shape of landforms such as valleys and erosion forms. Caves are essentially 'erosion forms' but, different from surface landforms, they can be preserved for a very long time from the relentless processes that mould the surface of the Earth.
In this sense the Underground River, along with the other caves of Mount Saint Paul, ia a unique karst system which can tell us the geological history of the last millions of years.
One of the most significant features of the PPUR is the fact that tides affect a large part of the cave, up to about 6 km from the coast. Along the whole navigable part, marine water lies under a thin layer of fresh water, just a few centimetres thick, with a transition zone of variable thickness. During floods the cave is cleared of salt water, which later returns slowly through tidal action. But this is only the present situation. In the past sea level was usually lower than now and the PPUR has not been a marine cave.
Indeed, despite the occurrence of corrosion produced by the mixing of fresh water with saline water, the speleogenesis of the PPUR is mainly due to solution by continental water and to mechanical erosion by suspended load during floods. Only in its downstream part, mixing corrosion has produced typical forms of coastal caves, such as waterline notches, spongework and lateral conduits. From this perspective, the system may be considered a classic example of an underground estuary.
Features that indicate former water levels are present along the PPUR up to 5 or 6 km upstream from the coastal spring. In the last sector of the navigable path, where the ceiling of the main tunnel rises up to 20 m or more, there are two evident old corrosion notches due to persistent levels of water. The upper notch is at +11-12 m above present mean sea level (pmsl). The second notch is at +7-8 m above pmsl. Some of the lateral branches of the PPUR contain alluvial terraces consisting of sands and gravels, which are related to this second highstand notch. This circumstance allows us to correlate the lower notch to the marine one, visible on the coastal cliff at about 7 m above sea level, which dates back to the last interglacial phase (about 120,000 years before the present time).
The morphology of the active level of the PPUR is clearly adjusted to the current sea level, but we have to consider that in the last 500,000 years BP, the sea was most of the time lower than now (mainly 50-60 m lower). This implies that the PPUR has functioned as a vadose through-cave affected by fresh water flow, with a substantial load of insoluble material, forming a subterranean canyon that was buried by the alluvial sediment that forms the current riverbed.



The small holes formed by sea water corrosion close to the entrance of PPUR (dimension of the photo about 300 mm)

The explorers must take their shoes off to avoid damaging the crystallized floor of the 150 Years Gallery

The PPUR profile also shows several large passages at an elevation of mainly 50-80 m. This level consists of large inactive tunnels parallel to the current river containing thick alluvial deposits covered by flowstones, which in places almost completely fill the conduits.
In the upstream sector of the cave, erosion forms may be found, indicating a long phase of vadose entrenchment. This ancient 'underground river' could reasonably be dated back to the Early Pleistocene (about 1 million years BP), as suggested by the extrapolation of the recent low uplift rate of the coastal zone.
Several morphologic features, such as the presence of corrosion notches at +12.4 m asl, and the huge concretion masses corroded and interbedded with alluvial deposits, suggest that this lower and presently active level passed through more than two sea level highstands and could have formed during most of the Middle-Late Pleistocene (from 700,000 years ago to present).

Speleothems and cave minerals

P. F.

Until recently the PPUR was supposed to be a cave with just 'normal' speleothems (stalactites, stalagmites, flowstones etc…) of local or regional importance at most. Some of them have noticeable aesthetic interest and can easily be seen by the tourist along the normal tourist path. Among them the gigantic stalagmites, like The Cathedral not far from the cave entrance, or some large 'canopy bells' about 1-1.5 kilometres inside, are surely worth mentioning for their beauty and dimension.

But the latest studies proved that this karst system is exceptional worldwide also from this point of view. In fact the PPUR hosts aesthetically astonishing speleothems: they are presently restricted in branches far from the river and at the moment impossible to be visited. One of these speleothems is 'calcite grass', an extremely rare kind of helictite, consisting of bended and twisted calcite monocrystals growing from the cave floor and covering several tens of square metres of the 150 Years Gallery in the new paths of the Gaia Branch. In the same area, large transparent calcite rhombohedrons have been found inside pools just at the bottom of gigantic orange flowstones.

But PPUR hosts, in God's Highway, a completely new type of drapery. This speleothem, some 10 to 12 metres high, resembles a 'sail' with several transversal strengthenings (sudden widening). Its genesis is still unknown even though it is clear that it underwent a complex multiphase evolution requiring periods in which water flowed by gravity, followed by stages in which the capillary process ruled.

From the mineralogical point of view the PPUR was, until present, known as hosting very few and common cave minerals: just calcite and gypsum. But the mineralogical studies, still under development now, are evidencing that the situation is more complex and the number of cave minerals is much higher than supposed and, even more important, some of them have never been seen before anywhere else in the world. Most of the minerals of the system are concentrated within the huge 'black crusts', which are widespread along the main galleries of the PPUR. These crusts, often completely detached from the cave wall, are related to periods of strong corrosion controlled by biogenic reactions induced by the mineralization of guano. The same process was active in all the other caves of the St. Paul karst: in two of these cavities the process also allowed peculiar black cave pearls to develop. In general the crusts consist of several very thin layers of different colour: beside the far more dominant black ones, other layers are present from black to reddish and from yellow to white. Each colour corresponds to one or more com-

A perfect crystal of calcite (dimension about 15 mm)

pounds. In the black layers most of the minerals are manganese compounds, the reddish are characterised by iron-manganese minerals, while the white and yellow ones consist of gypsum and phosphates, many of which are amorphous.
Up to now eleven different minerals have been detected in the PPUR: calcite ($CaCO_3$), gypsum ($CaSO_4 \cdot 2H_2O$), apatite [$Ca_5(PO_4)_3 \cdot (C,F,Cl,O,OH)$], variscite [$AlPO_4 \cdot 2H_2O$)], strengite [$(Fe, Al)PO_4 \cdot 2H_2O$)], manganite [$MnO(OH)$], rhodochrosite ($MnCO_3$) pyrolusite ($MnO_2$), robertsite [$Ca_6Mn_9(PO_4)_9O_6(H_2O)_6 \cdot 3(H_2O)$], janggunite [$Mn_{5-x}(Mn,Fe)_{1-x}O_8(OH)_6$] and serrabrancaite [$MnPO_4 \cdot 2H_2O$)]. The first 8 minerals were already known from the cavern environment while the last three (robertsite, janggunite and serrabrancaite) are new cave minerals, being restricted to the single St. Paul karst: in particular serrabrancaite is very rare even outside caves, being found until now only once in Brazil.
Thanks to these recent findings the PPUR has to be considered among the most interesting caves of the world from the mineralogical point of view.

Calcite is one of the most common minerals on Earth, and also one of the most beautiful

The Sirenian fossil

F. F., P. F.

During the scientific explorations carried out by La Venta Esplorazioni Geografiche inside the Puerto Princesa Underground River (February-March 2011), several partially articulated bones (ribs and dorsal vertebrae) exposed for approximately 10 cm of their length were observed about 3 m above the river on the left wall of God's Highway. The bones emerged from the rock wall due to the differential dissolution of the limestone with respect to bones. At that time we decided to take only pictures of the bones because sampling would surely result in a noticeable depletion of the preservation of the whole fossil.
A detailed comparison of the bones with several available photos of closed related taxa, and with the fossil specimens present in many museums all over the world, has allowed us to state that they belong to a sirenid.

Sirenians (commonly referred to as sea cows) are an order of fully aquatic, herbivorous mammals that inhabit swamps, rivers, estuaries, marine wetlands, and coastal marine waters. The order is divided into four families: two are extinct and known only from the Eocene epoch, two have living members today. These are the dugongs (*Dugong dugon*) of the Indo-Pacific region, and manatees (3 species, *Trichechus spp*.) of the Atlantic basin. Sirenians also include the Steller's sea cow (*Hydrodamalis gigas*), hunted to extinction in the 18th century, as well as a number of species known only from their fossil remains. The order evolved during the Eocene, more than 50 million years ago.
Sirenians represent the only extant herbivorous mammals with fully aquatic adaptations: forelimbs have evolved

into arms used for steering, the tail has modified into a paddle used for propulsion, and the hind limbs (legs) are reduced to small remnant bones floating deep in the muscle. They appear fat, but are fusiform, hydrodynamic, and highly muscular. Their skulls are highly modified for taking breaths of air at the water surface and dentition is greatly reduced. The postcranial bones of both the manatee and dugong are robust, which helps to neutralise the buoyancy of their blubber. The unlobed lungs of sirenians and their diaphragm extend the entire length of the vertebral column. These adaptations help sirenians control their buoyancy and maintain their horizontal position in the water. Living sirenians grow between 2.5 to 4 metres long and can weigh up to 1500 kg.

Sirenians' evolution is largely documented in Europe, the Mediterranean-North African region, the West Atlantic-Caribbean region, and both American and Asian shores of the North Pacific Ocean. The latter, however, have barely begun to be sampled for fossils of these animals. Apart from isolated and fragmentary findings in Madagascar, Java, Pakistan, and Sri Lanka, nearly all the known sirenian fossils from this region are from India. The specimen recovered on the Island of Palawan represents the first from the Philippines and the easternmost occurrence in the region. The partially articulated thoracic elements include a well preserved vertebra with exposed neural spine and processes, partial centrum and complete articulation with the head of the ribs. Several rib fragments are preserved in situ, showing broad and recurved ribs typical of sirenians. The specimen is approximately 60 cm wide, whereas the vertebra is 10 cm wide and 15 cm high including the centrum. It is therefore possible to estimate a total length, for the individual, of 180 cm. This sirenid is obviously coeval with the hosting rock, the St. Paul Limestone, which is Oligo-Miocene in age. Presently we are not able to define the exact location of the fossil bones

The skeleton of a sirenian emerging from the rock wall of the Underground River

within the stratigraphic column and therefore its age is still unknown ranging from 25 to 10 million years BP.
Until now the presence of sirenians in the Far East fossil record is rare and proved only as far east as Java. Therefore the fossil of the Underground River is extremely important because it pushes the limit of diffusion of these animals some 1500 km eastward. At the moment, by using only the photos of the outcropping bones it is impossible to state if the sirenian of the Underground River belongs to a known fossil family or to a new genus yet to be defined. It would surely be possible to exactly define the genus of this fossil but to perform these studies it would be necessary to extract as much as possible of the bones from the rock, thus completely destroying the location. Therefore we strongly discourage making these studies because, in the near future, new techniques could allow us to study this fossil preserving it.

Underground meteorology

G. B.

Io venni in loco d'ogne luce muto,
che mugghia come fa mar per tempesta,
se da contrari venti è combattuto.
Inferno, Canto V

I arrived in a place where all light was mute,
which bellowed like a sea in storm,
when battled by contrary winds.
Dante, Inferno Canto V

One of the many reasons that make this cave, carved by the Underground River, so exceptional, is that the underground meteorological phenomena are at their most intense level. We could even say that there is a permanent invisible 'underground storm', stirred up by the shape of its deep galleries.
The Underground River cave is a type of tunnel into which an external river flows and which transports all the meteorological events from the outside deep into

Recording meteorological data is the best way to study the energy balance of a cave

the rocks: precipitation peaks, large biological load and temperature jumps. This in itself is not exceptional: around the world there are many caves of this type, some having much more impressive rivers. The peculiarity which makes this cave so unique is that it reaches the sea level already within the mountain, in the core of Mount St. Paul.
This gives the cave several extraordinary characteristics. Not only can you enter directly from the sea, not only it is navigable for kilometres, but in this way the sea carries its dynamics through tidal currents - tied to the positions of the Sun and the Moon - which penetrate up to over 6 km from the entrance. So, part of the meteorology inside Mount St. Paul depends on the Sun and the Moon; therefore the Underground River environmental conditions have a clear astral origin.
The flows of fresh water from upstream and salt water from downstream are not connected to each other and, on the contrary, for long distances they don't mix, the former flowing on top of the latter. This creates pockets of cooler air in contact with the water and, seasonally, generates flows of relatively warm and humid air which fills the galleries. Micro-meteorological niches and extremely complicated ecosystems are thus created,

each having their own seasons, which at the moment we have only barely glimpsed.
The St. Paul 'underground storm' is probably the warmest in the world, because the cave lies on the thermal equator, that is, along that tortuous line which runs around the planet, usually slightly to the north of the geographic equator, and which divides the average annual temperatures which then diminish toward the poles. The island of Palawan lies directly on the thermal equator, therefore the PPUR cave isn't only hot, but has the maximum temperature possible for a cave created by external water flows.
Then there is the wind, which is very noticeable when you pass through the portal to visit the cave on the *bancas*. The galleries are crossed by an important airflow, with peaks of up to 150 cubic metres per second. The origin of air circulation inside caves is usually the temperature difference between inside and outside. But, unique also in this, the PPUR is affected by a subtle factor which is insignificant elsewhere: the variations in the humidity of the outside air. The cave has a very peculiar characteristic. On one hand it is very hot, as it opens in an area where the average temperature is especially high - in fact the highest possible -, on the other, it opens in an area where the climate is 'super-oceanic', that is characterised by a small - in fact, the smallest possible - thermal excursion between day and night and summer and winter. The result is therefore that the

Collecting water from a subterranean spring for chemical analysis

temperature difference between inside and outside is always small, just a few degrees difference, and it is very ineffective at creating an underground wind. In these conditions, a variation in the outside air density due to humidity variations can assume a decisive role. So, one of the forces of the 'underground storm' is the humidity of the outside air, which in other places doesn't manage to move anything.

A real storm should also have some big clouds, shouldn't it? And obviously this underground storm has some. Delicate, but very visible, we find them in the areas at the end of the upper branches. There, the air masses coming from the upper areas of the mountain meet the air and water flows of the underground river, which are some fractions of a degree warmer. This mixture produces condensation, forming stationary clouds. The bancas, at times, pass through very intense mists.

A storm should be accompanied by a great quantity of energy. From the measures taken, we know that the power of the flow entering the cave is 10 to 20 MW (millions of watt), which is much more than the power that enters most of the caves all around the world.

The last of the meteorological exceptional features that we will list in this text is deeply tied to this energetic aspect: unlike external ones, the storm here is also biological. All these flows of energy and fluids allow a tenebrous but sustainable life for large amounts of animals, which are more or less adapted to the dark. Therefore, external life can enter and sustain itself in the depths of Mount St. Paul, thanks to debris being constantly carried in by the water.

The huge galleries which were formed millions of years ago, and now abandoned by the water, present different conditions. There the wind is much weaker, clouds are absent or very thin and temperature excursions are more limited. These galleries are a sort of safe harbour from the 'underground storm', which has allowed fantastic concretions to grow and who knows how many and what types of ecological and meteorological niches. But, at the moment, we know very little about all this.

Right: The calcified skeleton of a bat

Calcite speleothems with different shape and colour

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Left: Climbing up the limestone pinnacles beneath the forest

PPUR Expedition team members

1930-1937
Alpha Phi Omega association

1965
Federico Celino

1973
D. Balázs and friends from the Philippines

1980 – Traditional Explorations and the Sydney Speleological Society
Ken Angel, Kimberley Baker, George Barnes, Mark Bonwick, Murray Bruce, Harry Coleman, Dorothy Coleman, Roger De Keyzer, Penny Figgis, John Fortes, Ellen Hagedorn, Richard Hankin, Peter Harlow, Debbie Harrison, Nigel Hawkins, Tom Hayllar, Gerald Hide, John Keevers, John Kersaitis, Robert Lachlan, John Ling, Jane Little, Chris McDonald, Jeanette McLaren, Leo Meier, Mark Nelson, Benjamin Nurse, Danielle Nurse, Julianne Nurse, Helen Pitt, Ian Smith, Linda Vining, Ross Vining, Brad Warren, Mayee Warren, Haydn Washington, Lynsey Welsh, Gerry Whitmont

1982 – Environmental Studies Association of Victoria for Associated Research, Esploration and Aid
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1992 – Società Speleologica Italiana (Italian Speleological Society)
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2000 – La Venta
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2001 – Gaia Exploring Club
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2007 – Philippine Speleological Society, Gaia Exploring Club, Western Visayas Caving Association
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2007 – La Venta
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2008 – La Venta
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2009 – Gaia Exploring Club
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2011 – La Venta
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St. Paul Bay, the landing place for the tourists visiting the Underground River

GLOSSARY

Aragonite – A crystalline form of calcium carbonate ($CaCO_3$), less common than calcite.

Biodiversity – The degree of variety of life forms expressed as the number of species living in a particular territory.

Biomass – The amount of biologic material deriving from living organisms.

Blind valley – A valley that is closed downstream by a slope.

Breakdown – A fall of rock from the roof or the wall of a cave.

Calcite – The commonest calcium carbonate ($CaCO_3$) mineral and the main constituent of limestone.

Cave adaptation – The morphologic modification of a species adapted to live in caves.

Cave pearl – A smooth, polished and rounded speleothem found in shallow hollows into which water drips. Internally, it shows concentric layers around a nucleus.

Chamber – A wide room inside a cave, with significant width and length.

Cockpit – A large, closed depression common in tropical karsts often presenting lobate or star-like shape.

Conduit – A tubular underground passage formed under hydrostatic pressure, commonly with circular or elliptical cross-section.

Cone – Conical, rounded residual hill typical of tropical karst.

Corrosion – Synonymous of solution - the change of a rock from the solid state to the liquid state by combination with water. In a physical solution the ions of the rock go directly into solution without transformation. In a chemical solution also acids take part, especially the weak acid formed by carbon dioxide (CO_2).

Doline – A closed depression draining meteoric water underground, usually with circular or elliptical plan. From a few to many hundreds of metres in size.

Endemism – A species that lives only in a particular and restricted region.

Estuary – The transition zone of a river to the sea, subject to tides.

Fault – A fracture separating two parts of a once continuous rock body with relative movement along the plane.

Flowstone – A deposit formed from thin films or trickles of water over floors or walls, usually of calcite.

Guano – An accumulation of bats and birds faecal products, often partly mineralized, including rock fragments, animal skeletal material and products of reactions between excretions and rock.

Helictite – A speleothem, which at one or more stages of its growth changes its axis from the vertical to give a curving or angular form.

Homoclinal relief – A long asymmetric ridge where the less steep flank has the same dip as the rock layers.

Hydrographic basin – A portion of a territory where the rainfall waters are drained by a single stream.

Hypogean – Concerning the subterranean environment.

Karst – The physical and chemical processes which lead to the formation of interconnected solution voids underground. A territory usually characterized by sinkholes, sinking streams, closed depressions, subterranean drainage, and caves. The name derives from the geograph-

ic name of a region shared by Italy and Slovenia.
Limestone – A sedimentary rock formed by calcite (calcium carbonate, $CaCO_3$).

Marls – A sedimentary rock formed by calcite and clay for more than 35%.

Metamorphic basement – A mass of rock laying below a sedimentary sequence made up of older and deformed rocks.

Meteorology – The study of the dynamics of the lowest part of the atmosphere.

Migalomorph – A group of large size spiders.

Mudstone – A sedimentary rock formed by grains ranging from 40 μm to 0.2 mm.

Phreatic – Referring to the zone where voids in the rock are completely filled with water.

Pleistocene – A geologic era starting 1.8 million years ago and finished about 8,000 years ago.

Rockpile - A heap of blocks in a cave, roughly conical or part-conical in shape.

Sandstone – A sedimentary rock formed by cemented sand, usually silicatic.

Scutigerimorph – A group of arthropods commonly named Centipedes.

Shaft – A vertical cavity much deeper than broad.

Sinkhole – Hollow in limestone, ranging in diameter from a few meters up to a kilometre and in depth from a few to several hundred meters, usually formed by the collapse of underlain rock.

Speleothem – A secondary mineral deposit formed in caves, most commonly calcite.

Stalactite – A speleothem hanging downwards from a roof or wall, of cylindrical or conical form, usually with a central hollow tube.
Stalagmite – A speleothem grown vertically upwards from a cave floor and formed by precipitation from drips.

Sump – A waterfilled part of a cave.

Survey – In caving, the measurement of directions and distances between survey points and cave details, and the plotting of cave plans and sections from these measurements either graphically or after computation of co-ordinates.

Swallow hole – A place where water disappears underground in a limestone region. A swallow hole generally implies water loss in a closed depression or blind valley.

Thermal water – Water that has a temperature at least 4 °C higher than the local mean temperature of the atmosphere at ground level.

Through-cave – A cave which may be followed from entrance to exit along the course of a stream or along a passage which formerly carried a stream.

Trophic energy – The energy provided by the food chain.

Troglobite – A cavernicole animal unable to live outside the cave environment.

Troglomorphic – A morphological character due to the adaptation deriving from living permanently in a cave.

Tunnel – A nearly horizontal cave open at both ends, fairly straight and uniform in cross-section.

Vadose – Concerning water flowing in free-surface streams in caves.

Water level notch – A long horizontal incision formed by corrosion and corresponding to the free face of a water body.

Weathering – The physical and chemical processes leading a rock to turn soft and subject to erosion processes.

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The River of Swallows
A brief guide to the environmental features of the Puerto Princesa Underground River - Philippines

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Butterflies are a usual presence in the Saint Paul forest

The City of Puerto Princesa

Anthony L. Abaya: President Natural Wonders Tourism Foundation Philippines Inc.

Sustainable development: "*a kind of development that tries to meet the needs of the present generation without compromising the ability of the succeeding generations to meet their own needs*."

In Puerto Princesa City (PPC), sustainable development became the preferred developmental model in 1992 at the start of Mayor Edward Hagedorn's administration, consistent with Agenda 21. A three-pronged approach was followed: protect what is there, rehabilitate what was destroyed and plan for intelligent utilization of the city's terrestrial and marine resources.

To protect the forests and seas, the local government established the multi-awarded Bantay (Watch) PPC Program with two components: (1) Bantay Gubat (Forest Watch), tasked to protect, conserve and rehabilitate forest resources; and, (2) Bantay Dagat (Bay Watch), tasked to protect and conserve marine ecology, by waging a no-nonsense drive against all forms of illegal fishing: dynamite, trawl or cyanide, the most pernicious and most difficult to control because it is hardly noticeable yet most profitable due to the high demand for live fish. To address this, a local ordinance banned shipment of live fish and lobsters - the catching of which caused widespread use of sodium cyanide.

To rehabilitate denuded forest lands, PPC embarked on a massive reforestation program. 'Pista Y Ang Kagueban' (Feast of the Forest), mobilized and motivated thousands of people from all walks of life resulting in nearly 2 million newly-planted trees in over 300 reforested hectares. Importantly, it inculcated the right attitude among residents, empowering them toward forest conservation. This resulted in increasing forest cover by as much as 2,088 hectares over a period of only six years (1992 to 1998)!

To rehabilitate mangrove areas, PPC launched 'Love Affair with Nature', a mangrove-reforestation festivity resulting in the planting of over 46,000 mangrove seedlings, reforesting about 40 hectares of mangrove areas. Celebrated on Valentine's Day, this unique program, offering a free wedding on the condition that newly-weds immediately plant seedlings dressed in their wedding regalia, captured the hearts and minds of many!

For its clean and green campaign, PPC launched the 'Oplan Linis' Program or Operation Clean-up, aimed at cleaning PPC's 'physical' surroundings while changing the attitude of residents. Value formation, through massive information and education campaigns, stressed the importance not only of a clean and balanced environment but also of a balanced existence involving life's spiritual, moral, and psychological dimensions. Following strict enforcement of PPC's anti-littering ordinance, the attitudinal transformation succeeded in getting residents to watch over their own surroundings.

PPC did not overlook the basic needs of its residents by providing informal settlers with homes, farmers with carabaos and tractors, fishermen with fishing gear, teachers and students with decent and comfortable classrooms, the urban poor with livelihood, and rural folks, in far-flung areas, with satellite hospitals. And, with more mobility, communication facilities and performance-based incentives, PPC's police force was awarded 'Best Police Station', ensuring a strong sense of peace and order to residents and tourists who plan to visit PPC, known now as the 'City in the Forest'.

Not surprisingly, with 70% forest cover and eight times more CO_2 removal versus emissions, Puerto Princesa has been declared the First Carbon Neutral City in the Philippines, possibly in Asia, a true model for sustainable development!

On the western coast of Palawan a karst mountain conceals an incredible natural treasure: the Puerto Princesa Underground River. A national park since 1971, it was later declared a National Geological Monument and included in the World Heritage List of Unesco. Recently, it was elected among the New 7 Wonders of Nature.
Among the unique features of this underground world, which you will discover in the following pages, the ecological approach to the cave is probably the most amazing one: the Puerto Princesa Underground River is one of the most visited caves in the world and, at the same time, the least damaged. This is absolutely exceptional, and represents the true point of force of this tourist site; in a world led by mere economic interests, the international community will never thank enough the authorities and the park personnel for this farsighted policy.
While entering the cave, every visitor feels the same powerful, unique feelings of the first explorers. The total length of the cave is over 30 km; but, due to technical difficulties or environmental sensitiveness, most of it may not become reachable by tourists.
This book represents an opportunity to communicate, by words and images, the fascination of this secret world.

Hon. Luca Fornari
Ambassador, Republic of Italy

The Puerto Princesa Underground River explorations by the La Venta group of scientists prove, without doubt, that this entire river cave system is so rich of biodiversity and historicity that one cannot help but marvel at its unique features. This book *"The River of Swallows"*, detailing La Venta's findings, will allow readers to explore the inner chambers of this amazing natural heritage that is a "must see" for all who wish to appreciate what Mother Nature has created over millions of years of geologic evolution.

Ambassador Alfredo Yao
President, Zest Air, Chairman Zesto Group of Companies

After visiting the Puerto Princesa Underground River cave, many tourists have expressed their feelings with these words: breathtaking, unimaginable, a once-in-a-lifetime experience, unique and one of God's best creations. For tourists seeking a different experience, away from the brick and mortar urban jungle, the visit to PPUR will be worth the trip. Either before or after the trip, the book *"The River of Swallows"* will help visitors appreciate the natural beauty of this UNESCO world heritage site as seen by the scientists who explored, studied and unearthed discoveries we would otherwise not have known nor seen.

Dr. Avignor Abelson
PhD, Marine Scientist/Professor, Tel Aviv University

The best way to experience the awesome features of the Puerto Princesa Underground River is to join La Venta's explorations deep into the cave's various chambers and tributaries where you will hear the symphony of sounds of millions of bats, swallows and other living creatures and share with them one of the most balanced ecological environments inside an entire karstic or cave system. *"The River of Swallows"* gives readers a chance to go through a virtual exploration with La Venta who now reveal and share their well-studied scientific discoveries, breath-taking panoramic pictures of the inner chambers tourists will not normally get to see and detailed maps of the cave system.

Mrs. Rebecca Labit
Tourism Director, Puerto Princesa City

Up until the La Venta group explored the Puerto Princesa Underground River even locals did not fully appreciate the significance and importance of their scientific findings. Now, with the book *"The River of Swallows"*, the self-sustaining environment of the entire cave system can be preserved while one travels-through, imagines and feels its inner chambers. This book will take you through La Venta's cave explorations as if you were part of it! So sit back, enjoy reading it and witness the astounding biological and geological wonders of the cave. Enjoy your visit to the PPUR, the centerpiece of our country's top flagship tourist destinations in the cleanest, greenest and most environmentally friendly undiscovered paradise dubbed as a City in a Forest. Mabuhay!

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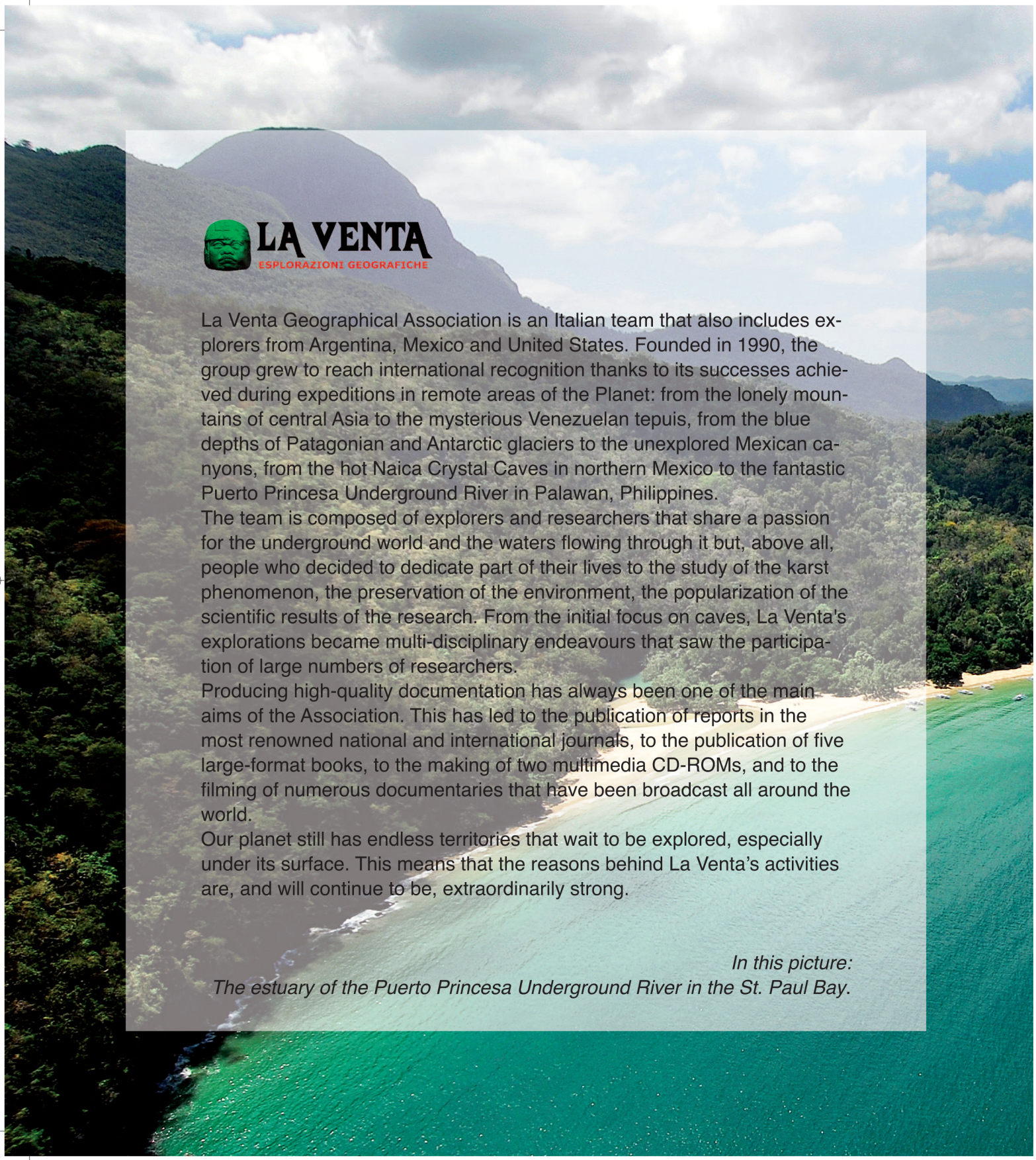

LA VENTA
ESPLORAZIONI GEOGRAFICHE

La Venta Geographical Association is an Italian team that also includes explorers from Argentina, Mexico and United States. Founded in 1990, the group grew to reach international recognition thanks to its successes achieved during expeditions in remote areas of the Planet: from the lonely mountains of central Asia to the mysterious Venezuelan tepuis, from the blue depths of Patagonian and Antarctic glaciers to the unexplored Mexican canyons, from the hot Naica Crystal Caves in northern Mexico to the fantastic Puerto Princesa Underground River in Palawan, Philippines.
The team is composed of explorers and researchers that share a passion for the underground world and the waters flowing through it but, above all, people who decided to dedicate part of their lives to the study of the karst phenomenon, the preservation of the environment, the popularization of the scientific results of the research. From the initial focus on caves, La Venta's explorations became multi-disciplinary endeavours that saw the participation of large numbers of researchers.
Producing high-quality documentation has always been one of the main aims of the Association. This has led to the publication of reports in the most renowned national and international journals, to the publication of five large-format books, to the making of two multimedia CD-ROMs, and to the filming of numerous documentaries that have been broadcast all around the world.
Our planet still has endless territories that wait to be explored, especially under its surface. This means that the reasons behind La Venta's activities are, and will continue to be, extraordinarily strong.

In this picture:
The estuary of the Puerto Princesa Underground River in the St. Paul Bay.