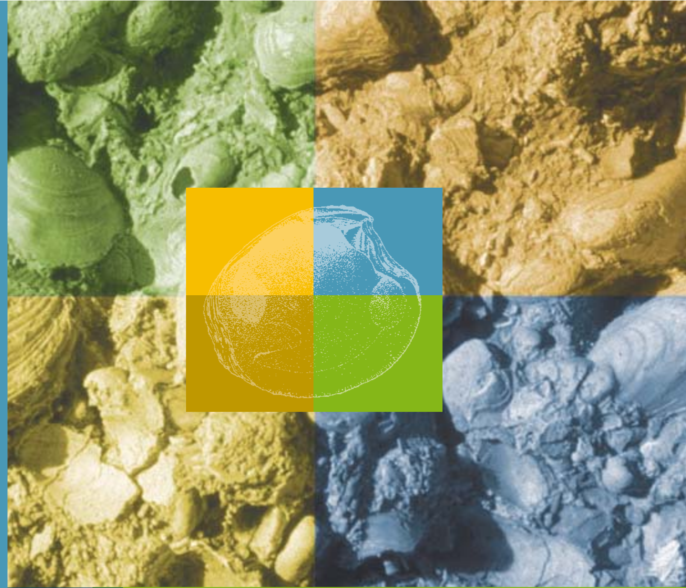
Geology of the Arid Zone of Almería

South East Spain



An educational field guide

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South East Spain

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During recent decades, the Province of Almería has developed as one of the more economically dynamic regions of Andalucía and Spain. Its exceptional environmental conditions due to a favourable geographical situation, and the enterprising character of its people, have made the blossoming prosperity and rapid consolidation of one of the most vigorous and technologically advanced horticultural zones in Europe possible. However, through time, this shining development has come to have a negative bearing on a historical problem in Almería: the scarcity of hydrological resources. In reality the hydrological demands for agricultural use considerably exceed the natural resources that are available, so that as a consequence, it has motivated a growing social sensitivity and demands for solutions to this problem.

This situation has required, on the basis of their competency, the intervention of the Medio Ambiente (Environmental Agency), which through the public company Aguas de la Cuenca Sur S.A. (ACUSUR), has put an ambitious plan of action into practise: the Global Plan of Priority Hydrological Action in Almería Province, known as Almería Plan, whose work, is declared to be of general state interest. This plan has meeting the demands for water of the agricultural organisations in the Almerían coastal zone as the main objective.

Part of this work, on the other hand, has been the need to achieve protection of a region with exceptional ecological and environmental value, at times not fully recognised amongst its own population. Indeed, through strict application of the criteria developed by the European Union in its Strategy for the Preservation of Biodiversity, the Province of Almería, and especially its semi-arid zones, are declared to be one of the regions of greatest environmental and ecological importance in Europe. The presence of unique habitats, the biological diversity that provides a wealth of species, turns the east coast of Almería into a veritable "Natural Wonder" in the context of continental Europe. To all this can be added the exceptional geological value placed on these arid landscapes. All of these conditions mean that Protected Natural Spaces have already been declared and proposed as places of community interest, and these occupy a considerable area of Almería. By European law, the Spanish government must guarantee their conservation.

In order for the partly unavoidable work of the Almería Plan to go through in these precious spaces, both the Junta de Andalucía (provincial government) and the Medio Ambiente (environmental agency), given their respective environmental concerns, decided to maximise the methods of environmental protection. All joint work has been subjected to rigorous controls and has employed a significant use of correctional means, whose aim is to reduce the extent of the possible environmental impact that work generates in the construction phase.

In a complementary fashion, several administrations had agreed to fulfill the European Habitat Directive, putting into place a broad program of compensatory measures. In this case the ultimate aim is contributing to an improvement in the global quality of the natural environment of these regions that were affected by the management of new hydrological resources, but also with the purpose of spreading an awareness amongst the inhabitants of these regions that everyone must keep a vigil and act in a responsible manner in order to conserve the environment.

The volume that is presented is framed in this context. A publication that we hope will contribute to drawing the Almerían population closer to the exceptional qualities of the natural environment which surrounds them. A recognition essential for establishing the basis of respectful relationship, that will make both the conservation and sustainable use of this noble region a possibility.

Teófilo García Buendía
Manging Director of ACUSUR

Fuensanta Coves Botella
Director of the Medio Ambiente

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PROLOGUE

The arid landscapes of Almería are well known amongst professors of geology, and other taught subjects related to the teaching of earth sciences, of an astonishingly high number of European universities, who appreciate it and use it as a huge natural laboratory to carry out practical field investigation. This has been due to two special features, an extraordinary geological record within its sedimentary basins and the high quality of outcrop exposure.

The geology of this region has, in fact, inspired an enormous scientific literature produced at the highest level. However, up until now publications of a more informative tone that seek to focus their efforts on the general educational potential of this exceptional geological landscape, have not existed.

This has been the objective of this work, to deal with this singularly important geological region with a broad vision in a manner that is more widely informative. Within this volume, three itineraries are put forward, each one of which connects a series of field stops where it is possible to observe or interpret several of the most outstanding geological features in Almería Province. These features are of great importance for understanding the origin and evolution of the geological landscape in Almería; a history peppered with events so extraordinary as the formation of the volcanic archipelago of Cabo de Gata, the desiccation of the Mediterranean Sea or the colonisation of the coastline by tropical coral reefs.

The guide aims to be a product that is simple to use. On one hand it is intended for self-interpretation, or interpretation without the assistance of a guide or teaching professional, at the higher end of secondary education, the university level, for different disciplines related to the teaching of earth and environmental sciences. On the other hand, it is a didactic guide to support the teaching professional, that clearly "translates" information, so that it can be adapted to the most suitable pedagogical level each time.

It has been structured into four large chapters, an initial one of introductory character, and three more corresponding to each of the three sedimentary basins that might be visited. These three chapters each consist of a general part, in which basic concepts required in order to understand the phenomena that are interpreted in the field locations of the itinerary area explained, folowed by a detailed description of the proposed itinerary.

The itineraries are can be completed within the three most emblematic Natural Protected Spaces in eastern Almería and the immediate surrounding area: the Cabo de Gata-Níjar Natural Park, the Gypsum Karst Natural Park of Sorbas and the Tabernas Desert Natural Park. These are places where the didactic use of the guide for environmental purposes will arise, as well as it being the first, basic line of evidence in management material used by the public. It is hoped that in this sense the guide can be easily used and will increase the environmental understanding of the population visiting these emblematic Natural Spaces.

Miguel Villalobos Megía
Guide Co-ordinator

How to use this guide

THE COLOURS IN THE GUIDE

This guide is structured in various sections that can be identified by a colour code in the lower and upper right corners of each page.

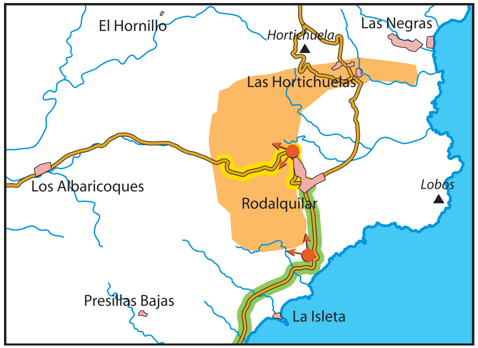
The colours correspond as follows:

	Introduction
	The Almería-Níjar Basin
	Didactic Itinerary of the Almería-Níjar Basin
	The Sorbas Basin
	Didactic Itinerary of the Sorbas Basin
	The Tabernas Basin
	Didactic Itinerary of the Tabernas Basin

SYMBOLS AND COLOURS OF LOCATION MAPS FOR POINT OF INTEREST

Location maps for points of interest are found in the didactic itinerary sections. These are located in a box in the upper right corner of the page. The full page maps that appear at the beginning of each chapter have an additional explicative legend.

The symbols and colours correspond as follows:



Foot access

Vehicular access

Observation and stopping point

Area of interest for observation

INTRODUCTION. The Geological Timescale and some basic geological principles

Juan C. Braga - José M. Martín

There is a series of basic principles that one needs to understand prior to setting out on any explanation about the geology of a region:

- The geography and landscape of a region are always changing. The mountains and valleys that surround us or the position of the coastline today have not always been as we know them now, now, neither have these features always been there. The land that we walk on, in the majority of cases, has risen up from the depths of an ancient sea, and the distribution of land and sea will change through time.

- These changes result from complex geological processes: sediments that are transformed into new rocks and erosion of rocks that already exist into sediments; uplift or emergence of land areas, with the consequent retreat of the sea, and flooding of other areas, that are invaded by seas and oceans, where accumulation of sediment starts again that will later be transformed into other rocks, followed by renewed emergence and further destruction, etc.

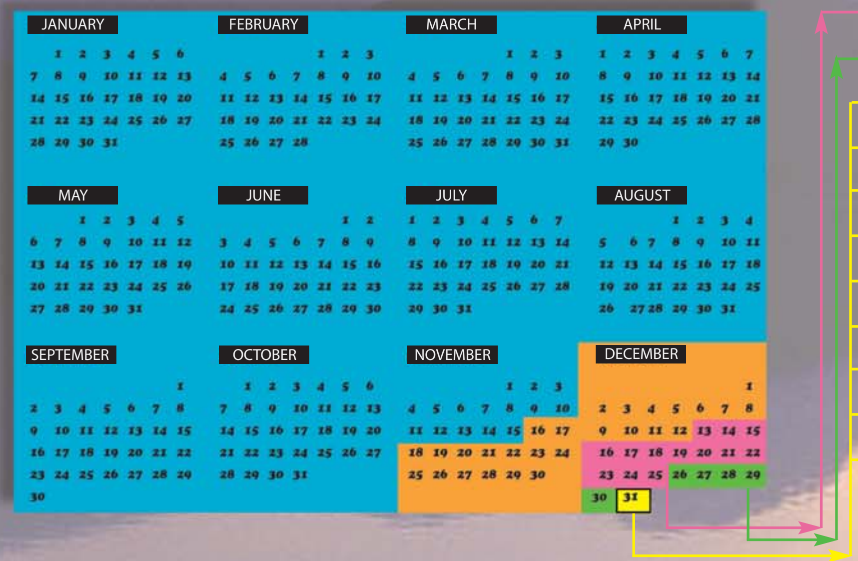
- By studying the internal structure and composition of rocks, their age (that should be measured in millions of years) and the way that they are distributed in a region, geologists can reconstruct the way in which the landscape and geography of the region has changed, where the coastline was situated at different times, where there was a volcano, when the mountains were uplifted that are emerged now, etc. This reconstruction is not simple and requires the accumulation of much knowledge from very distinctive specialist fields within geology. However, once recognised, even with provisional status, such that our understanding will improve with time, it is converted into a story that can be entertained.

- All of these geological processes, without exception, are extraordinarily slow from a human perspective. The duration, the pace, of geological processes is counted in millions of years. The pre-history and history of humans has been instantaneous in comparison with the long history of our planet that began at least 4,600 million years ago.

THE GEOLOGICAL YEAR

If we compressed all of the known geological time of our planet, some 4,600 million years, into a natural year of only 365 days, we would observe:

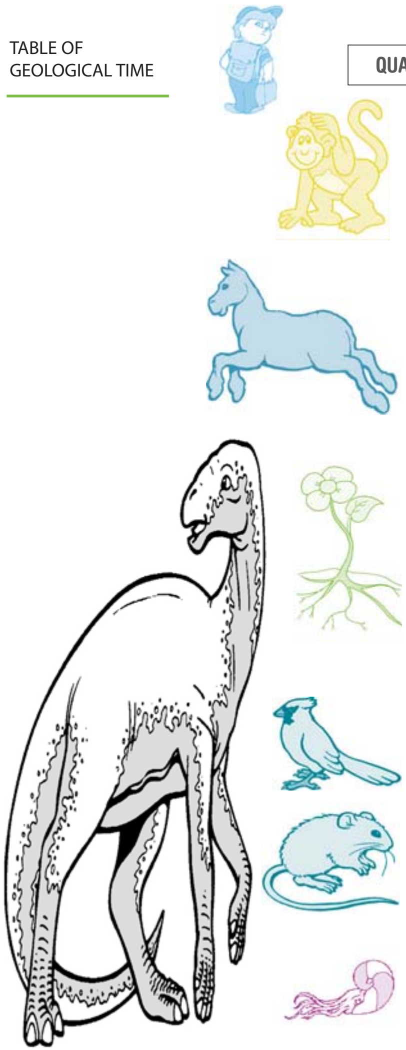
- That through the Precambrian, about which we know virtually nothing, save that it gave shelter to practically no life, only extremely primitive forms lived through until the 16th of November, almost a complete year.
- That the Palaeozoic era, in which distinct forms of life developed and diversified, reached up to the 13th of December.
- That the Mesozoic era, that of the large reptiles, lived through to the 26th of December, the time at which, for example, the great dinosaurs became extinct.
- That the Tertiary era, with the development of the majority of mammals, reached up to the 30th of December. The first primates did not appear until the 29th of December.
- That the Quaternary era, with the appearance of our more immediate relatives, occupied only part of the 31st of December. In fact, only towards the last minute of the year did Homo sapiens sapiens, ourselves, appear.



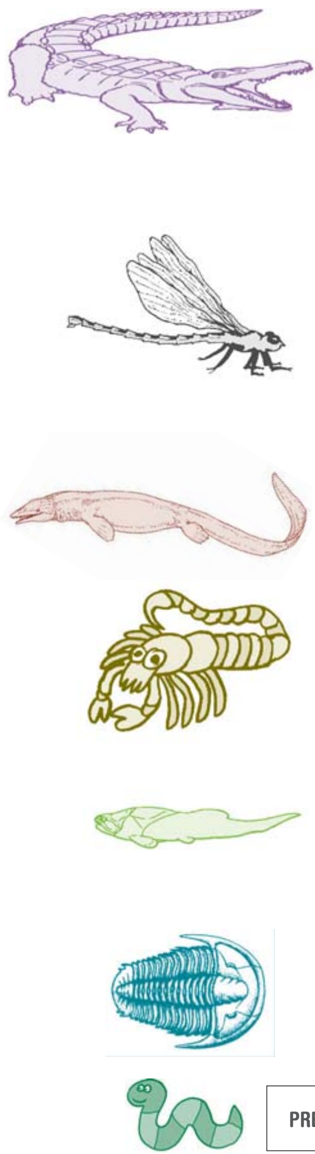
20 : 19 : 00.00	Sudden extinction of large reptiles (65 m.a.)
19 : 99 : 33.91	Appearance of the first primates (40 m.a.)
18 : 17 : 19.19	Appearance of Homo erectus (3 m.a.)
21 : 08 : 58.52	Appearance of Homo habilis (1.5 m.a.)
23 : 52 : 00.11	Appearance of Homo sapiens neanderthalensis (70,000 a.)
23 : 58 : 00.09	Appearance of Homo sapiens sapiens (35,000 a.)
23 : 59 : 48.28	Start of the Christian era (2,000 a.)
23 : 59 : 49.02	Fall of the Roman Empire (1,600 a.)
23 : 59 : 58.57	Discovery of America (500 a.)
23 : 59 : 58.89	French Revolution (200 a.)
29 : 59 : 59.30	Start of the industrial revolution (100 a.)
00 : 00 : 00.48	Average duration of human life (70 a.)

- Precambrian
- Palaeozoic era
- Mesozoic era
- Tertiary era
- Quaternary era

TABLE OF GEOLOGICAL TIME



Era	Period		Epoch / Series	Millions of years
QUATERNARY			Holocene	0.01
			Pleistocene	1.8
CENOZOIC/TERTIARY	NEOGENE		Pliocene	5.3
			Miocene	23.5
	PALAEOGENE		Oligocene	34
			Eocene	53
			Palaeocene	65
MESOZOIC	CRETACEOUS		Upper	96
			Lower	135
	JURASSIC		Upper MALM	154
			Middle DOGGER	180
			Lower LÍAS	205
	TRIASSIC		Upper	230
			Middle	245
			Lower	250



Era	Period	Series	Millions of years
			250
PALAEOZOIC	PERMIAN	Upper	272
		Lower	300
	CARBONIFEROUS	Upper	325
		Lower	360
	DEVONIAN	Upper	375
		Middle	385
		Lower	410
	SILURIAN	Upper	425
		Lower	435
	ORDOVICIAN	Upper	455
		Middle	470
		Lower	500
	CAMBRIAN	Upper	
		Middle	
		Lower	540
PRECAMBRIAN	Proterozoic		2.500
	Archean		4.600

MILLIONS OF YEARS

Largescale Geological Units in Andalucia

Juan C. Braga - José M. Martín

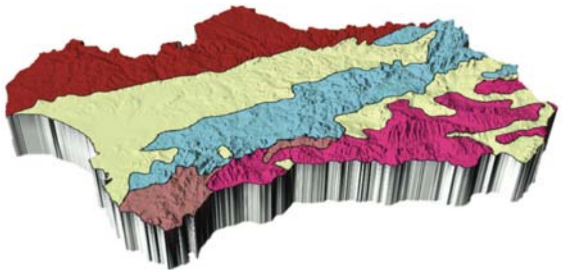
In Andalucía three largescale geological units may be differentiated:

1. **The Iberian Massif or Hercynian Massif** of the Meseta outcrops to the north of Guadalquivir and forms the mountainous lineament of Sierra Morena. It consists mainly of strongly folded and deformed, metamorphic (schists, quartzites and limestone marbles) and igneous (granites and similar) rocks, of very ancient age formed between more than 550 and 250 million years ago (Precambrian and Palaeozoic). They form part of the old Iberian continent whose coasts were covered by the sea that occupied the greater part of the modern Andalucían territory.

2. **The Betic Cordillera** constitutes the second largescale unit, and the first formed from extension. This much younger, large alpine mountain chain, had already started uplifting approximately 25 million years ago (in the Lower Miocene) and continues uplifting today. It runs from Cádiz in the west to Almería in the east, extending to Murcia, Valencia and the Balearics. At the latitude of the Rock of Gibraltar it is inflexed producing a more or less symmetrical structure along the north of Africa. Internally, a complex structure is present as a consequence of the piling up of rocks through thrusting during the slow collision of the Alboran Plate up and onto the Iberian Plate, and later uplifting. The primary internal structure is divided into a younger External Zone, nearer to the Iberian Massif, and an older Internal Zone, closer to the modern littoral zone. Within the latter, several stacked tectonic units can be recognised, in turn, essentially from the bottom towards the top they include the Nevado Filábride Complex, Alpujárride Complex and Maláguide Complex.

3. **The Neogene Basins** or depressions overall comprise the third largescale unit in Andalucía. During the emergence of the Betic Cordillera there were times in which the sea extensively covered depressed regions that are emerged today, such as the Guadalquivir Basin and other intermontane basins like Guadix-Baza, Tabernas, Sorbas or Almería-Níjar. They are young sediments, less than 25 million years old, characterised by having a very limited degree of deformation, such that they hold a great value for studying the recent geological history in this western sector of the Mediterranean.

GEOLOGICAL UNITS



Largescale Geological Units in the arid region of SE Almeria

Juan C. Braga - José M. Martín

Almería is located, from a geological point of view, at the southeastern extreme of the Betic Cordillera. The old Betic relieves (Sierra de Gádor, Filabres, Alhamilla, Cabrera, etc.) constitute the margin and the basement of a series of much younger intermontane marine basins (Tabernas, Sorbas, Almería), that were filled with sediments simultaneously with the emergence of the Betic Cordillera structure. Meanwhile, in the vicinity of Cabo de Gata, numerous similarly recent volcanoe rumbled in full activity. These three geological terrains are clearly distinguishable today in the surrounding Almerían desert landscape.

Characteristic flaggy appearance (schistosity) of dark micaschists in the core of the Nevado- Filábride Complex.

Quartzite crests in the Nevado- Filábride core of the Sierra Alhamilla (photo M. Villalobos).

THE BETIC SIERRAS

The core of the mountains in this region consists of very old rocks, some even around 550 million years old. They are grouped under the generic name of the Nevado-Filábride Complex (alluding to the fact that they make up a good part of the Sierra Nevada, and its eastern extension, the Sierra de los Filabres). They are mainly graphitic micaschists: display dark, yellowish and orange colours with a slaty appearance and a flaggy characteristic, that is to say, they are divided into well-defined, more or less irregular laminations. Quartzites which form rough crests and sharp cliffs, due to their better resistance to erosion, are also common.

Quartzites display dark, yellowish and orange colours, and also have a flaggy appearance, although poorly defined. Metamorphosed limestones and marbles are also found but to a lesser extent, such as those quarried in the Sierra de Macael. Locally rocks related to granite appear, known as gneiss. All of these arose from the transformation (metamorphism) of existing rocks that suffered elevated temperatures and pressures at great depth in the interior of the earth.

Skirting the core of the previously mentioned mountains another band appears, also consisting of very old rocks although somewhat younger than the former, that are grouped under the name of Alpujárride Complex (alluding to the fact that it extends from Alpujarra, where for one part it constitutes the southern flank of the Sierra Nevada, and for the other, the coastal chain: sierras de Lújar, Contraviesa, Gádor, etc.).

Typical purple colour of phyllites or 'Launas' in the material of the Alpujarride Complex (Photo, M. Villalobos).

Alpujarride limestone relief of the Sierra de Gador (Photo, M. Villalobos).

This strip mainly comprises two very distinct types of rock, easily recognisable in the field. One of these are schists, known in the region as 'Launa', which are slightly transformed clays, of vivid blue, red and glossy grey colours. Traditionally they have been used to make impermeable roof slates in the construction industry. The other rocks are limestones and dolomites, composed of calcium and magnesium carbonates, which produce white, grey or black escarpment relieves, for example, the north flank of the Sierra Cabrera, Sierra Alhamilla, the escarpments of Lucainena or Turillas, close to Níjar, or the many cliffs of the Sierra de Gador. All of these limestones and dolomites were formed at the bottom of a tropical sea more than 200 million years ago. Afterwards, in the same manner as the rest of the material from the Alpujarride complex, they suffered transformation (metamorphism) at elevated temperatures and pressures, which came about at great depth in the earth's interior.

Material from the old Betic mountains has suffered an intense deformation expressed as folds of distinct scales and fractures, in addition to their slaty characteristics (schistosity). In some places the rocks are literally destroyed, mashed up by fractures. They are also mineralised, and have historically been the object of exploitation to yield iron (Sierra Alhamilla), lead and silver (Sierra de Gador and Sierra Almagrera), and other minerals.

THE SIERRA DE CABO DE GATA

The Sierra de Cabo de Gata is an individual mountain range, different to the others, formed from volcanic rocks during two stages of volcanicity, one from approximately 14 to 10 million years ago and the other from 9 to 7.5 million years ago. In reality, they represent only a small percentage of rocks of this nature, constituting the bottom of the Alboran seafloor and extending to Melilla, outcropping discretely in the Isla de Alboran.

Detail of stratification in Alpujarride limestone rocks (Photo, M.Villalobos).

Volcanic rocks from this area formed a landscape of volcanoes, submarine or emergent, individual or grouped, to form small islands. These volcanic structures are recognisable in the terrain of Cabo de Gata, in many cases, where they are seen to form steep, more or less conical hills in the area: Los Frailes, Mesa de Roldan, Cerro de los Lobos, La Tortola, etc. Brecciated volcanic rocks (formed from fragments of different composition or aspect) are very abundant, resulting from diverse volcanic processes: differential cooling of distinct parts of lava flows, eruptions, nuee ardentes, avalanches down the sides of volcanoes, etc.

DEPRESSIONS OR *LOW-LYING AREAS*

The rocks that occupy the low-lying areas of the Almerían landscape, modern depressions such as the Almanzora Valley, Andarax Valley, Tabernas, Sorbas Basin, Campo de Níjar plain or El Poniente or El Poniente, consists of geologically young material, accumulated in the last 15 million years, while the Mediterranean Sea surrounded the mountains and the volcanoes of Cabo de Gata forming a small archipelago. The Betic mountains, and in general all of the Iberian Peninsula, were uplifted from the depths of the Mediterranean Sea.

In these marine inlets the products of sedimentary erosion of the emerged land accumulated: boulders, pebbles, gravel, sand and mud. Limestone rocks also formed from the accumulation of the remains of marine creatures. In a changing global climate, the region passed through cold and much warmer periods.

In the warm periods, the seawater temperature (in the western Mediterranean) was similar to those of the tropics today, in the order of 20º C, and coral reefs developed along the margins of islands and emerged lands. Theses coral reefs, like those of Purchena, Cariatiz, Nijar, Mesa Roldan, etc., are amongst the best fossil examples that exist in the world.

In colder periods, the western Mediterranean had a temperature similar to today, and limestones were formed from the remains of red algae, bryozoans, molluscs etc., like those occurring on the actual seafloor of the platform that encircles Cabo de Gata. These conditions, or yet colder ones, prevailed in the region from 5 million years ago.

Geological history and geographical evolution of SE Almeria

Juan C. Braga - José M. Martín

The Betic mountains (Nevado-Filabride and Alpujarride complexes) originated from collision of the African continent with Europe. The Betic rocks are formed from sediments deposited at the bottom of the sea hundreds of millions of years ago. These rocks were buried at many kilometres of depth (beneath other rocks), under such pressure and temperature that they were transformed, changing the appearance of the minerals that make them up (this process is known as metamorphism). Later, they slowly emerged. The structure of the Betic Cordillera was yet to be uplifted at different speeds according to the arrangement of blocks compartmentalised by large regional fractures.

The Sierra Nevada-Sierra de los Filabres block, for example, was the first to emerge from the sea, around 15 million years ago, and has stayed up since this time, as the most elevated relief in Andalucía and one of the most elevated in Spain and Europe. The bottom of the Alborán Sea is subsiding and extending, thanks to fractures through which volcanic material of Cabo de Gata was once extruded. Since emergence of the Sierra Nevada-Sierra de los Filabres, that still continue to be uplifted, the Sierra de la Estancias emerged from the sea around 9 million years ago.

Later, around 7 million years ago, the Sierra de Gádor and Sierra Alhamilla emerged. Although today they seem like high mountains to us, they are believed to be quite young in geological terms, and their rate of uplift on a human scale is very low, For example, the average velocity of uplift for the Sierra Alhamilla since emergence from the sea is less than 2 cm each year.

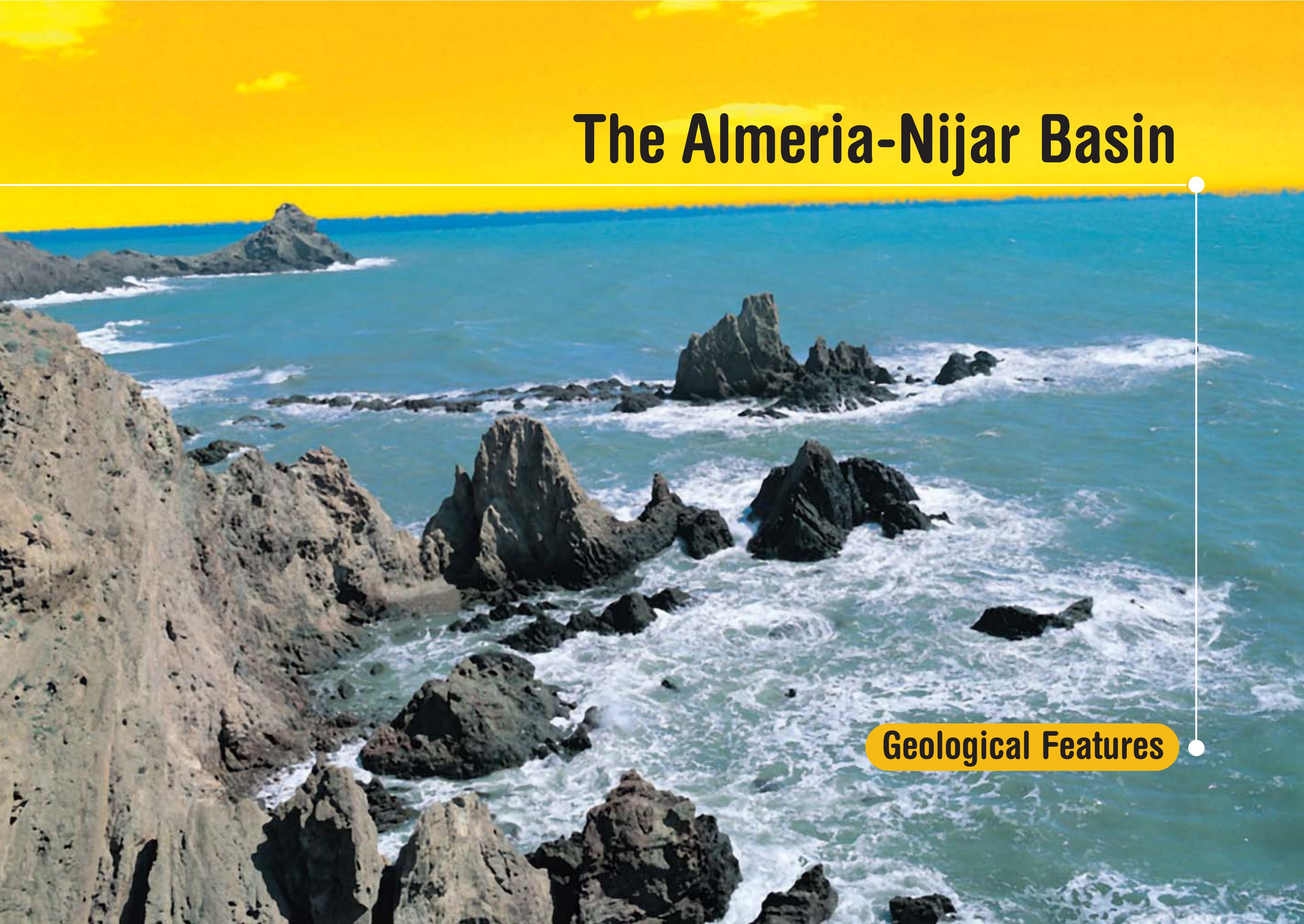
The last relief to emerge, which is for certain the youngest mountain range of the peninsula, is Sierra Cabrera that came out of the sea 5.5 million years ago.

During the past 2 million years, Almería, like the rest of the planet, has suffered from strong Quaternary climatic variations. In the glacial stages, the sea fell more than 100 metres from its present level and the climate was much colder. In the interglacial stages, as now, the sea was in a position similar to that of today, and the climatic conditions would also have been similar in character.

The process of marine retreat from these basins can also be seen in relation to the present-day geography, in that the interior depressions, those most removed from the modern Mediterranean, were the first to emerge, whilst those closest to the coast have been abandoned by the sea only recently from a geological point of view. For example, the high valley of Almanzora, above Albox, was vacated by the sea around 7 million years ago, however, the sea extended over land surrounding the Bay of Almería until just 100,000 years ago.

With the final retreat of the sea to its current position, for the moment, the impressive geological record for this area, accumulated over a period of 15 million years, is exhibited in Almería under exceptional conditions of preservation. It is an area of maximum educational and scientific value for studying and understanding the evolution of the Mediterranean and the formation of the Betic Cordillera over the past 15 million years.

The Almeria-Nijar Basin



Geological Features

Geological Features and Evolution

Juan C. Braga - José M. Martín

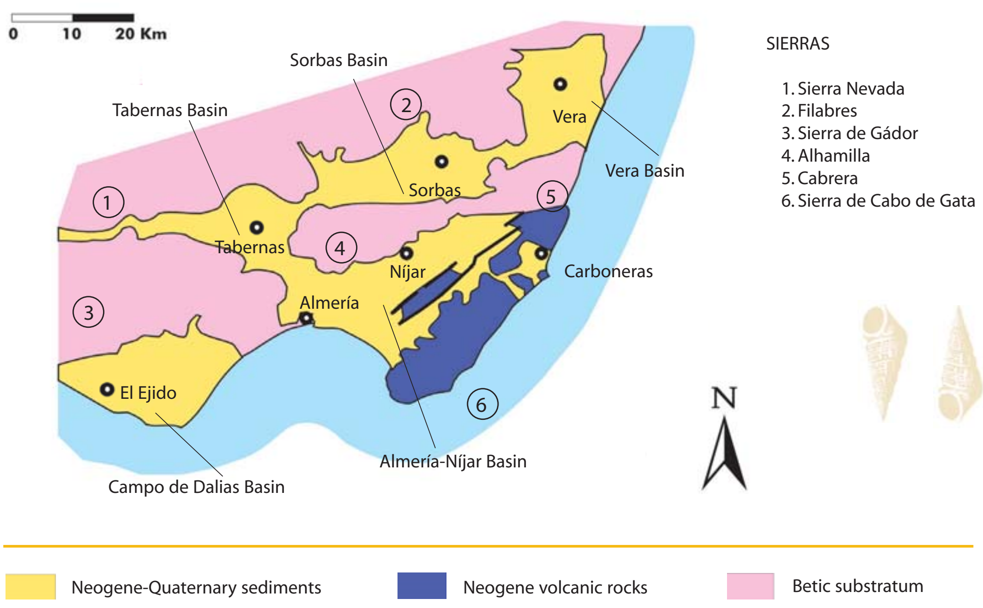
The Almería-Níjar Basin has been a small marine sedimentary trough since 15 million years ago, the time at which emergence of the relieves occurred, that today constitute the Sierra Nevada and the Sierra de los Filabres massifs, whose foothills were located at the coastline.

In this period, however, the Almería Basin was not individualised from the Sorbas and Tabernas basins. In this marine basin, sediments started to arrive from the dismantling of the emergent relieves through the fluvial network. Extensive submarine fans were generated on top of the marine platform, while the fully active volcanoes of Cabo de Gata were rumbling, probably fashioning a tropical volcanic archipelago.

It was much later, about 7 million years ago, when uplift of the Sierra de Gádor and Sierra Alhamilla caused the individualisation of the Almería-Níjar Basin, to the south of these same hills and between the emerged volcanic relieves of Cabo de Gata.

Sierra Cabrera emerged 5 million years ago, and it definitively separated the Sorbas and Vera basins.

GEOLOGICAL LOCATION OF THE ALMERIA-NIJAR BASIN



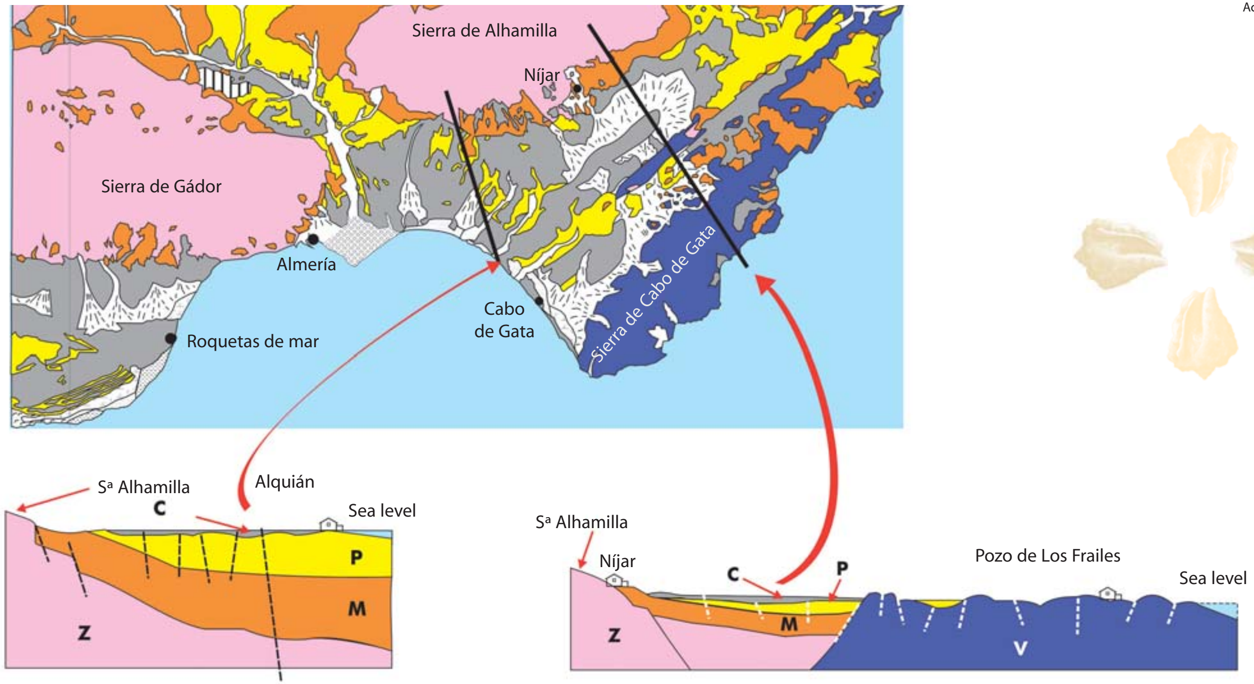
The Almería-Níjar Basin therefore included all of the current, low-lying land present between Sierra de Gádor, Sierra Alhamilla, Sierra Cabrera and the coastline, including the volcanic relieves of the Sierra de Cabo de Gata.

A region that had constituted a marine seafloor during the last 15 million years in which a sedimentary record has remained, with unsurpassed observable characteristics, exceptional for the understanding of evolution in the Mediterranean Basin at this time, and its geography, climate and ecology.

Geological Features and Evolution

SIMPLIFIED GEOLOGICAL MAP OF THE ALMERIA BASIN

According to Zazo and J. L. Goy



- **C** Old Quaternary terrain (Pleistocene: 1.8 Ma to 10,000 yrs)
- **P** Pliocene terrain (5.2 to 1.8 Ma)
- **M** Miocene terrain (23.7 to 5.2 Ma)
- **V** Miocene volcanic formations (15.7 to 7.9 Ma)
- **Z** Ancient basement

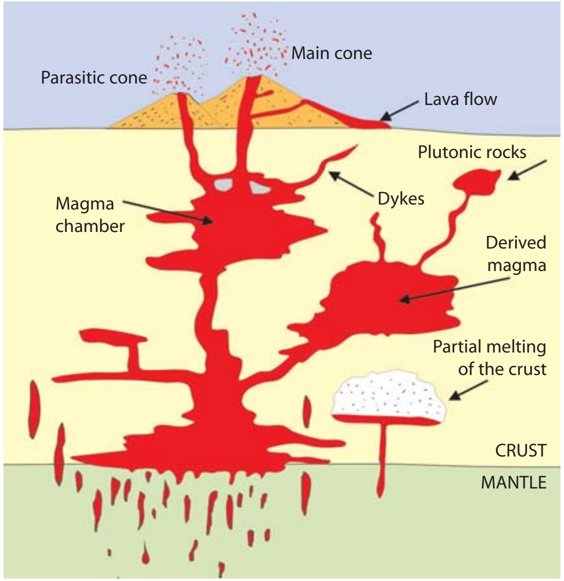
Recent Quaternary (Holocene) formations, from 10,000 years ago to present

- Fluvial deposits
- Alluvial fans
- Littoral barries and/or fringes
- Albuferas (saltpans)
- Travertines
- Deltas
- Dunefields

VOLCANIC EPISODES
Origin of magmatic processes and volcanic features

Juan M. Fernández

MAGMAS AND MAGMATIC ROCKS



MELTING OF PRIMARY MAGMAS

Magmas are formed through the partial melting and emplacement of rocks at high temperature in the interior of the Earth. They consist of a mixture of liquid, dissolved gases (water vapour and carbon dioxide) and minerals.

Magmas that come directly from the partial melting of rocks at depth are called primary magmas. Sometimes they reach the surface straight away, however, it is more common that they remain static at different levels within the mantle and the continental crust, forming magmatic chambers. In such a situation the magmas may partly crystallize, assimilate the country rock and suffer other modifications, the final result of which is a series of derived magmas of different compositions. This process is known as magmatic differentiation.

Magmas are generally less dense than the material within which they are forming, and, therefore, they tend to climb up through the mantle and continental crust, until they cool and crystallize, giving place to intrusive rocks.

Magmas that solidify slowly underneath the terrestrial surface form bodies of intrusive rocks. Cooling happens very slowly, so that the minerals may crystallise in an ideal manner, creating rocks with large-sized crystals such as granites.

When the magma reaches the surface, it gives way to volcanic or eruptive activity. The results are volcanic rocks and so-called volcanic features. Cooling is very rapid, so that the rocks do not crystallise well, forming a vitreous matrix or a very fine crystal size. Within this matrix a proportion of small minerals of larger size (phenocrysts) may be present, which had crystallised previously in the magma chamber.

At times, during its ascent, the magma is injected into fissures, forming dykes. These are also known as hypabyssal rocks.

Origin of magmatic processes and volcanic features

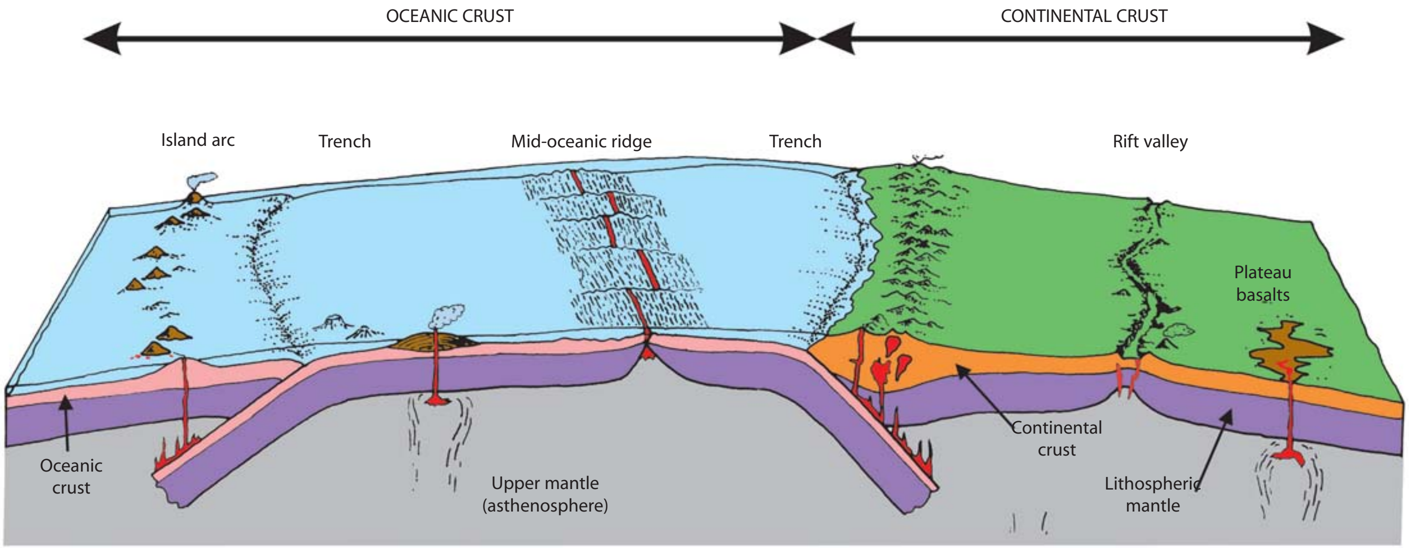
MAGMAS AND PLATE TECTONICS

Although there are a great variety of types and compositions of magmas, the three most important generic types are the basaltic group (or basic, 50% of silica), the siliceous group (or acid, 65 to 70% of silica), and the andesitic group (or intermediate) such as those of Cabo de Gata.

The origin of magma is related to the dynamics of the lithospheric plate margins: The majority of basaltic magmas originate through partial melting of the mantle in divergent plate boundaries (mid-oceanic ridges). Andesitic and siliceous magmas are generated in subduction zones by partial melting of both the oceanic plate and the continental crust.

The origin of Cabo de Gata volcanism is complex, and under discussion at present.

In whatever case, it is related with the orogenic process of crustal thickening in this area, the Alborán domain, due to the collision of the African and European plates; and afterwards their thinning through phenomena of extensional or transtensional character.



Origin of magmatic processes and volcanic features

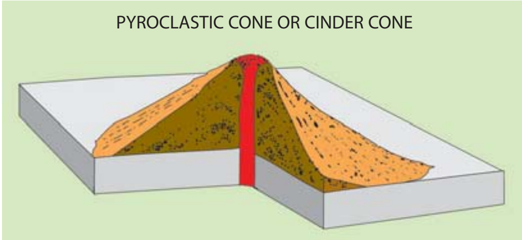
ACTIVITY AND VOLCANIC FEATURES

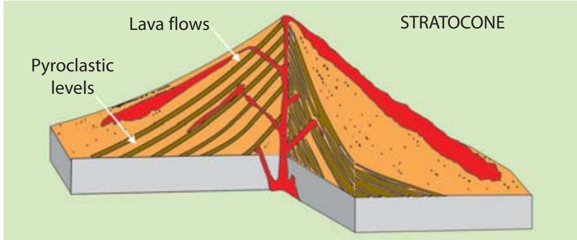
The type of eruption and the products resulting from volcanic activity depend, above all, on two important aspects: the viscosity of the lava, which determines fluidity, and the gas content of the lava.

Basaltic magmas, poor in silica, are fluid. At the surface they flow rapidly, forming lava flows that at times travel great distances (this type of volcanism is known as effusive). If the basaltic lava is rich in gas, it is released with ease by means of intermittent explosions, creating pyroclastic types of cone (also known as cinder cones). The alternation of lava flows and pyroclastic episodes fashions another type of volcanic edifice known as the Stratocone volcano.

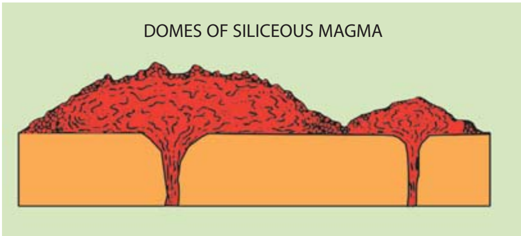
Acidic magmas, on the other hand, rich in silica, are much more viscous. Upon exiting onto the surface, they cannot flow easily, and form accumulations around the eruptive mouth (domes), or flow very slowly forming lava flows over short distances (this type of volcanism is called extrusive).

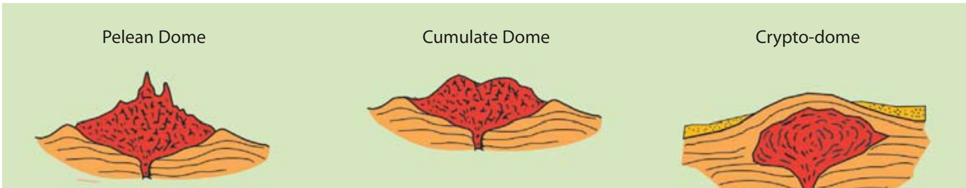
BASALTIC MAGMAS





ACIDIC MAGMAS





SOME TYPES OF DOME

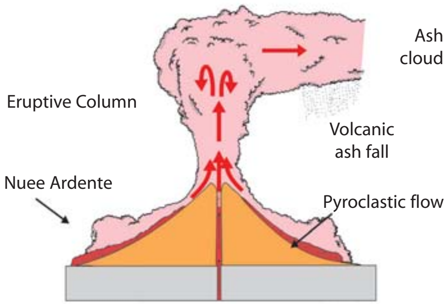
EXPLOSIVE VOLCANISM
PYROCLASTIC FLOWS

The high viscosity of lavas from acidic magmas means that on occasions gases cannot be easily liberated, accumulating as bubbles, and increasing their internal pressure until they are unleashed in enormous explosive phenomena that violently erupt huge volumes of semi-molten rock into the atmosphere.
The so-called pyroclastic flows are generated by this means, their solidification then produces rocks known as pyroclastics.
They can be of different types:

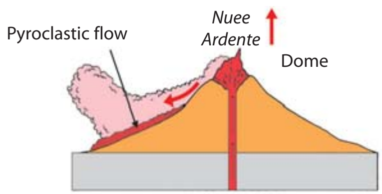
Ignimbrites
A mixture of very hot gas, ash and rock fragments is launched from the volcano in an eruptive column. The density of the mixture, greater than that of air, means that it falls rapidly, smothering the underlying hillside in the form of a covering flow comprising a glowing cloud of gas. They create rocks rich in ash and pumice.

Lithic Breccias or Agglomerates
The flow forms from the rupture, explosive or otherwise, of the summit of the volcano. Rock fragments that made up the actual dome dominate in this case.

IGNIMBRITES



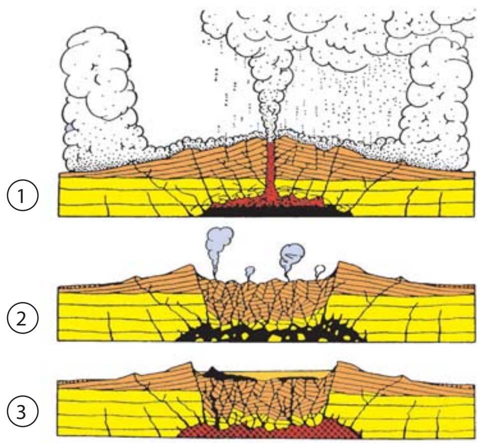
BRECCIAS AND AGGLOMERATES



CALDERAS

The largest and most explosive volcanic eruptions throw out tens and hundreds of cubic kilometres of magma onto the earth's surface. When too high a volume of magma is extruded from a magmatic chamber, the earth subsides or collapses into the vacated space, forming an enormous depression called a caldera. Some calderas can be more than 25 kilometres in diameter and several kilometres deep. When, after the formation of a caldera, the magmatic chamber receives new supplies from deeper zones, the interior of the caldera can return to a state of uplift, a phenomenon known as resurgence.
The calderas are one of the most dynamically active volcanic features and are frequently associated with earthquakes, thermal activity, geysers, hydrothermal waters etc.

FORMATION OF A VOLCANIC CALDERA



The Cabo de Gata Volcanic Complex

Juan M. Fernández

GEOLOGICAL CONTEXT AND AGE

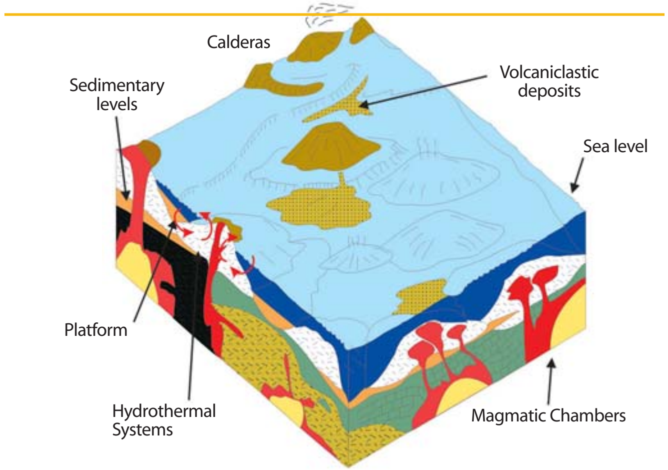
The Cabo de Gata volcanic complex is the largest-sized element of all the volcanic manifestations in SE Spain. It continues to expand beneath the Alboran Sea, and has been brought into its present position by the operation of the Carboneras-Serrata Fault. The greater part of volcanism in the Alboran basin is actually submerged. The volcanic structures of Cabo de Gata also indicate signs of having been generated, by and large, beneath the sea. Some of the oldest volcanic structures could have grown out of the sea sufficiently enough to reach the surface, forming islands of volcanic origin fringed by marine sedimentary platforms.

The age of the Cabo de Gata volcanic complex is known through the study of fossils present in sedimentary rocks associated with the volcanic elements and from dating with isotopes (mostly Potassium/Argon) in the volcanic rocks. Volcanic activity developed in a broad period that extends from around 14-15 to around 7.5 million years ago (that is to say, Middle and Upper Miocene). During this interval the volcanic activity occurred in various cycles. The better-known and conserved volcanic features are the most recent, produced between 9 and 7.5 million years ago.

The base of the volcanic complex outcrops at various points (Serrata de Níjar and Carboneras) and is formed of Betic basement rocks (carbonate rocks and phyllites of the Malaguide and Alpujarride complexes) and some marines sediments (marls) from the Lower-Middle Miocene. Towards the top, the volcanic activity is fossilised by marine sedimentary deposits of the terminal Miocene (Messinian reefs).

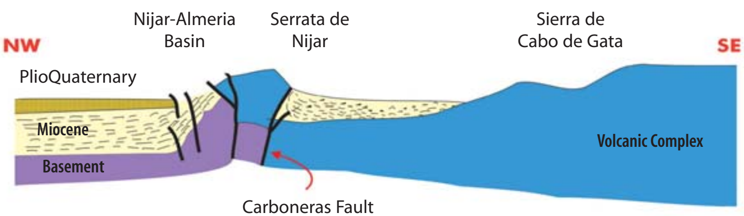
THE CABO DE GATA VOLCANIC COMPLEX WITHIN THE CONTEXT OF THE ALBORAN SEA

SUBMARINE VOLCANISM



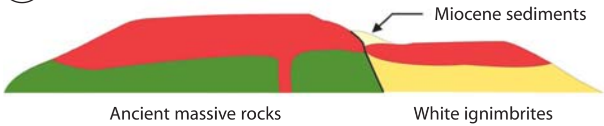
RELIEF FEATURES OF THE CABO DE GATA VOLCANIC COMPLEX

(A)

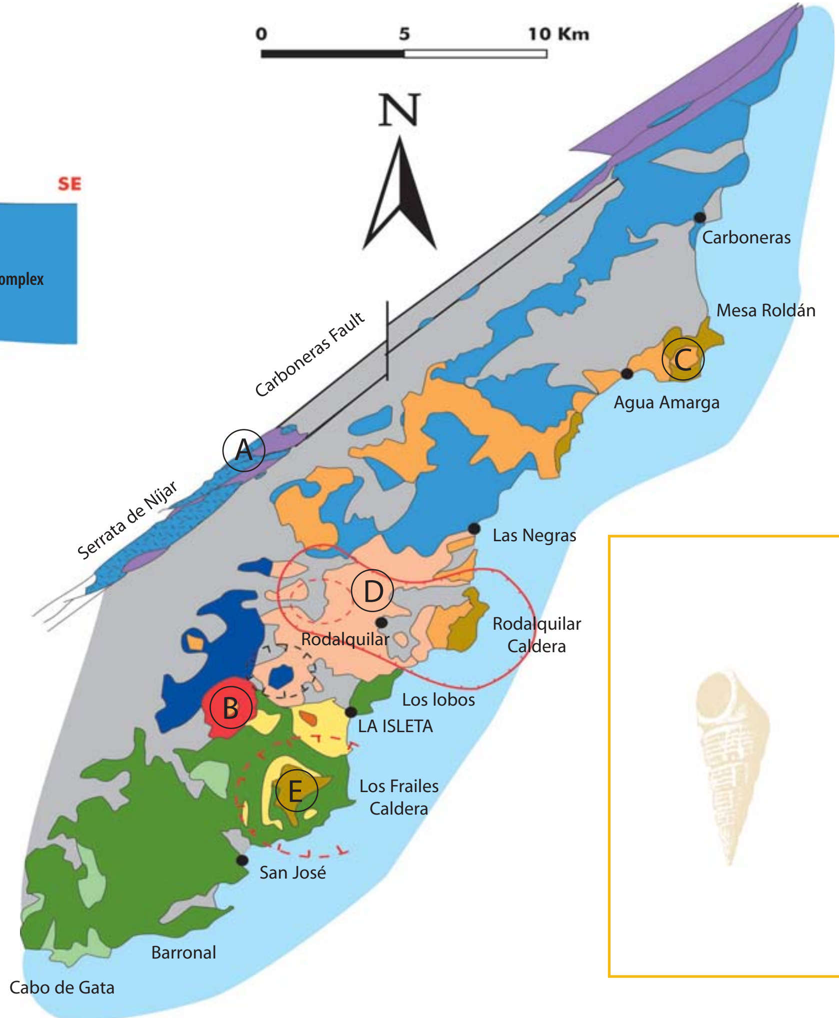


La Serrata de Nijar is a zone of volcanic origin, associated with the Carboneras Fault. The rocks, concealed beneath the sedimentary filling of the Campo de Níjar, have been uplifted and project outwards at the surface of La Serrata because they are caught up between different fractures in the fault zone.

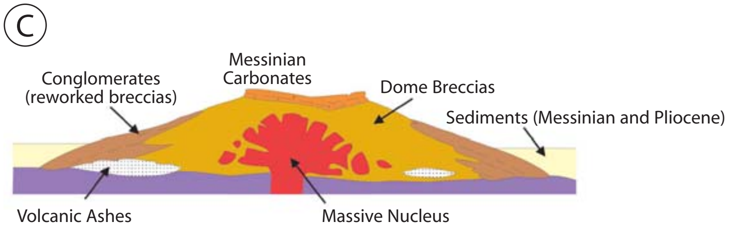
(B)



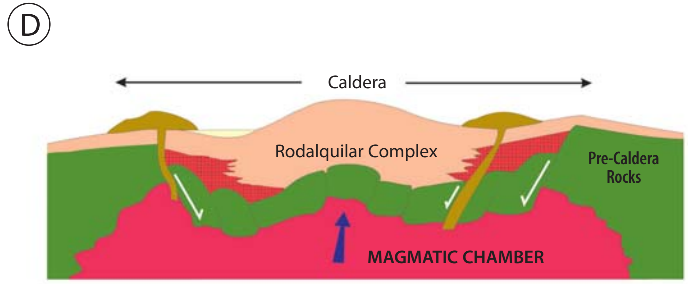
El Cerro de Garbanzal is a unique volcanic structure, almost circular in plan, formed by the extrusion of a massive dome-flow. The geometry of this type of structure is known in some places as fortified domes or 'tortas'. Quite eroded, it is preserved as a ceiling above marine sedimentary remains.



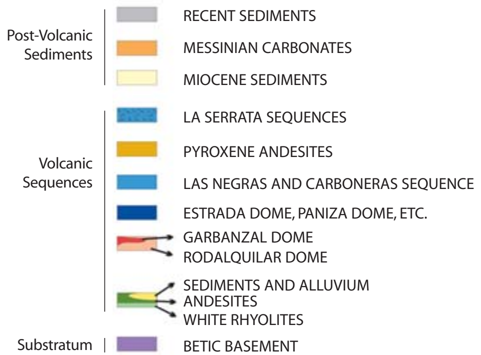
The Cabo de Gata Volcanic Complex

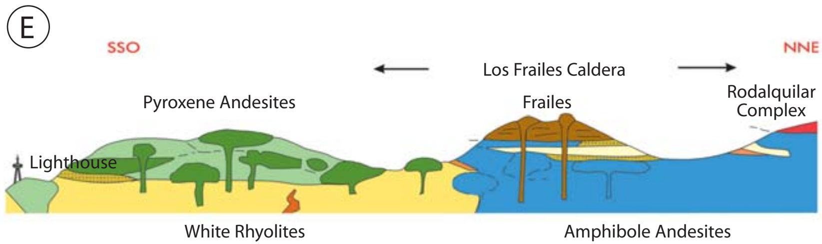


Mesa Roldan (and Los Lobos) are excellent examples of volcanic structures fossilised by marine sedimentary rocks and crowned by terminal Miocene coral reefs. It may be characterised by an andesitic lava dome, enclosed by fragmented rocks (dome breccias), produced by submarine eruptions with little or no explosiveness. Linked with the Los Frailes volcano, they are the most recent volcanic emissions in Cabo de Gata.



The Rodalquilar Caldera, one of the most notable volcanic features, was generated because of the collapse of the caldera floor into the underlying magma chamber in a series of highly explosive volcanic processes, producing the deposition of various pyroclastic rock units (ignimbrites). The later hydrothermal alteration of these rocks gave place to the characteristic mineral deposits of this area, especially gold.





The Los Frailes Volcano formed around 8 million years ago above older rocks (more than 10-12 ma) that extended towards the southern limit of the Sierra de Cabo de Gata. In this case, the volcanic activity did not give place to typical central volcanoes, but to an extensive landscape of more or less dispersed volcanic domes. Levels of fossiliferous marine sediments were deposited between the phases of eruption of the different domes that serve as guide levels. Additionally, they produced some highly explosive eruptive processes (ignimbrites), related to the collapse of calderas.

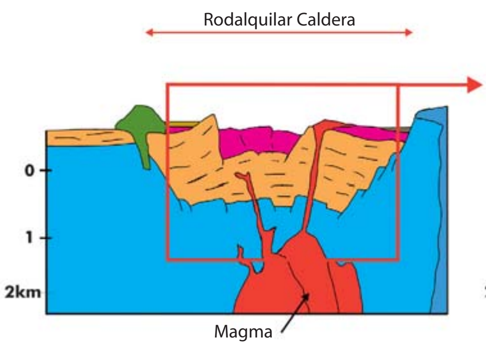
Hydrothermal Alteration and Mineralization of the Volcanic Complex

Juan M. Fernández

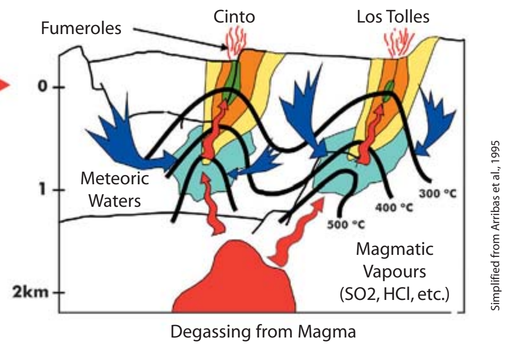
HYDROTHERMAL SYSTEMS

The hydrothermal systems associated with the volcanic complex of Cabo de Gata has generated important mineralization of economic interest whose profits have left a marked impression in the history and upon the countryside of this district. Without doubt, the most acclaimed deposits are gold from Rodalquilar, exploited until very recent times. Exploitation of other lesser metals has existed, however, such as lead and zinc, copper and manganese.

A. GEOLOGICAL SKETCH



B. HYDROTHERMAL SYSTEM



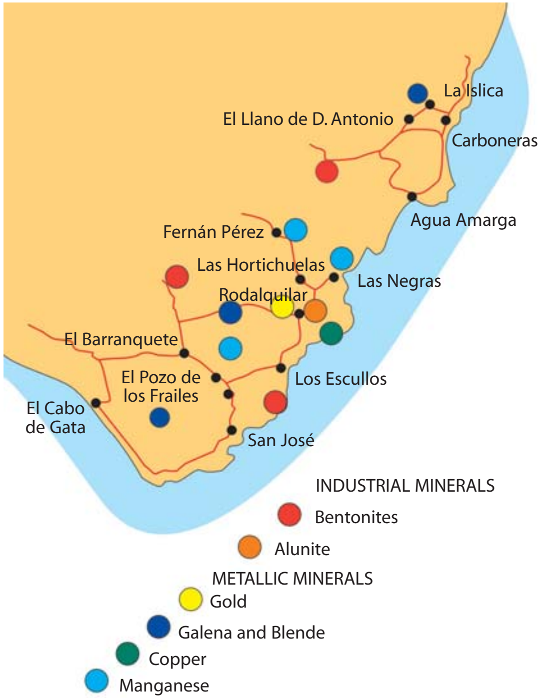
Other non-metallic mineralization of commercial interest has also been generated in association with this system. Bentonites are actually the most important. Long ago the area had benefited from alunite, a mineral (aluminium sulphate and sodium or potassium) that was concentrated in yellow-coloured virgin seams cutting the white-coloured and pulverised looking, altered volcanic rock. It has numerous industrial applications, amongst others it is used as a source for the production of alum, for the tanning of leather, etc.

Hydrothermal processes are a frequent phenomenon in volcanic areas. They are produced when a magmatic body cannot reach the surface, cooling slowly at hundreds of metres or a few kilometres of depth. In these conditions, the sub-volcanic body supplies heat to the surrounding area, that can reach temperatures of around 400-500 C, and emits gases and acid-rich fluids, such as hydrochloric or sulphurous (between 200 and 350 C). These hydrothermal fluids rise up through the intruded rocks, transforming them (hydrothermal alteration) and cleaning many chemical components out of them (lixiviation), such as gold and many other metals that were originally very dispersed in the rocks. Upon arriving in more surficial zones the fluids cool and mix with water of subterranean or marine origin, which provokes the metals and other disassociated components to precipitate in fissures and fractures, forming hydrothermal deposits, such as the famous Rodalquilar gold.

In Cabo de Gata, the main hydrothermal gold deposits are located in the Rodalquilar complex of calderas, associated with an intense zone of hydrothermal alteration. This alteration zone is produced by intrusion and cooling, beneath the calderas, of a magmatic body. The hydrothermal fluids carried by this body wash out the gold at depth and utilised the various fractures existing in the caldera to circulate and deposit the gold in more superficial zones. The formation age of the deposits is estimated at around 10.4 million years.

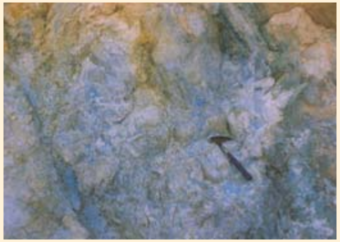
Hydrothermal Alteration and Mineralization of the Volcanic Complex

LOCATION OF MINERALIZATION THROUGHOUT CABO DE GATA



MINERALIZATION

Smelting works of Los Alemanes Nuevos, to the west of San José, for the recovery of lead and zinc (photo J. M. Alonso).

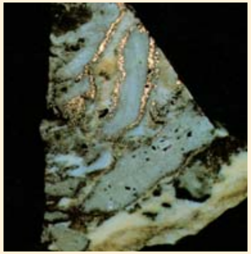


Bluish and greenish colouration corresponding to superficial alteration minerals of copper and lead sulphides.

Exploitation of Manganese from Cerro del Garbanzal. Mineralization corresponds to the dark zone.

Overview of typical scenery in bentonite clays: white-coloured powdered masses, greasy to the touch and very plastic.

Exploitation of alunite from galleries in the proximity of Rodalquilar. The mineralization corresponds to yellow-coloured veins (lodes).



Hydrothermal breccia of white chalcedony with native gold (Photo Arribas).

The Rodalquilar Gold

Carlos Feixas

THE DISCOVERY
(End of the 19th century - 1939)

The existence of gold in the Almerian district of Rodalquilar was casually discovered at the end of the 19th century. Gold was detected in lead smelting works of Cartegena and Mazarron, that utilised quartz coming from the lead mines of Cabo de Gata as a flux. The Mazarron smelters sought out the gold-bearing quartz, and with its scarce gold content they financed the cost of transport.

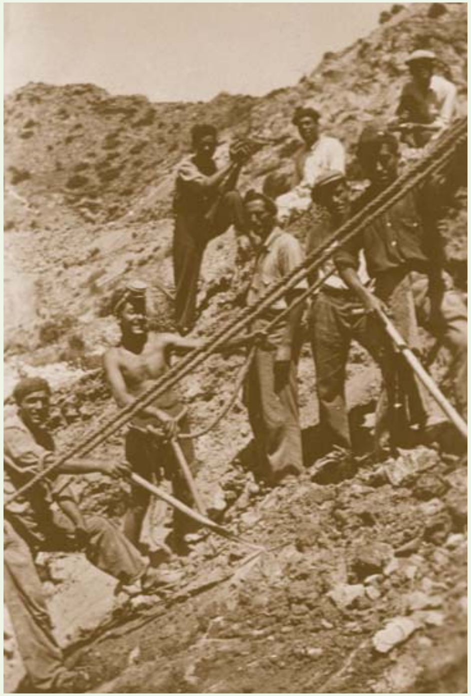
In an authentic state of gold fever many concessions were registered in this era that gave way to a multitude of litigation that delayed the mine consolidation throughout the whole of the 20th century.

This first stage of discovery of gold from Rodalquilar, and the development of the first mines, coincided with the great Almerian economic crisis. This involved emigration of workers to Algeria, and subsequently to America, a decline in lead mining and later in iron mining, and a crisis in the grape market.

The English company Minas de Rodalquilar handled a total of 107,000 tons of mineralized rocks until 1939, obtaining 1,125.5 kg of gold. Of these only 39 tons corresponded to the period 1936-1939.

Ruins from the first treatment plant installed around 1915 in the Ma Josefa mine, in El Madronal (Rodalquilar) (Photo, Col. Evaristo Gil Picon).

Old lodes economic for lead at the end of the 19th century in quartz dykes, from some of which the existence of gold was detected in Rodalquilar (Photo, Col. Evaristo Gil Picón).



Extraction workers in the Los Ingleses Mine (around 1930) (Photo, Col. Evaristo Gil Picón).

THE DREAM (1940-1966)

In 1940, the state decreed the seizure of the mines, entrusting the task of investigation to the Spanish Institute for Geology and Mining (IGME), that looked at the old lodes that had been exploited without favourable results. Until 1942, the date at which this seizure ended, a total of 37 kg of gold was recovered.

At the end of 1942 the National Institute of Industry (INI), through the Adaro National Enterprise for Mineral Investigation (ENADIMSA), amplified and intensified investigations, abandoning the lodes and concentrating in the Cerro del Cinto area, where mineralisation appeared in a disseminated form in the acidic volcanic rock body, determining a 4000 ton mass of mineralised rock with 4.5 grams of gold per ton.

Until 1966 Rodalquilar lived its golden dream. Its population came to reach 1400 inhabitants. It was furnished with infrequent services for this time in rural populations, cinema, social club, administration buildings, school, etc.

'El Ruso', first transport lorry for the Rodalquilar mines (around 1940) (Photo, Col. Evaristo Gil Picon).

Drilling workers in the open cast mines opened during the ENADIMSA period of exploitation (Photo, Col. Evaristo Gil Picon).

May 1956. The head of state at that time attends the production of one of the gold ingots, with all of the propaganda exhibited by the regime (Photo, Col. Evaristo Gil Picón).

In the first years of activity from this period in the order of 700 manual labourers worked in Rodalquilar, the greater part of them dedicated to the construction of infrastructure and workings. At the end of this, between 200 and 300 workers were permanently involved in the exploitation. ENADIMSA continued, in principle, with the subterranean system of extraction that had been emplaced by the English. In1961, however, the first open cast workings were undertaken in the Cerro del Cinto.

During this period the bulk of gold production in Spain shifted to Rodalquilar, with more than 90% of the total production. However this dream only lasted a while. Investment exerted pressure to make new workings, and salary rises in the 70's decade considerably increased the production costs in a deposit already so difficult because of the irregular distribution of economic reserves. All of this forced the closure of the workings in 1966.

REALITY (1967-1990)

The closure of the mines in 1966 put an end to the period of splendour. A little afterwards the population declined very abruptly to 75 inhabitants, in summary nearly identical to that of today.

After exploitation was carried out by ENADIMSA in the previous period, the concessions and licences returned to their owners. Even though investigation had been forgotten in this period, so often realised by national mineral concerns, including, to a greater degree, foreign ones. This period is characterised by intensive investigation of the Rodalquilar mining district, but having emphasis on genetic models of gold mineralisation.

In spite of all this reality prevailed, although it is estimated that that around 3 tons of gold reserves are awaiting recovery, their exploitation is not possible because of the complexity of the deposit.

Mining town of Rodalquilar (photo Evaristo Gil Picón).

SEDIMENTARY BASINS IN THE VOLCANIC ARCHIPELAGO
Sedimentary Episodes

Juan C. Braga - José M. Martín

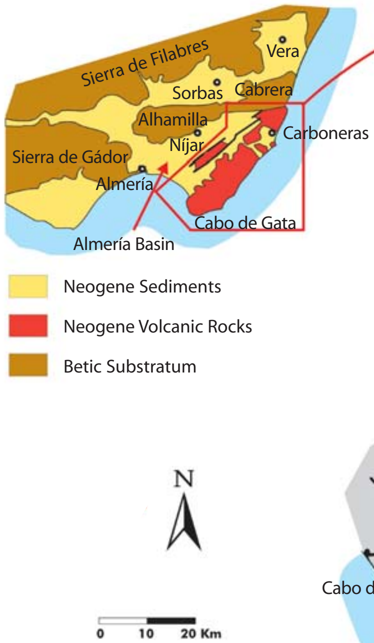
From the first volcanic episodes and subsequent to the last, the sea invaded the volcanic relieves generating an extensive archipelago. In the marine basins between volcanic relieves marine sedimentary deposits were produced. Five sedimentary episodes can be recognised:

1. In an early episode sediments were deposited upon the first volcanic rocks. Their age is Lower Tortonian (between 9 and 8.7 million years). They are mainly bioclastic carbonates.

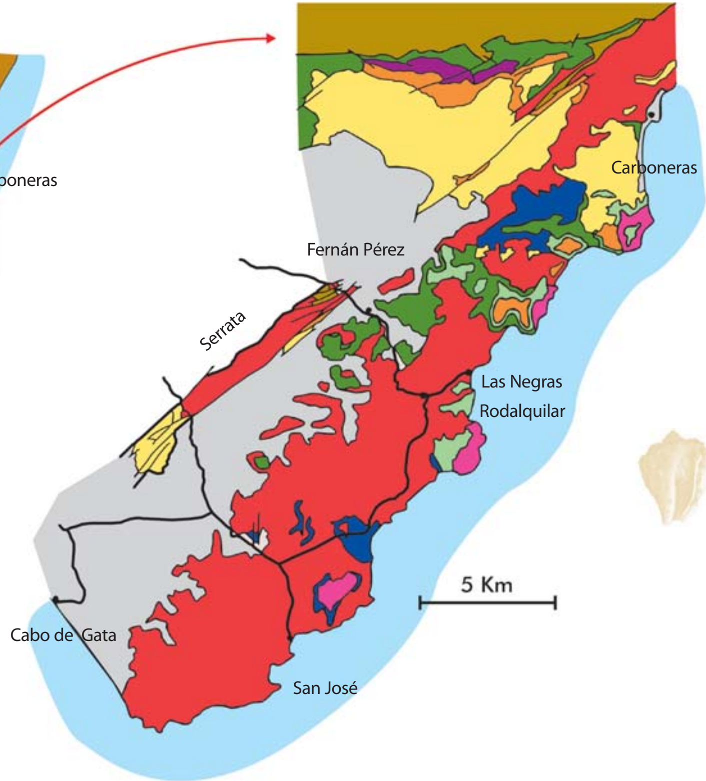
2. In a second phase sediments formed above rocks of the last volcanic event. Their age is Upper Tortonian to Messinian (between 5.5 and 6.5 million years ago). They are also bioclastic carbonates, and marls, that accumulated in deeper zones.

3. Above the previous episode, a series of related units characterised by the presence of reef bodies were deposited. Their age is Messinian (around 6 million years old).

TERTIARY BASINS IN THE SOUTHEASTERN PENINSULA



GEOLOGICAL MAP OF THE CABO DE GATA AREA



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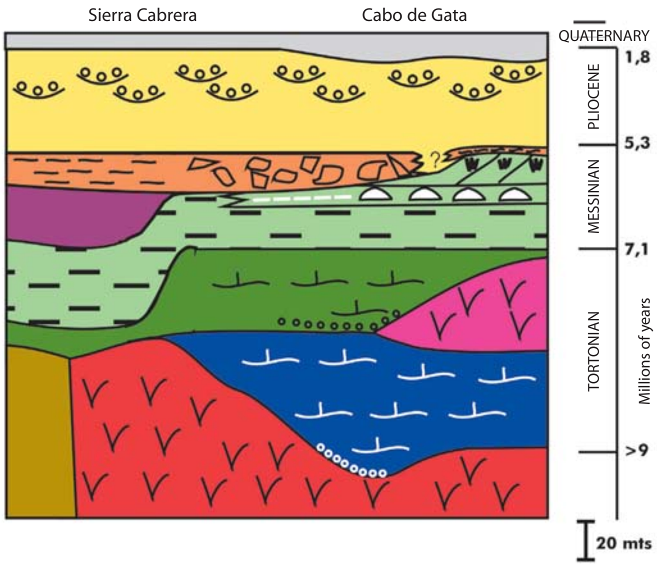
SEDIMENTARY EPISODES

4. After the deposition of the reefs a phenomenon known as the Mediterranean Messinian Salinity Crisis took place. The Mediterranean dried out 5.5 million years ago as a consequence of its disconnection with the Atlantic. During this period material around the borders underwent partial erosion and in the central area of the large Mediterranean Basin, and in its marginal basins, important thicknesses of gypsum and other salts were deposited. Above these, or above the eroded surface, carbonate sediments typical of warm seas were deposited: oolites and stromatolites.

5. A last marine episode that passes into continental deposition half way through (in the Pliocene, between 5 and 2 million years ago).

STRATIGRAPHY OF THE CABO DE GATA AREA



Deposits of the First Marine Basins

Juan C. Braga - José M. Martín

Since the formation of the earliest volcanic relieves of Cabo de Gata the sea invaded the area generating small marine basins, extensions of the self-same Mediterranean Sea. In these small marine basins, and above the volcanic relieves, the first marine sediments known in the Cabo de Gata area were deposited, some 9 to 8.7 million years ago (Lower Tortonian).
The majority of the rocks are carbonates coming from sediments formed by skeletons (fossils) of bryozoans, bivalves, calcareous red algae, echinoderms (sea urchins), barnacles, and foraminferans (these types of rock are denoted as bioclastic carbonates). These fossil remains (shells, winkles etc.) are quite similar to those organisms that are actually living in the Mediterranean waters just off of Cabo de Gata today. Together with carbonates generated by living marine beings, sediments also accumulated through the denudation of the volcanic relieves emerged there (these are called volcaniclastic deposits).

The Agua Amarga Basin, towards the west of the town, is one of the areas where these sediments are better represented.

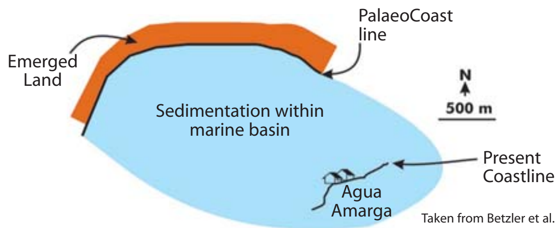
The sea, in the Lower Tortonian, surrounded the volcanic relieves. The coastline had characteristics similar to those of today.

Details of the present-day sea bottom at La Polarca. The organisms (bryozoans and red algae) are similar to those that were living and producing sediment in this period.

Sediments (bioclastic carbonates) from the Lower Tortonian comprising the remains of fossils of bryozoans, red algae and bivalves.

The Agua Amarga Basin, for example, was a small prolongation of the Mediterranean during this period that extended between recently emerged volcanic relieves in the Cabo de Gata area. Sedimentary structures indicate that the bioclastic carbonates from the Lower Tortonian in the Agua Amarga Basin formed in littoral and shallow marine environments. Furthermore, one can understand a succession in this material, in which each phase had a distinctive geography, characterised by different sedimentary processes.

PALAEOGEOGRAPHY OF THE AGUA AMARGA AREA 9 MILLION YEARS AGO (LOWER TORTONIAN)



Taken from Betzler et al. 1997

Cross stratification stemming from the accumulation of sand-sized carbonate grains of the skeletons of marine organisms (bryozoans, bivalves, red algae, etc.) in submarine dunes at little depth.

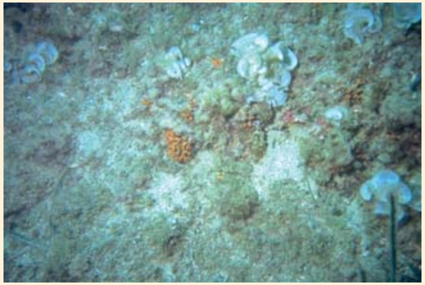
The Re-initiation of Sedimentation After the Last Volcanic Episode

Juan C. Braga - José M. Martín

The last volcanoes in the Cabo de Gata area were active between 8.7 and 7.5 million years ago. In this period the domes of some of the most characteristic relieves of the Natural Park were formed, like those of the upper part of Los Frailles, the Cerise de Lobos and Mesa de Roldan. The extrusion of volcanic material broke through the older sedimentary rocks in some places, enclosing blocks within some of the lavas.

On top of these new volcanoes, and on occasions on top of older rocks, towards the end of the Tortonian geological stage, around 7 million years ago, a shallow marine platform was initiated that marked a renewed incursion of the Mediterranean around the archipelago of small islands generated by the volcanic activity. In this shallow marine environment mostly carbonate sediments formed from the remains of marine fossils that were deposited, for which reason they are called bioclastic carbonates.

Volcanic eruptions fragmented the sedimentary rocks from the lower episode (Lower Tortonian), light pink material in the photo, and enveloped them in lavas, dark material in the photo.



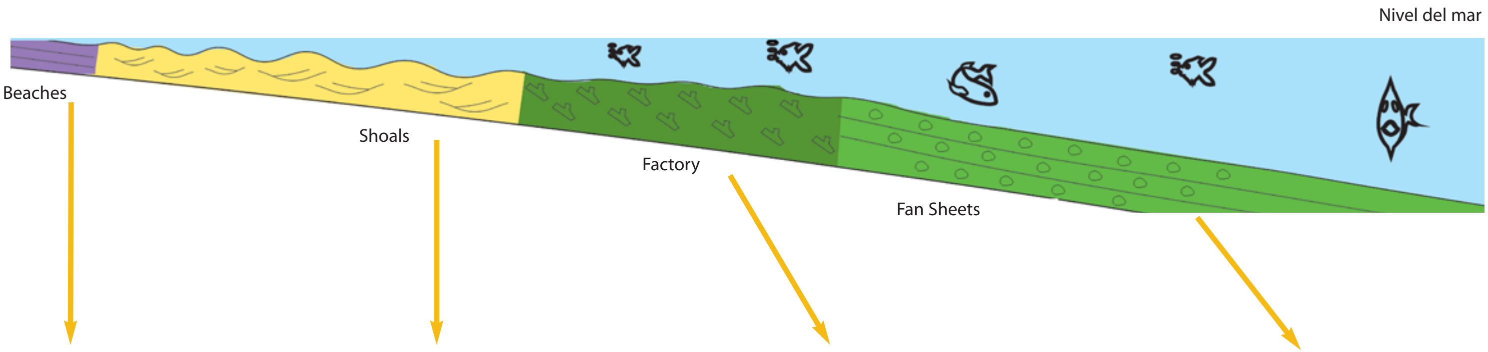
Present-day marine bottom in Cabo de Gata. The organisms present (bryozoans, bivalves and red algae), are the carbonate producers, that accumulate on the bottom generating carbonate sediment.

Upper Tortonian bioclastic carbonates comprising the fossil remains of bryozoans, bivalves and red algae.

The Re-initiation of Sedimentation After the Last Volcanic Episode

Inside these shallow marine basins the organisms produced from carbonate, that is to say those that have shells, chambers etc., lived in a preferred style immediately beneath the zone pounded by the surf, associated to a great extent by plant meadows with a marine flora. The carbonate particles produced in this factory were distributed by storms towards the coast, where they accumulated in beaches and bars, and out towards the sea, in successive sheets. Towards zones of even greater depth the carbonate particles became finer each time and, finally, gave way to marls formed from a mixture of clays, transported into the sea by suspension, and microskeletons of planktonic organisms.

SEDIMENTARY MODEL FOR THE UPPER TORTONIAN



Stratification and cross-lamination typical of beach depsoits.

Trough stratification typical of submarine dunes in shoals.

Accumulations of the remains of organisms that produce carbonates.

Sheeted fans in the Rambla de los Viruegas.

Messinian Reefs

Juan C. Braga - José M. Martín

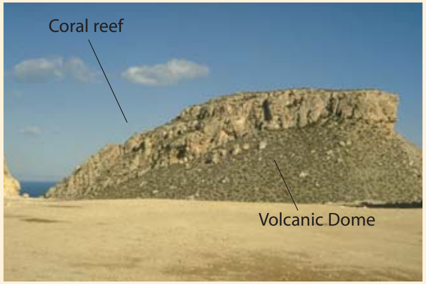
CORAL REEFS

Some 6 million years ago, in the Messinian geological stage, and after deposition of the temperate carbonates and marls described previously, an increase in the water temperature allowed the formation of coral reefs in the SE Peninsula and, particularly, in the Cabo de Gata region. At the present day, coral reefs live in waters of little depth in intertropical latitudes, where the average winter water temperature does not fall under 20º C. In these sites huge volumes of rock and sediment are constructed by means of their calcareous skeletons. The presence of reefs in our region indicates that, in the period of their formation, the water was warmer than in the modern Mediterranean.

In Cabo de Gata the coral reefs formed on top of or around the volcanic relieves.
Some of the most characteristic places within the Natural Park are found to be the reefs of Cerro de Los Lobos, la Molata de Las Negras, La Higueruela and Mesa de Roldan. These relieves were islands or high sea bottoms that were colonised by coral reefs and could be completely covered or surrounded by reefs.

Reefs constructed from coral (light tones in the photo), fringing islands of volcanic origin in modern seas, as would have happened 6 million years ago in Cabo de Gata.

Calcareous corals that presently live in the tropics are the constructors of reefs.



In Mesa Roldán, 6 million years ago, a coral reef fringed and covered a volcanic dome (dark tone).

Evaporites and Carbonates After the Recovery of the Mediterranean

Juan C. Braga - José M. Martín

In certain sectors of Cabo de Gata such as La Molata de las Negras, Mesa Roldan and others, above the last reefal episode an erosion surface is observed that affects the reef and removes the greater part of its deposits. This erosion surface is the expression of Messinian desiccation in this part of the Mediterranean, known as the Salinity Crisis.

Its age is approximately 5.5 million years (Terminal Messinian). In effect, around this time the Mediterranean dried-up, by closing the communication between the Atlantic and the Mediterranean, therefore removing the entry of water from the former. During this period, the reefs around the border remained exposed to erosion, and in the central sectors, as much in the main marine basin, the Mediterranean, as in the small marginal basins that communicated with it, like that of Sorbas or Almería, important massive deposits of gypsum were formed.

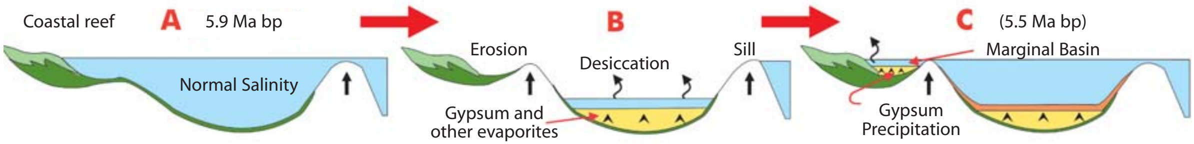
Field view of gypsum banks.

Field view of stromatolites features, with their typical laminar structure.

Following deposition of the gypsum, both above this level and on top of the erosion surface that reached the reefs, a sedimentary deposit formed fundamentally by carbonates with stromatolites and oolites can be identified.

The oolites are particularly spherical, with an internal structure of concentric calcium carbonate layers.

SEDIMENTARY INTERPRETATION FOR THE GYPSUM IN A MEDITERRANEAN CONTEXT



Situation prior to deposition of the evaporites, with formation of reefs in the margins and muddy-marly sediments in the basin.

Deposition of evaporites in the centre of the Mediterranean while it is disconnected from the Atlantic and dries out.

Deposition of evaporites in the interior of marginal basins as they are being invaded by the first pools of water in the process of Mediterranean reflooding.

RECENT EVOLUTION AND EMERGENCE OF THE BAY OF ALMERÍA

J. Baena - C. Zazo - J. L. Goy - C. J. Dabrio

The Bay of Almería and Andarax Valley, Campo de Níjar and area of Roquetas del Mar surrounding it, made up a large sedimentary basin during the Pliocene and Quaternary (since 5.2 million years ago), with material mostly deposited in a marine environment.

At the start of the Pliocene the sea occupied all of the present low-lying areas: in the west up to the slope of the Sierra de Gádor, through the Andarax Valley reaching up to the location of Rioja and bordering the Sierra Alhamilla, penetrating across all of the Campo de Níjar where only the Sierra de Cabo de Gata and parts of the Serrata de Níjar were emerged. The Andarax River, that presently discharges into the sea close to Almería and in a north-south direction, was located further to the northeast, between Rioja and Viator, during the Pliocene.

The high relieves that bordered the sedimentary basin were traversed by ramblas which, as at present, provided detrital material (blocks, pebbles, sand) to the marine basin.

During the Plio-Quaternary uplift in the region was initiated, leading to the displacement of the coastline in a southerly direction.

Detail of a cemented sand beach. Remains of a typical tropical marine fauna (Strombus bubonius) indicated by the pencil. Rambla de Amoladeras.

Marine deposits of a pebble beach covered by continental deposits with a calcareous crust above it. Retamar.

Detail of a cemented pebble beach. Retamar.

During the Quaternary, as a consequence of repeated climatic changes, alternating cold glacial periods and warm interglacials, the sea level suffered strong variations that could have been in the order of 130 metres. These variations were responsible for continuous changes in the position of the coastline, and for the distribution and abundance of the different marine and continental deposits.

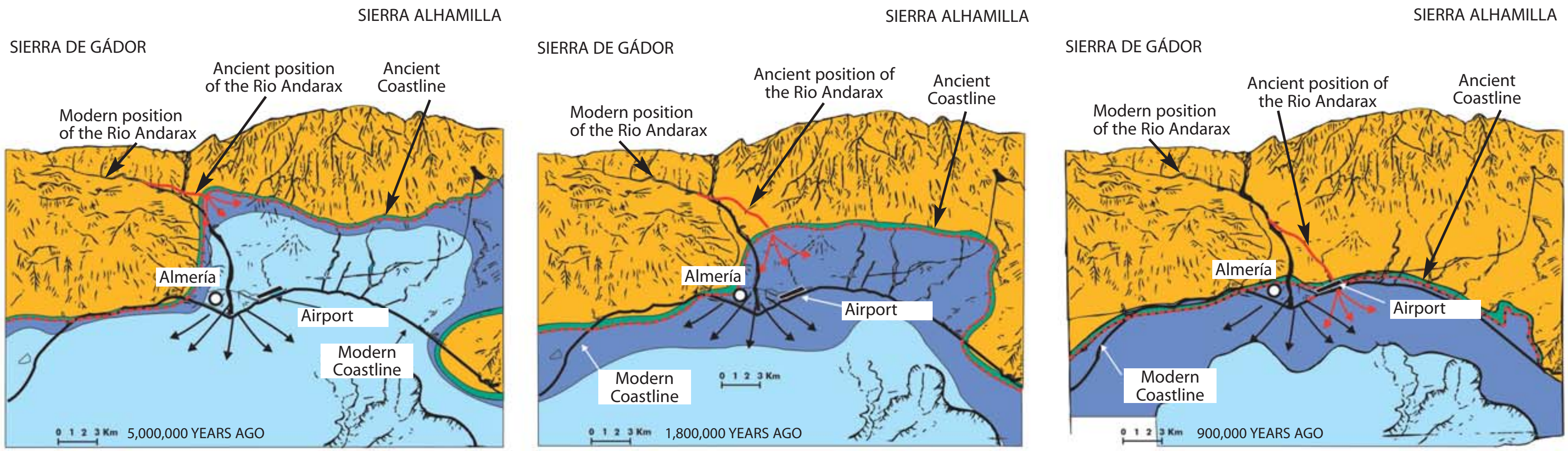
In the Bay of Almería a magnificent record of these distinctive sedimentary environments can be observed, ranging from continental (alluvial fans, dune systems, etc.) to littoral and transitional (submarine deltas in ramblas, beaches, lagoons and littoral features, etc.).

Deep marine deposits in the Bay of Almería. Yellow muddy limestones, locally called Marls with Leprosy.

Shallow marine carbonate deposits. Whitish calcarenites with fauna.

RECENT EVOLUTION AND EMERGENCE OF THE BAY OF ALMERÍA

EVOLUTION OF THE COASTLINE IN THE BAY OF ALMERÍA FROM THE PLIOCENE (5 MILLION YEARS AGO) UNTIL THE PRESENT



CONTINENTAL AREAS

- Continental Interior
- Littoral Fringe

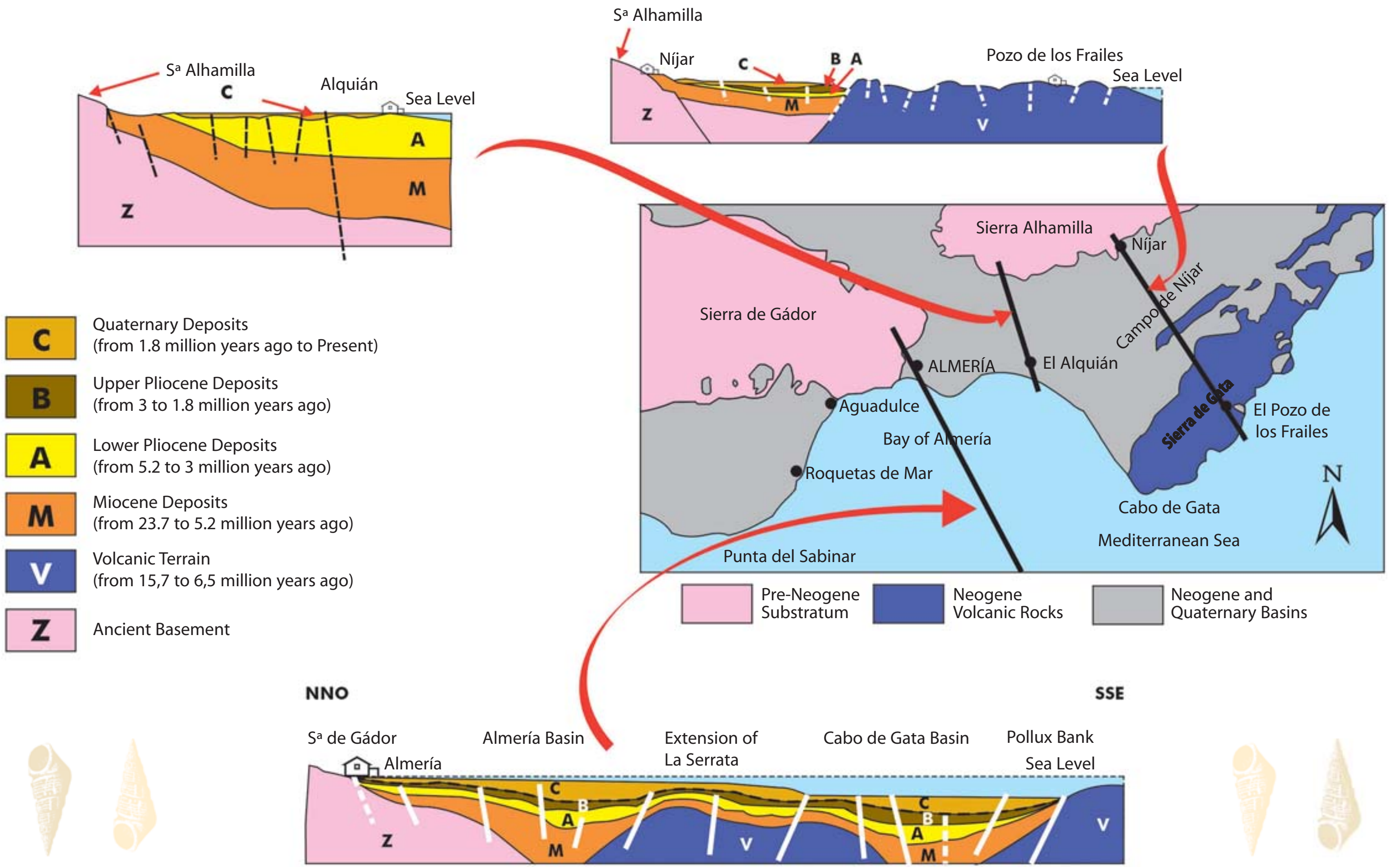
MARINE AREAS

- Shallow Water
- Deep Water

- Ancient Delta
- Modern Delta
- Ancient Coastline
- Modern Coastline

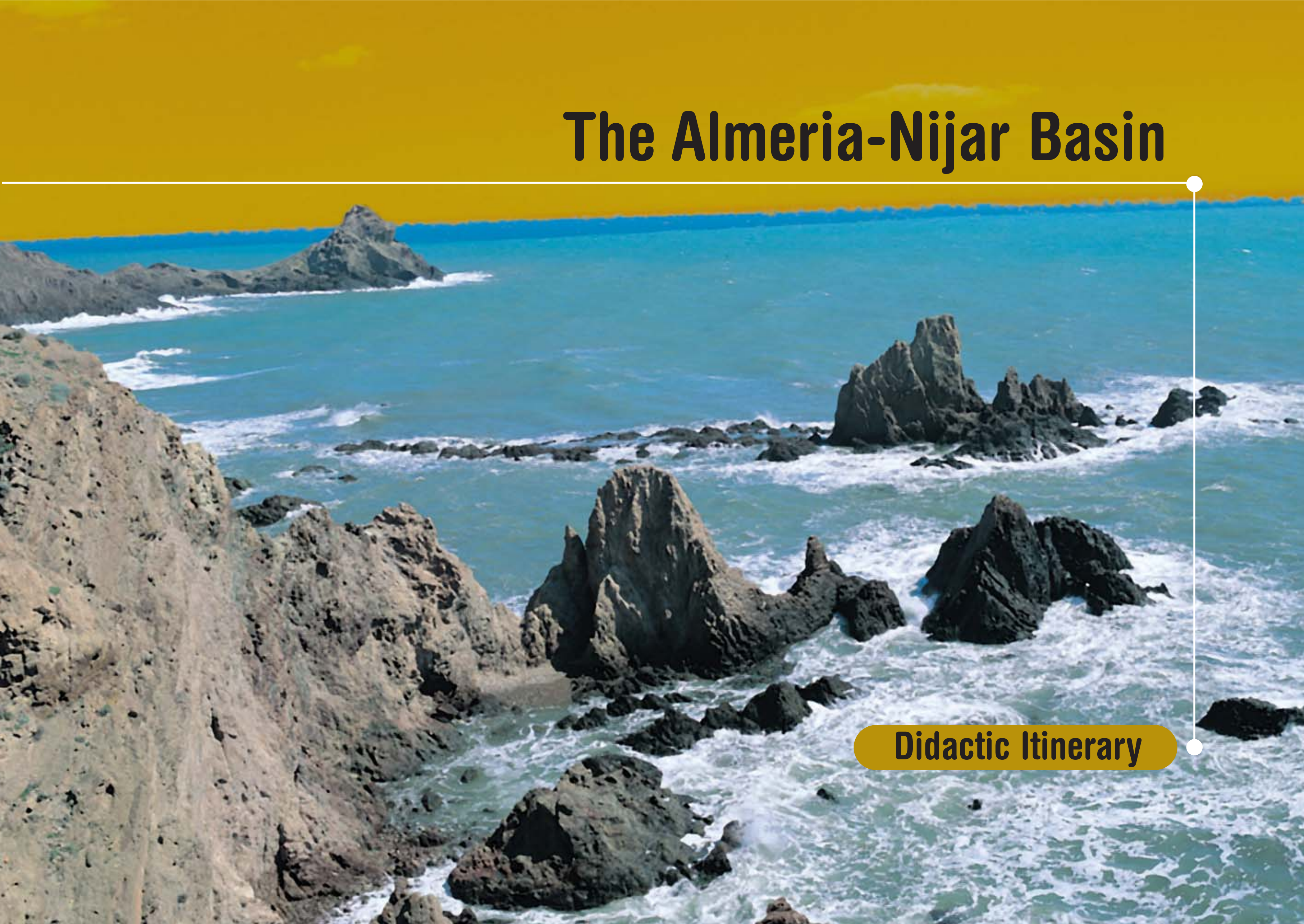
RECENT EVOLUTION AND EMERGENCE OF THE BAY OF ALMERÍA

ILLUSTRATIVE GEOLOGICAL PROFILES OF THE STRUCTURE OF THE SEDIMENTARY FILL IN THE BAY OF ALMERÍA



The Almeria-Nijar Basin

Didactic Itinerary




Tabernas
Lucainena de las Torres
Turrillas
Polopos
La Cueva del Pájaro
Gafares
El Argamasón
Carboneras
El Llano de Don Antonio
Huebro
Níjar
Los Baños de Sierra Alhamilla
Abriojal
Campohermoso
Las Cuevas de los Úbedas
CABO DE GATA-NIJAR NATURAL PARK
Agua Amarga
Puebloblanco
San Isidro de Níjar
Fernán Pérez
Las Cuevas de los Medinas
Atochares
El Viso
Las Negras
El Boticario
El Alquián
Los Albaricoques
Rodalquilar
Costacabana
La Cañada de San Urbano
Almería
El Barranquete
Ruescas
Presillas Bajas
La Isleta
Los Escullos
Pujaire
El Cabo de Gata
El Pozo de los Frailes
San José
El Corralete
N
1:250,000 Scale
Cabo de Gata-Nijar Natural Park
Observation Point
(see sketch of each point)
Recommended Itinerary
Access restricted
to road traffic

1. Alluvial Dynamics of Ramblas: Las Amoladeras

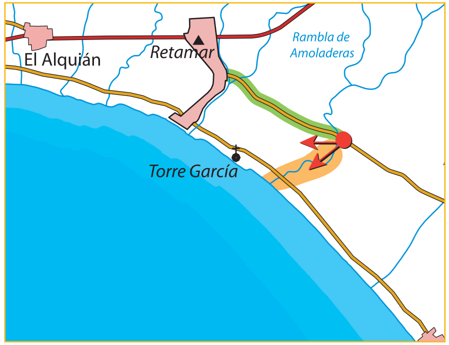
A. Martín Penela

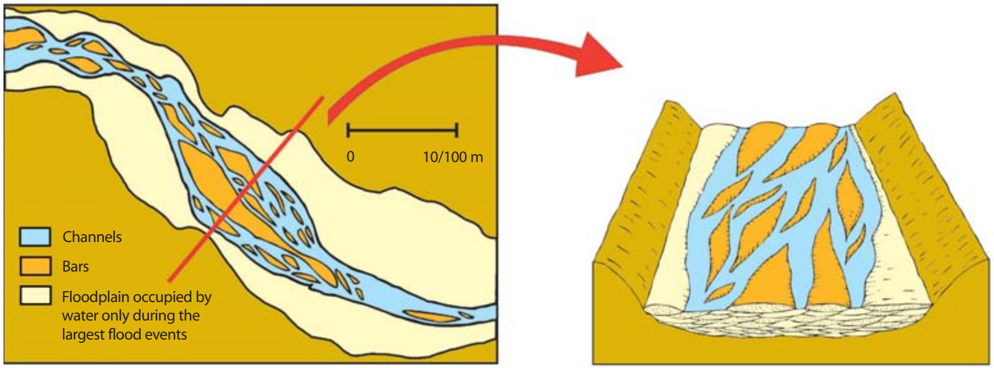
THE RAMBLAS

The Rambla de las Amoladeras is a superb example of alluvial systems in arid zones. These river courses, usually dry, represent channels in which currents of short duration can flow as a direct result of precipitation, scarcely receiving water from other sources.

The dynamics of this alluvial system are fundamentally controlled by the climate and the shortage of vegetation. Seasonal rains, frequently stormy and of short duration, create an important surface torrent, with great erosive power, that supplies water and sediment to theses river beds.

A broad valley floor is exhibited, usually with a low sinuosity. Its river bed is occupied by numerous interweaved channels and the bottom covered by sediments organised into bars and channel deposits. Their sediments are mostly made up of gravel-sized particles.





The channels are very mobile, and develop as furrows that interweave amongst themselves, adjacent to the bars, that appear as small mounds, upon which vegetation is frequently established. The bars, of different form and size, change their arrangement and morphology after each flood.

The floodplain represents a portion of the river bed that is only inundated during important floods. In it a great part of the fine materials that were transported in suspension can be deposited, giving rise to deposits that favour the development of fertile soils.

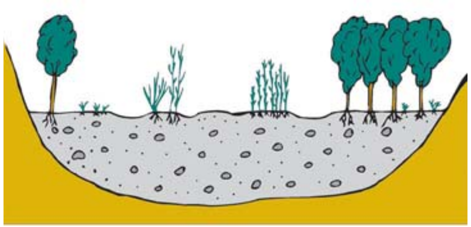
FLOODS

As a result of intense storms, the dry riverbeds in the ramblas can be transformed, in a short time, into violent torrents of water loaded with sludge and detritus. These very intensive floods, sudden and powerful, can be unduly catastrophic and cause great destruction in agricultural zones and to built structures, in the river beds of the ramblas or within the same floodplain. The large floods take place sporadically, tied to seasonal changes or times of rain.

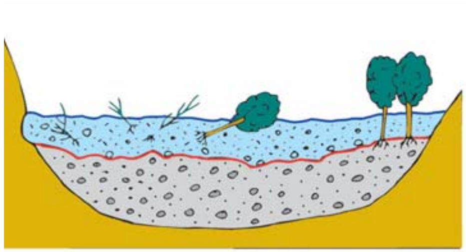
Damage caused by a flood .

PHASES IN A FLOOD

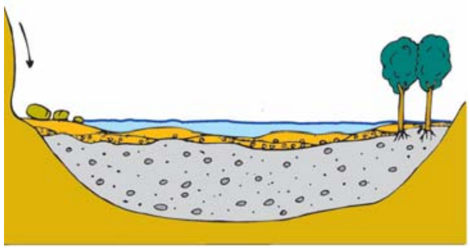
1. DRY PERIOD



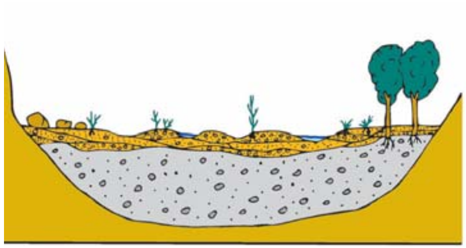
2. PERIOD OF STRONG FLOODS



3. PERIOD OF DIMINISHING FLOW



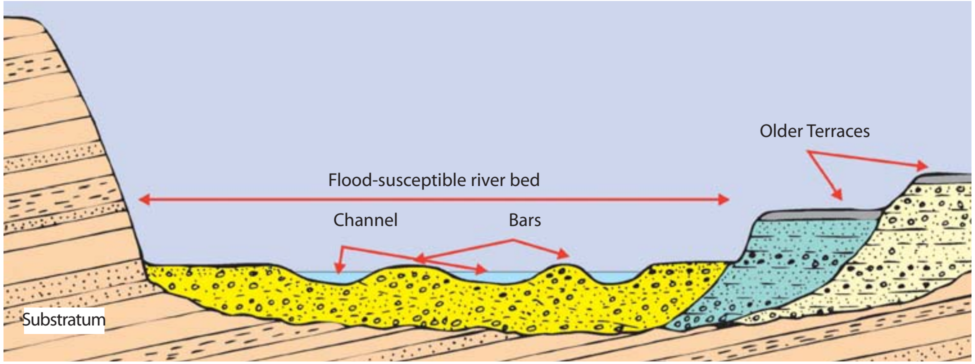
4. PERIOD OF SCARCE ACTIVITY



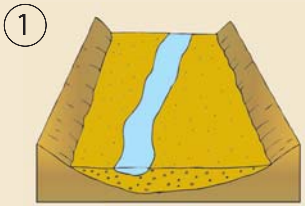
ALLUVIAL TERRACES

Alluvial terraces are deposits positioned sporadically along the side of a valley that correspond to non-eroded segments of earlier alluvial sediments. When a rejuvenation of the alluvial system is produced by climatic, tectonic or other changes, water currents deeply erode the sediments within their channel, giving rise to a new river course in a lower topographic position with respect to the older channel.

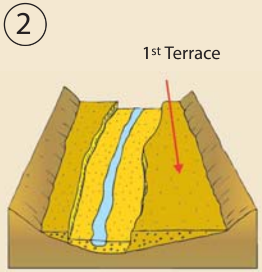
Alluvial Terrace in the Rambla de Amoladeras.



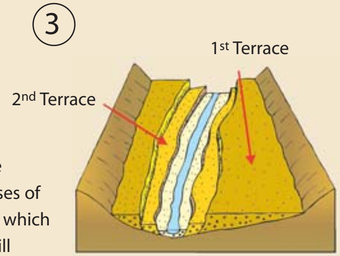
STAGES IN THE FORMATION OF A SYSTEM OF TERRACES



Stage of alluvial infilling. The current deposits most of the sediments that it transports and produces a river fill.



A change in base level means that the rambla evolves in order to reach a state of equilibrium. On top of the previously formed deposits a new channel is emplaced which erodes the pre-existing alluvium that had come to construct the older terrace level.



If the conditions repeat themselves, they will be succeeded by new phases of filling and erosion from which various terrace levels will originate.

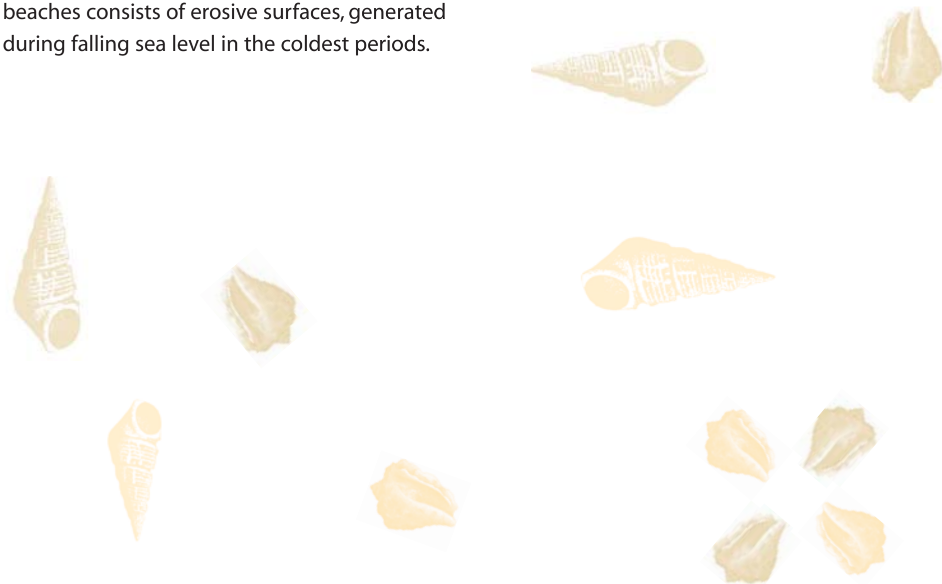
2. Fossil Beaches of the Rambla de Las Almoladeras

C. Zazo - J. L. Goy - C. J. Dabrio - J. Baena

The surrounding area of the Rambla de las Amoladeras are characterised by the presence of one of the most complete geological records of fossil Quaternary beaches, and with the best conditions for observation, in the Spanish coastal zone. These marine beaches, that fundamentally developed between the last 200,000 years and the present day, were partially covered on the surface by a dune system that started to form around 2500 years ago. In the talus of the right hand margin of the river mouth of the rambla, a mixture of deposits consisting of well-cemented sands and pebbles with a marine fauna can be seen, that represent ancient beaches, and consequently, the position of the coast at that time. Average absolute dating (Uranium-Thorium), has obtained ages of 180,000 years, 128-130,000 years and 95-100,000 years for the three differentiated beach levels. All of the beaches contain fossils of Strombus bubonius. They dominate Tyrrhenian beaches, a name that is derived from the Tyrrhenian Sea, for it was there that beaches with this characteristic fauna were described for the first time.

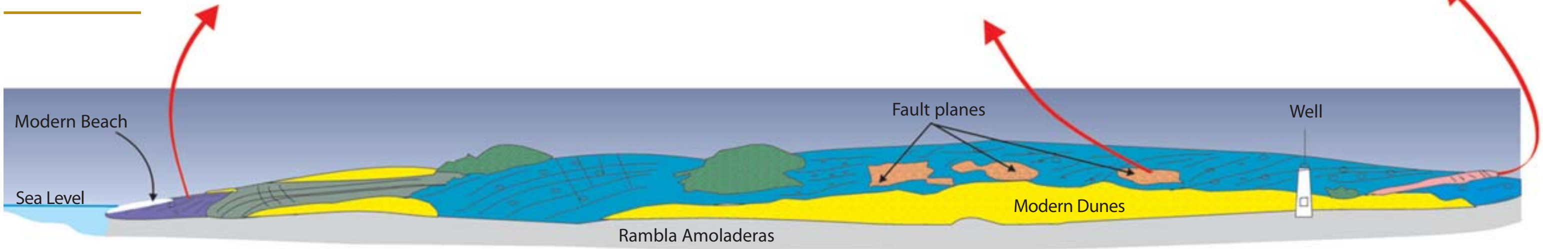
An interpretation of the geometry of the outcrop allows differentiation of, from left to right: in the first place some conglomeratic sediments (A) corresponding to the oldest beach, of unknown age, which contains the remains of a fossil fauna like that which actually lives in our coasts.

This beach is separated from those which follow it by a deposit of cemented sand that corresponds to a fossil dune field, that formed when the sea descended, leaving the beach deposits emerged and dried out, such that it allowed the wind to accumulate sand.
The following deposits (B, C and D) consist of cemented conglomerates rich in Strombus bubonius. The separation between the distinct beaches consists of erosive surfaces, generated during falling sea level in the coldest periods.

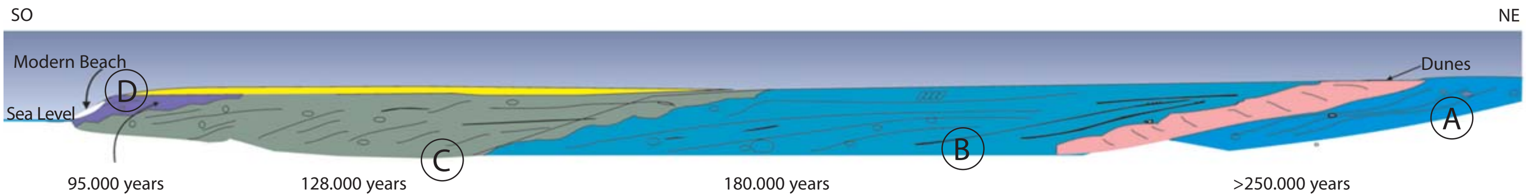


2. Fossil Beaches of the Rambla de Las Almoladeras

ACTUAL SECTION



INTERPRETED SECTION

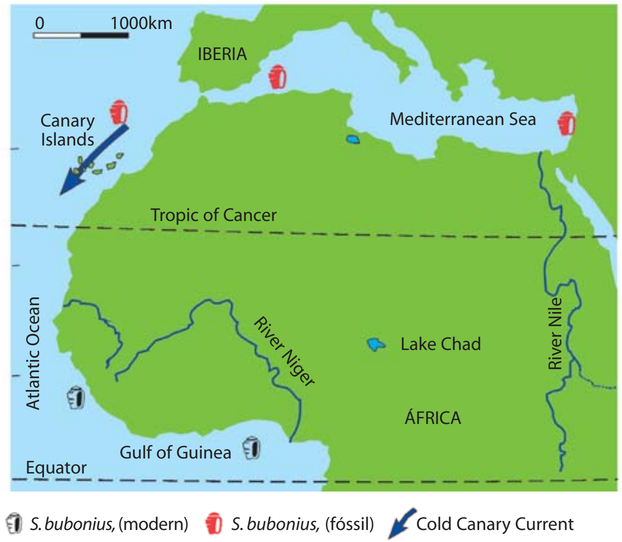


Each position of the coastline has left behind an associated fossil beach level. In the river mouth outcrop of the Rambla de las Almoladeras, four superimposed fossil beach levels can be observed with ages of more than 250000, 180000, 128000 and 95000 years, respectively. The latter three levels contain the remains of a marine mollusc (Strombus bubonius), that still persists in modern tropical coasts, so that a warm, almost tropical, climatic character existed in the coast during these stages.

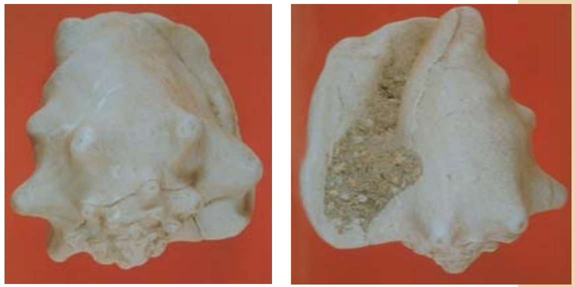
The fossil beaches of the littoral zone in Almería contain abundant fossils of marine species that do not inhabit theses coasts at Present times, although they had populated the littoral zone between 180,000 and 70,000 years ago. Strombus bubonius is, amongst others, a fossil of special importance. This has become used as an excellent palaeoecological indicator, in that it reveals variations in salinity and water temperature of the sea with great sensitivity. Its presence in these fossil beaches tells us that the sea which bathed the Almería coastline was at other times warmer, possessing subtropical conditions.

Strombus bubonius is a marine mollusc Gastropod, typical of warm seas, originating from the African equatorial Atlantic, entering into the Mediterranean through the Straits of Gibraltar when the atmospheric and surface water temperature of the sea are a few degrees higher than they are at present. During the last glaciation, between 65000 and 10000 years ago, oceanic waters cooled, so that they prompted a new migration of this species towards the African equator, in whose coastline they are found living today, actually forming part of the diet of townsfolk in this littoral zone.

MODERN AND ANCIENT GEOGRAPHIC DISTRIBUTION OF *STROMBUS BUBONIUS*



Details of the shape of Strombus bubonius from fossil beach levels, above which the modern littoral boundary is positioned.



Dorsal and Ventral views of an example of Strombus bubonius.

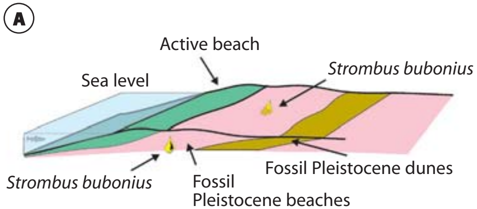
3. The Dune System in the River Mouth of Rambla Morales

C. Dabrio - J. L. Goy - J. Baena - C. Zazo

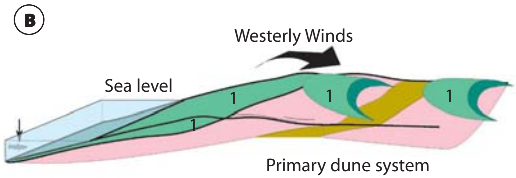
The dune systems that are observed in the surroundings of the river mouth of the Rambla Morales are produced by the action of westerly winds, that lift up sand from the beaches and transport it towards the river bed, accumulating it around small bushes or topographic irregularities in the surface. In this way dune construction is initiated.

The variation in sea level occurring in this coast throughout the Pleistocene-Holocene has given rise to various phases of dune formation.
The oldest dunes are cemented, the most recent may be: semi-mobile, covered over by vegetation, or mobile, which are those that finally bury the earlier ones, in their advance towards the land.

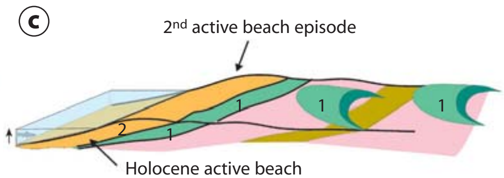
FORMATION AND DEGRADATION OF THE DUNE SYSTEMS OF CABO DE GATA



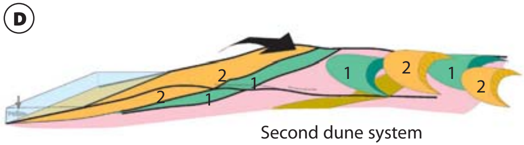
On top of the fossil beaches and dunes, the first active beach of Holocene (less than 10,000 years old) is deposited (1).



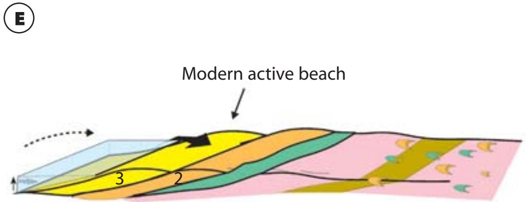
A slight fall of sea level leaves the beach, slightly more extended, under the effects of erosion by westerly winds, that carry along the finest elements (sand) in the form of a train of dunes (primary system).



A new rise in sea level deposits another beach episode (2) above the previous erosional surface. Dunes continue advancing.



Another rapid fall in sea level causes a repetition of the same phenomenon which forms a new train of dunes (2nd system), that advances mixing with the previous one.



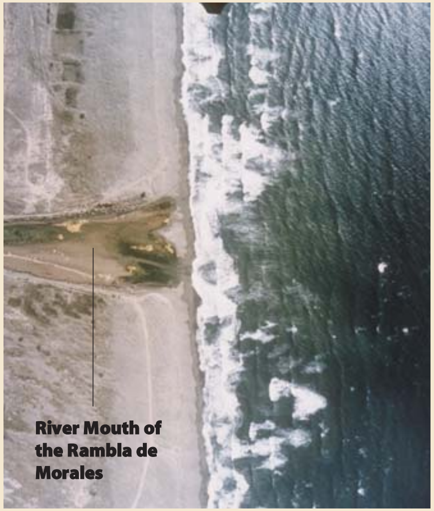
Finally the last rapid rise in sea level emplaces the modern beach (3). The dunes advance, but they have been disappearing due to intensive quarrying of sand in order to cover pastural land with sand. Exploitation of these dune systems is actually completely prohibited.

4. The Lagoon of Rambla Morales

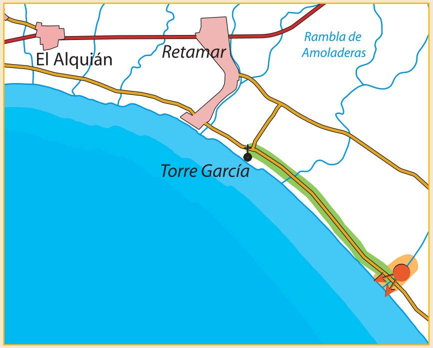
C. Dabrio - J. L. Goy - J. Baena - C. Zazo

In the river mouth of Rambla Molares a small lagoon, with an almost permanent character, has been created. Its origin stems from interaction between the rambla system itself with the beach. During two times of the year (end of spring - start of autumn) the phenomenon called gota fría is registered in the Mediterranean coast, that comprises intense and torrential rains concentrated in periods of very short time (several days). During these periods the ramblas transport a great quantity of water and sediment, that is finally to be deposited in the sea, eroded from the beaches that previously closed off the river mouth, showing a great capacity for cleaning out the rambla (high energy stage).

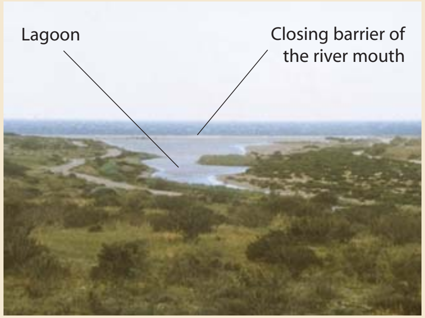
These sediments are redistributed along the length of the coastline, during periods of good weather (low energy stage), by means of littoral currents or drift currents, that in the case of the Rambla Morales circulate in a southeasterly direction, regenerating beaches and barriers once more. As these beaches are topographically higher than the bottom of the rambla, towards the land they leave a small depression that fills up with water from scarce rainfall that accumulates during inter-storm periods. This water, not having the strength of movement, remains stagnant creating a lagoon in the river mouth of the rambla.



Aerial view of the river mouth of Rambla Morales.



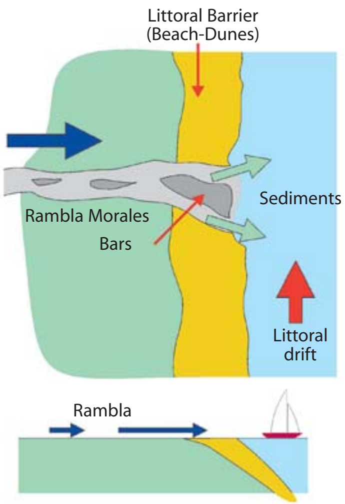

Aspect of the modern beach that forms part of the littoral fringe which closes off the inlet of the rambla.



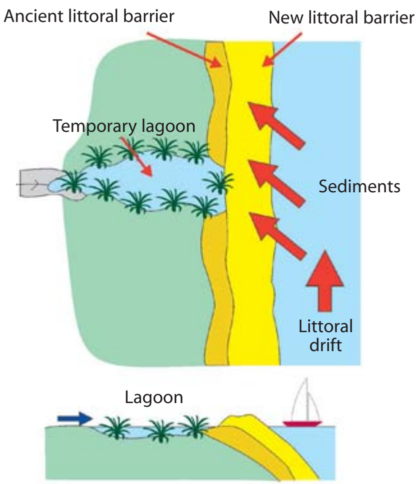
View of the lagoon from the river mouth of the Rambla Morales. It can be observed how the present, topographically higher, littoral barrier causes a closing of the rambla, such that it impedes its normal drainage into the sea. This situation persists up until when, in a state of high energy, the rambla breaks through the littoral barrier nourishing the sea with sediments.

SIMPLIFIED SCHEME OF LAGOON FORMATION PROCESSES IN THE RIVER MOUTH OF THE RAMBLA MORALES

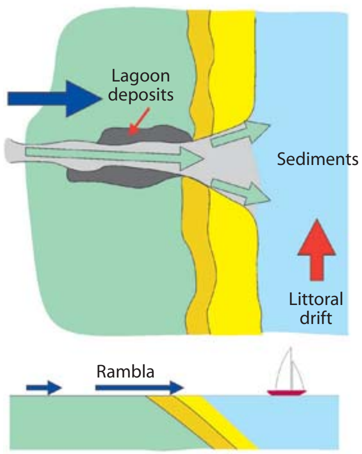
1. HIGH ENERGY STAGE



2. LOW ENERGY STAGE



3. NEW STAGE OF HIGH ENERGY



5. The Salt Pans (Salinas) of Cabo de Gata

J. L. Goy - C. J. Dabrio - J. Baena - C. Zazo

THE NATURAL ALBUFERA

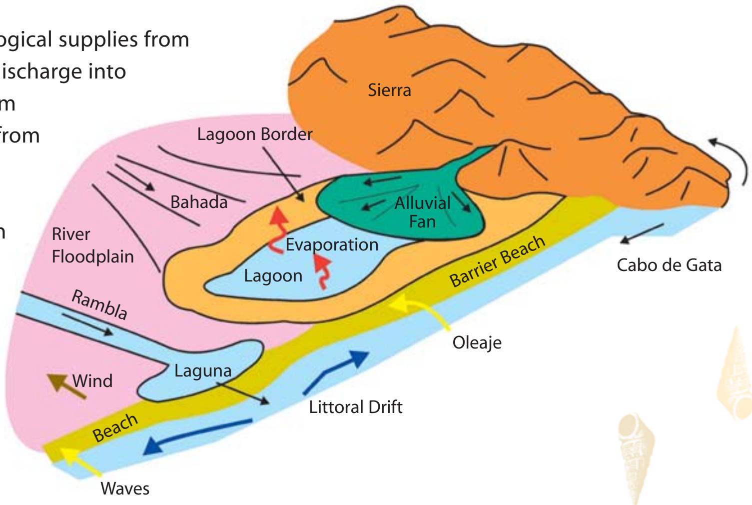
The modern salt pans (salinas) of Cabo de Gata constitute a magnificent example of an 'albufera' or backshore lagoon system set up as a Mediterranean salt pan by man. This type of system is natural, and is generated thanks to a depressed area at the back of the coastline, where freshwater accumulates. It is permanently separated from the sea by a beach-barrier, forming mainly from sandy sediments carried by the ramblas and displaced along the length of the coastline by littoral drift.

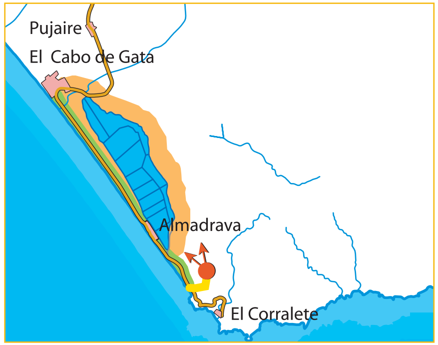
The lagoons receive hydrological supplies from rainwater, from rivers that discharge into them and, on occasions, from subterranean aquifers and from the sea itself.

The lagoon tends to fill with sediments from diverse sources. The most important are provided by the alluvial apparatus that drain the surrounding relieves of the sierras. Sandy sediments from the beaches that wash over the barrier beach and mud carried by the wind have less importance.

Evaporation, controlled primarily by direct sunshine and by the wind, plays a very notable part in the dynamics of these lagoons, contributing effectively to their desiccation, which is why they can be a suitable mechanism for the manufacture of salt.

IDEALIZED GEOMORPHOLOGICAL SKETCH OF THE SALINAS

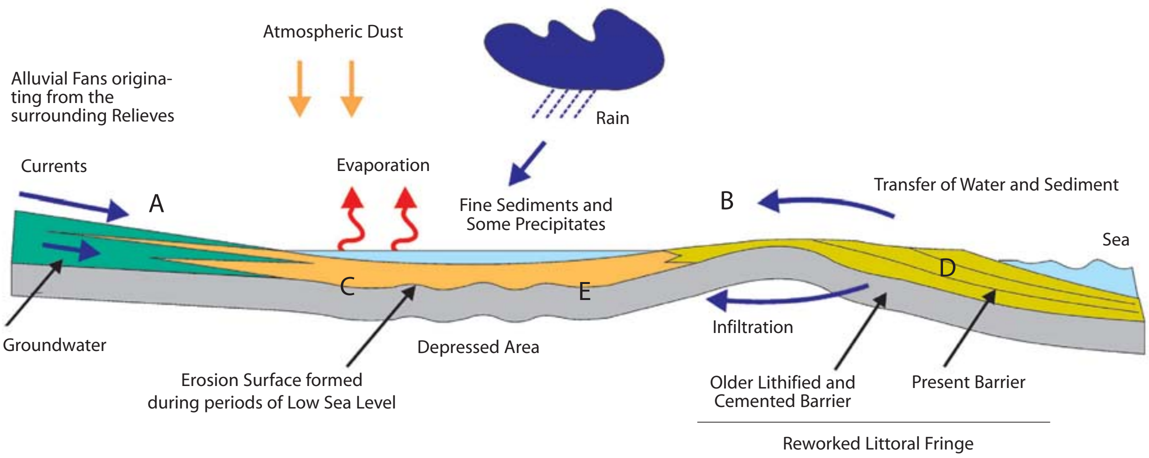




Aerial view of the active alluvial fan systems that originate from the Sierra de Cabo de Gata relief. In many cases they behave as coalescing fans, in that they are laterally connected and superimposed one upon another.

5. The Salt Pans (Salinas) of Cabo de Gata

IDEALIZED GEOMORPHOLOGICAL SKETCH OF THE SALINAS



A schematic section of the lagoon showing the diverse dynamic and morphological elements.

The deposits of the lagoon (E) connect with those of the alluvial fans (A) and with those of the backshore part of the beach (B) that obtains sediments carried during large storms when swells can spill over the barrier beach.

The model is only active, as at present, during the periods which high sea level is maintained that coincide with interglacials. On the other hand, during glaciation the sea level had remained lower, placing the beach towards the south. In these periods the zone could remain subjected to the erosive action of external agents (wind, currents, etc.), forming an erosive surface (C).

When the lagoon and the littoral fringe (strandplain) are active, during interglacial periods, the beach grows (progrades) towards the sea (D) and a thick covering of sediments accumulates in the lagoon (E).

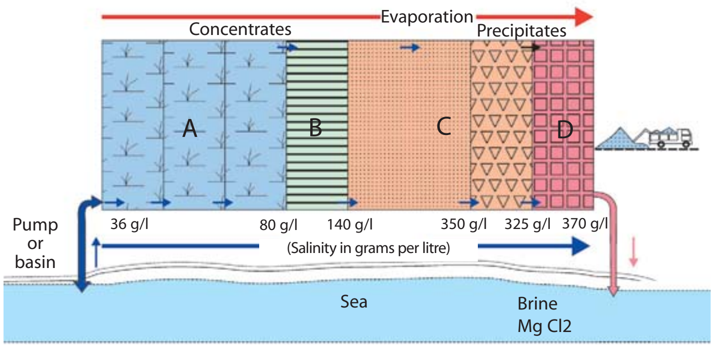
View of the salinas from the south.

WORKINGS OF A MARITIME SALT PAN

The natural lagoon systems like that of Cabo de Gata have historically been utilised by man in the extraction of salt: these are the characteristic maritime Mediterranean salt pans. Basically this consists of taking water from the sea in a controlled process of evaporation, by which means a progressive increase in salinity is produced, until a stage of saturation and precipitation of common salts (halite, NaCl) is reached.

In each a circuit that consists of several concentration pools (A, B, C) of broad extent and little depth is established, fed directly by water from the sea with a salinity of 36 grams per litre. The seawater is introduced by a channel to the first concentration pools (A), in which the marine macrofauna is retained (fish, gastropods,…) and a settling of (terrigenous) material from suspension is produced. Precipitation of calcium-magnesium carbonates (upon increasing salinity from 36 to 140 grams per litre) and the elimination of micro-organisms (algae, bacteria,…) occurs in the marine water upon achieving an intermediate concentration (B). After this initial phase, the water follows its path through different concentrations (C), favouring the precipitation of calcium sulphate (upon reaching a salinity of 140 to 325 grams per litre). Once these undesirable products have been taken out of solution, the brine goes through crystallisation (D) where the precipitation of common salt (at 325-370 grams per litre) occurs, extracted for storage, purification and finally sale.

SALINISATION PROCESS



Aerial view of the salt pans from the east. The letters correspond to the identification of different areas of the salt pans referred to in the text.

Floating salt (halite) layers formed in the absence of wind.

6. Volcanic domes of Punta Baja, El Faro and Vela Blanca

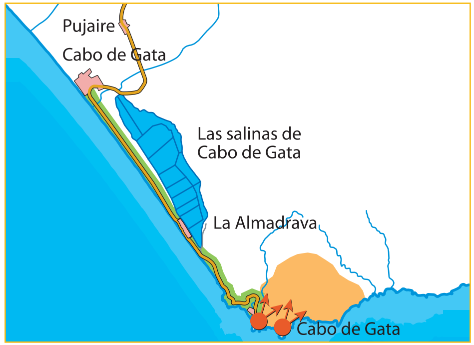
Juan M. Fernández

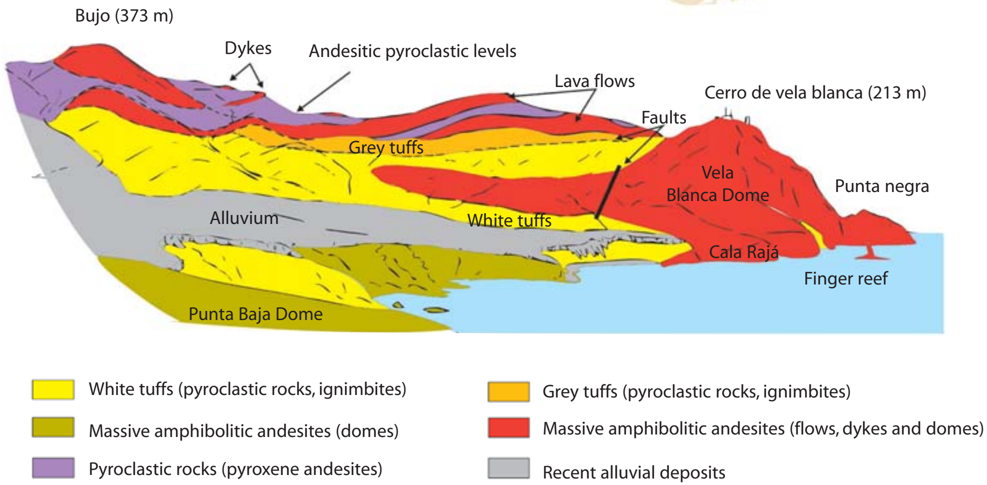
THE VOLCANIC SERIES

The coast in the vicinity of the Cabo de Gata lighthouse shows an excellent outcrop of massive volcanic rocks that form the structure of a volcanic feature known as domes. Their age of formation is greater than 12 million years. They are surrounded by a complex sequence of pyroclastic rocks and lava flows, of varying composition, that have been affected by hydrothermal alteration.

Climbing up the vela Blanca hill gives an overview of the volcanic rock succession that exists in the southern end of the Sierra de Cabo de Gata.:

- Surrounding the Punta Baja-Cabo de Gata domes, white-coloured rocks known as tuffs can be recognised. They have a pyroclastic origin (ignimbrites), that is to say, they are produced by highly explosive eruptions. These are the oldest rocks in the area.
- Above them, other levels of greyish-coloured tuffs are developed, also pyroclastic in character.
- On top of this andesitic lava flows (rock of intermediaate character) can be recognised. They form a well-defined promontory, that is repeated on the slope through the influence of various faults. At a distance, columnar jointing can be recognised.
- The Vela Blanca dome cuts across the tuffs and might have formed simultaneously with the previously mentioned lava flows. It is highly altered and impregnated with manganese oxides, which give it a very dark coloration (Punta Negra).
- Above the flows, another level of pyroclastic rocks appears that extends several kilometres towards the north.
- The highest peak (Bujo, 374 m) corresponds to an andesitic dome that cuts through the previous sequence. Similar domes are recognised at different points in the southern massif of Cabo de Gata.





VOLCANIC STRUCTURES

The dome complex of Punta Baja-El Faro-Vela Blanca comprises several massive lava bodies aligned in an east-west direction, probably exploiting a fracture in this orientation as they are extruded.

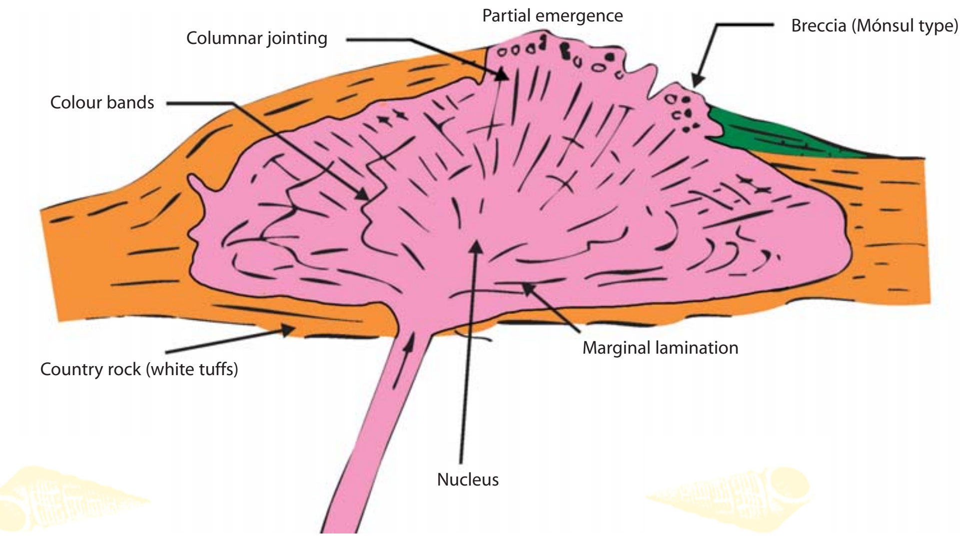
Domes are volcanic features that originated when viscous lava, rich in silica, flowed slowly onto the surface, and accumulated around, solidified and plugged its own exit point.
At times the lava does not manage to exit onto the surface, and forms an accumulation beneath the intruded rocks, that is called a 'cryptodome'.

The complex in this area contains two principal domes, one beneath the lighthouse and the other at Punta Baja, in both of which a spectacular series of characteristic volcanic structures may be recognised:

The most pronounced is columnar jointing, typical of massive rocks. It is produced through the slow cooling of lava after its emplacement. Upon cooling the volume of lava diminishes slightly, and this contraction is accommodated by the formation of regularly-spaced joints, in a perpendicular arrangement with respect to the cooling surface of the lava. The peculiar shape of these hexagonal columns of rock, means that they have been utilised, in this and many other place in the Sierra de Cabo de Gata, for obtaining paving slabs.

Other structures observed in these rocks are lamination and flow banding. This is mostly generated towards the margins of the domes, and includes folds that can be formed during the extrusion. The colour bands indicate slight differences in the composition of the lava during extrusion, whilst the flow lamination is produced by resistance to flow of viscous lava around the margins of the dome.

CRYPTODOME AND ASSOCIATED STRUCTURES



6. Volcanic domes of Punta Baja, El Faro and Vela Blanca

White tuff at Cala Rajá, pyroclastic material (ignimbrite) in which the domes of Punta Baja, El Faro and Vela Blanca are enclosed.

Columnar jointing in the Punta Baja dome.

Fanning of Columnar joints in Punta Baja, traditionally used for the extraction of decorative paving blocks.

Flow lamination on the margin of the El Faro dome in Cabo de Gata.

7. The Mónsul volcanoes

Juan M. Fernández

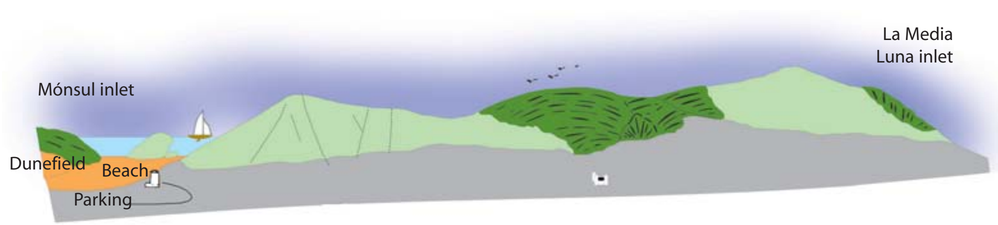
THE MONSUL SUBMARINE VOLCANOES

The steep volcanic cliffs surrounding the area of Mónsul consist of volcanic agglomerates (or breccias). They are a type of rock formed from angular blocks of (andesitic) volcanic rock, with a diameter that ranges from millimetres to metres, enclosed within a fine, sand-sized matrix, also of volcanic origin.

This material takes its origin from submarine eruptions produced around 10 to 12 million years ago, from submerged volcanoes. The volcanoes were located next to one another, in a manner in which, once an explosion had occurred, the erupted material was deposited in stacked layers on the marine seafloor.

In the panorama in front, the feeder zone of the volcano can be distinguished. It consists of darker, andesitic lavas, and exhibits a very characteristic structure known as columnar jointing. These structures are produced due to the contraction of lava upon cooling.

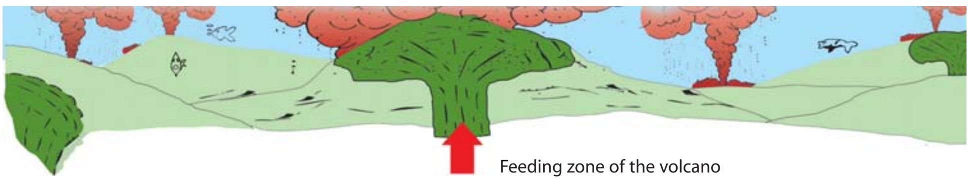
INTERPRETATION OF THE OBSERVED PANORAMA



Agglomerates or volcanic breccias | Andesitic lavas with columnar jointing | Beaches and Dunes | Debris

RECONSTRUCTION OF GENETIC PROCESSES

Sea level during the eruption



8. The 'barchan' dunefield of Barronal or Mónsul

C. Dabrio - J. Baena - J. L. Goy - C. Zazo

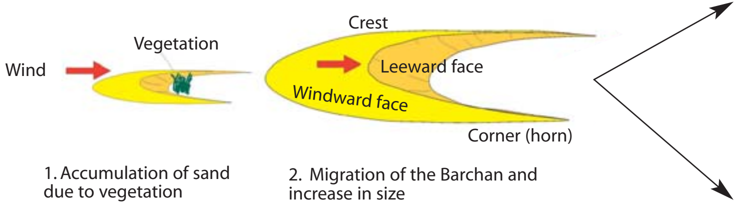
Wind carries out two fundamental processes, erosion and accumulation, which create certain morphological features; dunes are amongst these. The term 'dune' is used in a broad sense to designate the majority of accumulation features, of sand deposits.

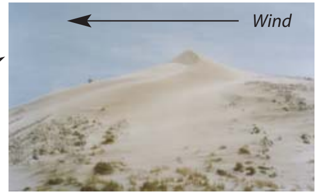
In the dunefields of the Almería littoral zone the dominant types, according to their morphology in plan view, are: barchans, or half-moon dunes, with their corners or points facing in the same direction as the wind; parabolic dunes, with the corners (horns) facing in the opposite direction to the wind; linear (seif) dunes, produced when a flat zone, with sandy material covering its floor, exists close to a relief orientated almost perpendicular to the dominant wind direction.

TYPES OF DUNES IN CABO DE GATA

PARABOLIC DUNES

BARCHAN DUNES

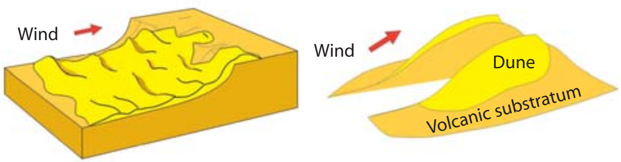




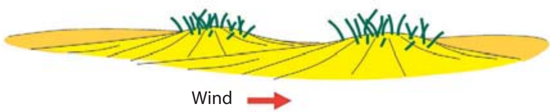
Mónsul barchan dunefield.

Movement of sand in favour of the wind direction in the Mónsul dunefield.

LINEAR (SEIF) DUNES



DUNES ACCUMULATING DUE TO VEGETATION



9. The Los Frailes Volcano

Juan M. Fernández

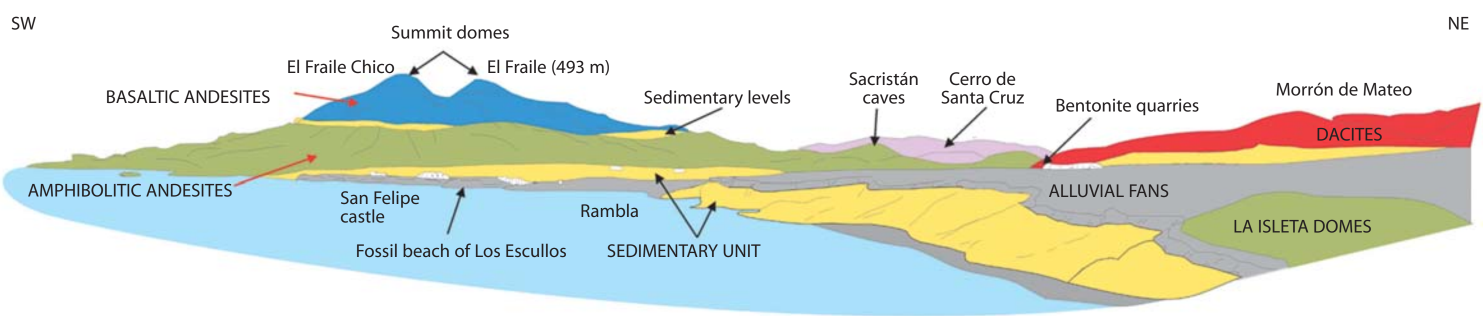
The Los Frailes hill (473 m), is one of the most distinctive elements of the volcanic Complex. It consists of two readily distinguishable units a lower unit of amphibolitic andesites and an upper unit of dark basaltic andesites, that correspond to the two main summits (El Fraile and the more recent El Fraile Chico). Both of the Los Frailes rest upon andesites, strongly altered by hydrothermal processes, that make up the southern volcanic massif of Cabo de Gata.

LOWER UNIT:
AMPHIBOLITIC ANDESITES

The lower unit of Los Frailes constitutes the collapsed floor of a magma chamber that was vacated during an individual or several very intense eruptions. In these eruptions a great volume of magmatic material left the surface through rapid and very explosive phenomena, and the roof of the magma chamber collapsed giving rise to a chaotic mixture of rock fragments, associated with dome remains and lava flows, that constitute the most common material in this lower unit. The explosive intervals are marked by intervals of pyroclastic rock (tuffs) of different types, that are found intercalated

between the units of chaotic breccias. In numerous places layers of sedimentary rocks are found in addition, pertaining to beach and shallow marine environments, rich in fossils;

GEOLOGICAL PANORAMA OF THE LOS FRAILES VOLCANO FROM THE LA ISLETA VIEW POINT



these are intercalated within the volcanic rocks of the lower unit, and are very abundant between the lower and upper units. The age of the lower unit is believed to be between 10.8 and 12.4 million years by some authors, and around 14.4 million years by others.

**UPPER UNIT:
BASALTIC ANDESITES**

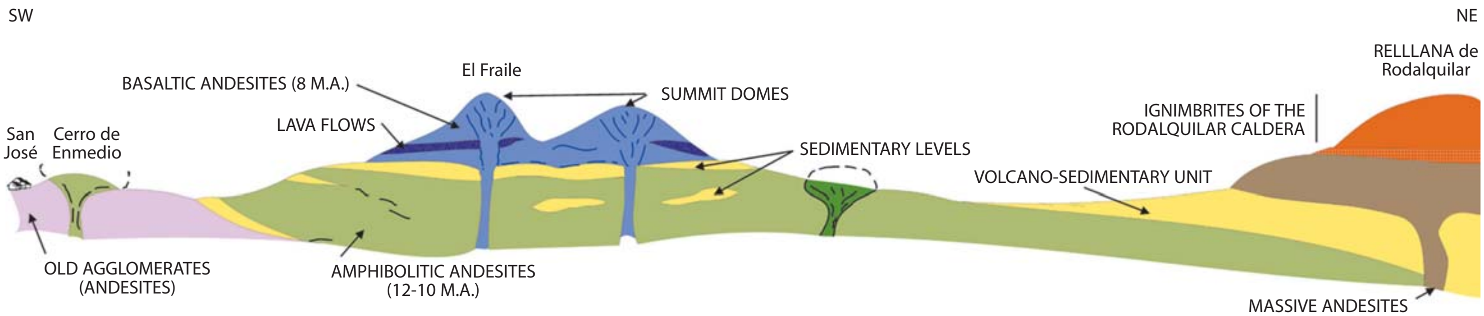
The summit of Los Frailes is composed of a unit of basaltic andesites. These rocks are the most basic (poor in silica) in Cabo de Gata, although with properties that did not reach the point of being basalts.

They are relatively well preserved rocks, without alteration, whose age is estimated at 8.5-8.6 million years. They are also situated above sediments rich in fossils from the Tortonian, belonging to shallow marine environments, and beach sediments. This data indicates that this upper unit of Los Frailes constituted a volcanic island during its formation 8 million years ago.

The unit is built from two main emission centres, that discharged several massive lava flows (at around 1000º C temperature), whose characteristic columnar jointing has been utilised for the quarrying of paving stones (several hills can be seen in the middle of the slope).

Other eruption phases gave rise to abundant agglomerates or pyroclastic breccias, in eruptions somewhat more explosive. The end of magmatic activity is marked by the extrusion of the domes that constitute the two previously-mentioned pinnacles (summit domes), that sealed the eruption vents. Erosion has been intense up until now, although the greater relative resistance of the massive lava domes has configured a roughly conical erosive morphology for this unit.

INTERPRETED GEOLOGICAL PANORAMA OF THE LOS FRAILES VOLCANO FROM THE LA ISLETA VIEW POINT



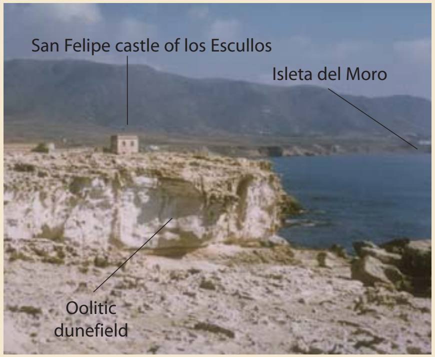
10. The fossil dunefield of Los Escullos

C. Zazo - J. L. Goy - J. Baena - C. Dabrio

In the Almerían littoral zone there have been three important phases dune system development during the Quaternary: greyish cemented dunes, formed of the fragments of schists, volcanic rocks, and quartz grains, such as those that are observed in Rambla Amoladeras, and which formed at a time known to be between 250,000 and 180,000 years ago; white-coloured oolitic dunes, consisting of rounded grains known as oolites, around 128,000 to 100,000 years old (last interglacial period); and finally, greyish, uncemented dunes , that illustrate the same coloration and composition as the first, although in this case they were not cemented, formed from around 6,000 years ago to the Present.

In the Los Escullos cove, beneath the San Felipe castle, we can observe, without doubt, the best exposure corresponding to white, oolitic dunes in the Natural Park. However, other exposures exist in the Rodalquilar and Los Genoveses beaches.

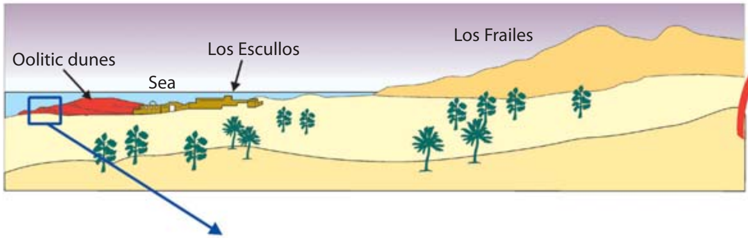
These ancient dune systems are excellent indicators, not only of the position of the coastline at the time of its formation, but of the ecological and environmental conditions.
In effect, the oolitic dunes were generated due to the movement of old oolitic beach sediments by the wind, formed in a warmer environment than at present. This is knowwn through the existence of an associated fauna (Strombus bubonius)that belongs to warm seas, and by the ooliths themselves. Through the microscope it can be observed that the ooliths are composed of a nucleus of quartz grains or rock fragments or faecal pellets and a coretex that shows concentric layers of aragonite. Oolites actually form in the infralittoral zone, at a few metres depth, on the seafloor of warm waters that are saturated in carbonate and highly agitated by waves.



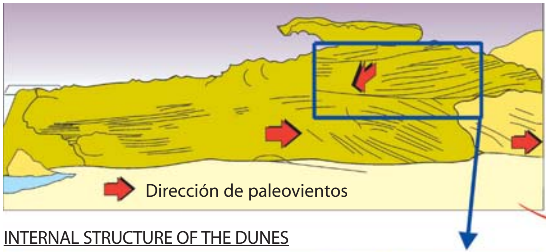
The San Felipe castle of Los Escullos sits on top of a spectacular fossil oolitic dunefield. Without doubt the best record of this type of deposit in the area of the Natural Park.

In the Cabo de Gata Natural Park area, fossil oolitic dunefields exist in other places: here the exposures of Los Genoveses may be observed.

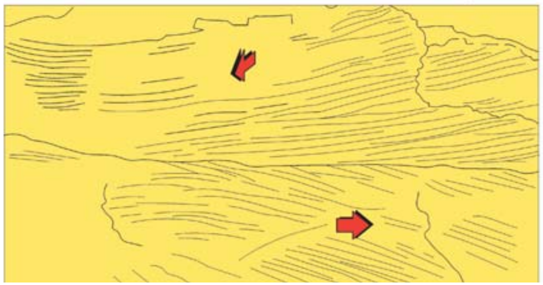
OOLITIC DUNES OF LOS ESCULLOS

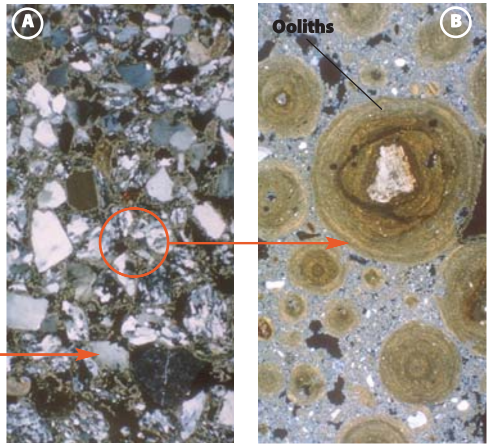


DETAIL OF THE OUTCROP



INTERNAL STRUCTURE OF THE DUNES





Microscopic view (thin section) of the components of dune oolites from Los Escullos (Photo A). Upon increasing the resolution (Photo B) the ooliths can be identified perfectly as the spherical structures that stand out within the sandy matrix.

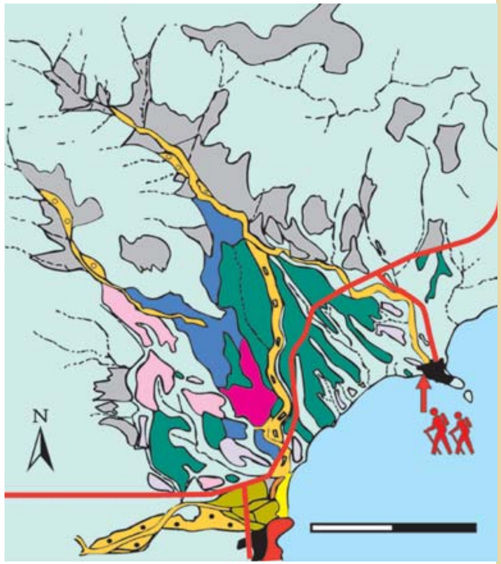
11. Alluvial fans of the La Isleta-Los Escullos coastal plain

J. L. Goy - C. Zazo - C. Dabrio - J. Baena

The Sierra de Cabo de Gata exhibits an abrupt relief, with strong slopes, that contrasts with the gentle morphology of the littoral depressions (coastal plains). The abrupt change of slope that is produced in the courses of small barrancos as they exit from the mountain relieves, and enter the depression, provokes a fall in their capacity to transport and the consequent accumulation (deposition) of the sediments (blocks, pebbles, silts, etc.) which they moved towards the most low-lying areas. An open alluvial fan in thus formed.

SIMPLIFIED GEOLOGICAL SCHEME OF THE QUATERNARY DEPOSITS IN THE LA ISLETA-LOS ESCULLOS AREA

		Fluvial deposits		Slope deposits	Littoral deposits	
		Alluvial fan deposits	Channel deposits of terraces and rivers	Gravity deposits	Marine deposits	Aeolian deposits
Quaternary	Holocene	Phase 6 (c)	Present river	Colluvium and undifferenciated slope deposits	Beach	
		Phase 6 (b)			Littoral barrier	
		Phase 6 (a)				
	Pleistocene		2nd Terrace			Aeolian dunes
		Phase 5	1st Terrace			
		Phase 4				
		Phase 3				
		Phase 2	Abandoned river			
		Phase 1				
	Miocene	Volcanic rocks				



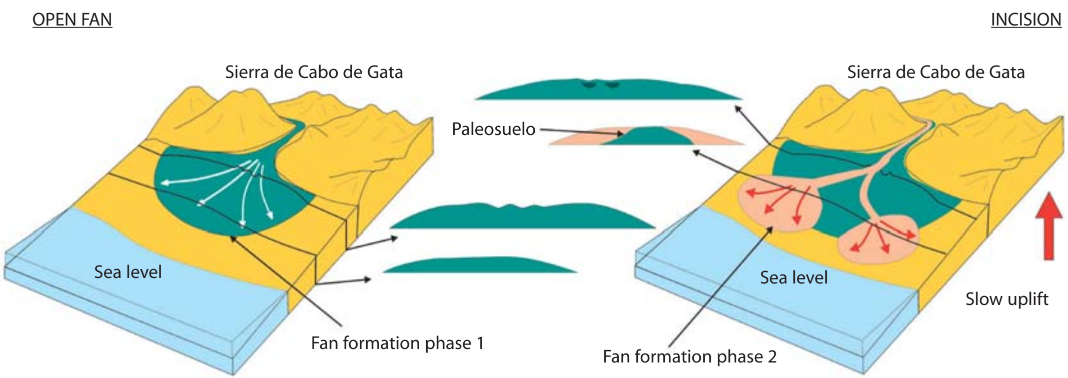
11. Alluvial fans of the La Isleta-Los Escullos coastal plain

A fall in sea level, linked to the slow uplift of the relief, caused incision of the initial barranco (primary river course) in the deposits of the older open fan, upon whose surface soils were already able to develop.

The formation of subsequent fans, during the initiation of a new rise in sea level, gives way to incised fans at a lower altitude to the previous one.

In the area of La Isleta-los Escullos, several incised surfaces (roofs of fans), inclined gently towards the sea are observed, that represent distinct phases of fan formation throughout the Quaternary. Theses are due to changes in the climatic conditions, tectonics and eustacy (oscillations of sea level), and their study provides very interesting information about such conditions.:

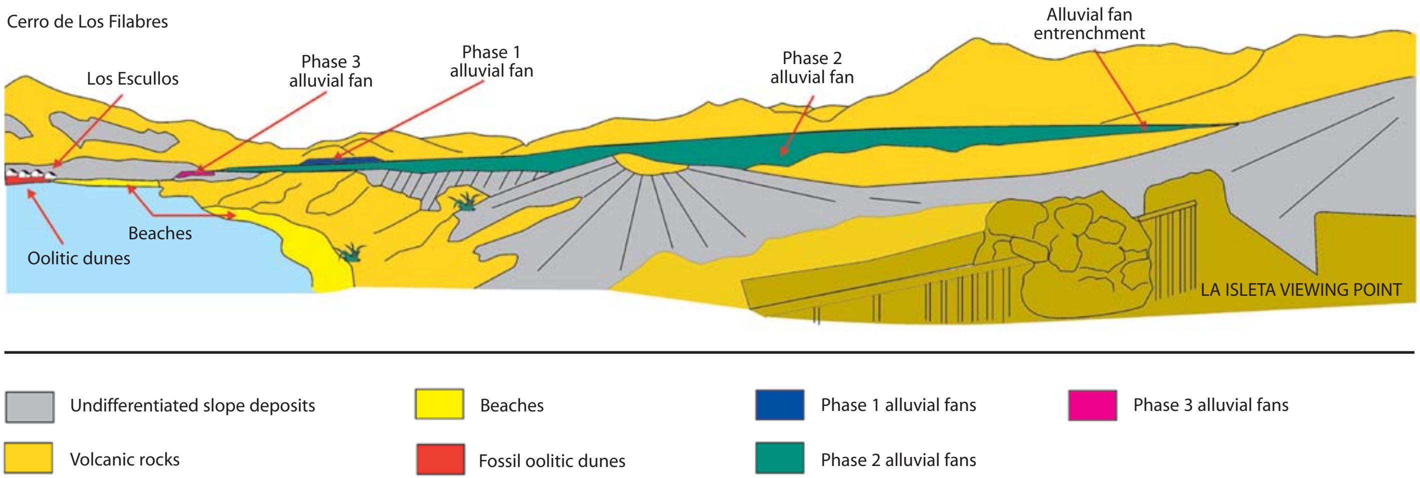
PROCESSES OF DEPOSITION AND INCISION IN ALLUVIAL FANS



Aerial view of La Isleta-Los Escullos in which phase 2 alluvial fans may be observed, with a schematic overlay.

11. Alluvial fans of the La Isleta-Los Escullos coastal plain

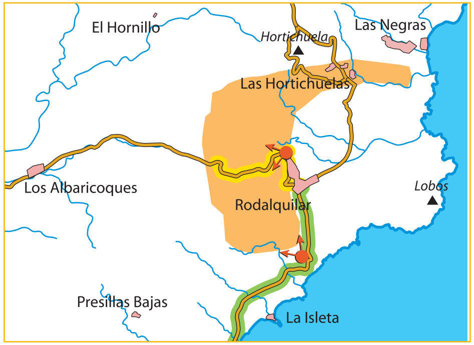
PANORAMA FROM THE LA ISLETA VIEWING POINT AND INTERPRETATION OF THE ALLUVIAL FAN SYSTEM

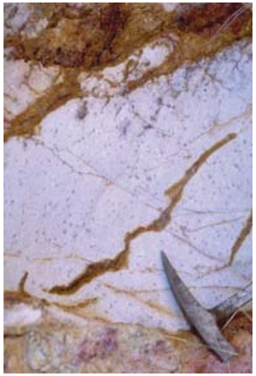


12. Rodalquilar volcanic calderas

Juan M. Fernández

One of the most significant volcanic structures of the Cabo de Gata Volcanic Complex are the Rodalquilar calderas, from the centre of which known gold deposits are located. Rodalquilar shows the superposition or nesting of two successive calderas; the larger is the Rodalquilar caldera, and inside it the La Lomilla caldera is located (thus named after La Lomilla de Las Palas). Theses calderas are collapse structures produced by highly explosive eruptions, that gave place to tow large units of pyroclastic rock, known as the Cinto ignimbrites and the Lázaras Ignimbrites, respectively. Calderas are collapse features that are produced when, during an explosion of great magnitude, the magma chamber is very rapidly vacated and its roof collapses, leaving behind a roughly circular depression.

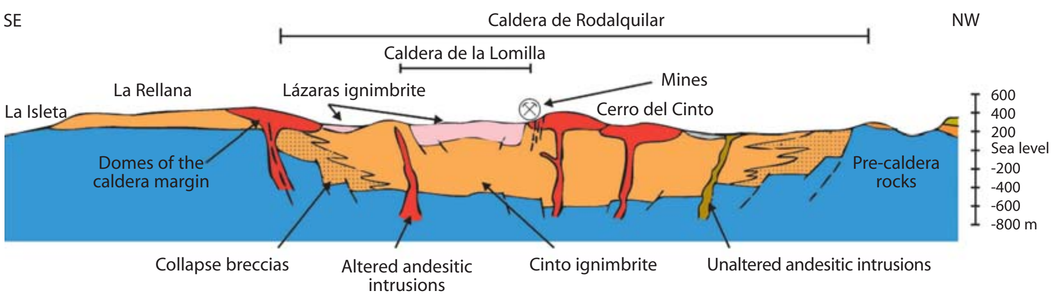




Detail of the Cinto pumice flows. The dark stippled area corresponds to large quartz crystals.

Detail of the Cinto collapse breccias. Concentration of (dark) blocks within a pumice flow (light-coloured).

INTERPRETED GEOLOGICAL SKETCH OF THE RODALQUILAR VOLCANIC CALDERA



GEOLOGICAL HISTORY

The Rodalqular Caldera and the Cinto Ignimbrite

The Rodalquilar Caldera is the larger, with a 4km by 8km width and an oval shape. Its origin is related to the thick pyroclastic unit of the Cinto Ignimbrite, which formed 11 million years ago, on top of a mass of older mass of andesitic flows (A), due to collapse of the magmatic chamber.

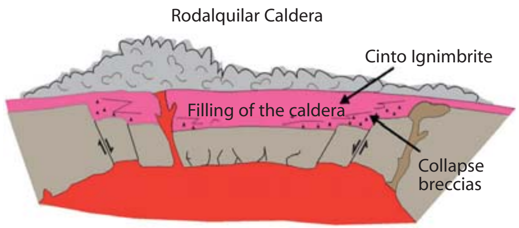
Since the collapse of the Rodalquilar Caldera and formation of the Cinto Ignimbrite (B), the magmatic chamber refilled itself, and the ignimbrites filling the caldera bulged outwards, making way for the present Cerro del Cinto (a resurgent dome). This phenomenon is very common during caldera formation processes, and is called resurgence (C).

La Lomilla Caldera and the Lázaras Ignimbrite

A new episode of intense eruptive activity gives way to the formation of the Lázaras Ignimbrite, simultaneously with the collapse of the La Lomilla Caldera 9D). this caldera is 2 km in diameter and is nestled in the Rodalquilar Caldera.

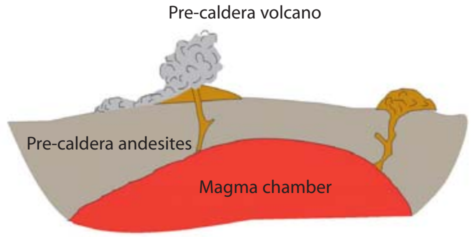
The system of fractures generated during the collapse were later infilled through the development of a hydrothermal system and by mineral deposits.

B. FORMATION OF THE RODALQUILAR CALDERA

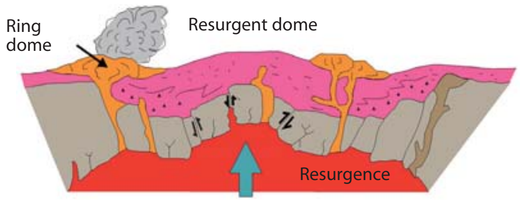


Thin layers of sedimentary and volcanic rocks were deposited on top of the planar surface of the Lázaras Ignimbrite.

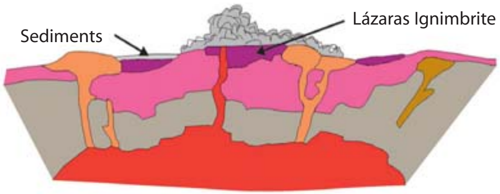
FORMATION OF THE MAGMATIC CHAMBER



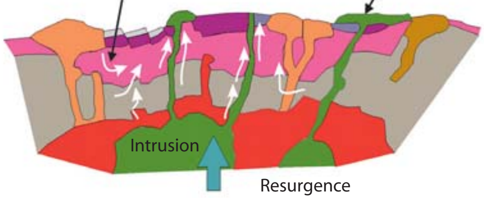
C. RESURGENCE



D. FORMATION OF THE LA LOMILLA CALDERA



RESURGENCE AND FORMATION OF THE HYDROTHERMAL SYSTEM



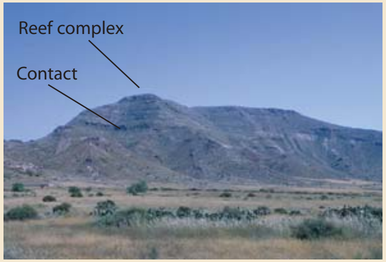
Resurgence and hydrothermal systems

The end of magmatic activity in Rodalquilar is marked by the emission of a series of flows and the extrusion of andesite on the surface, and the formation of an intrusion just underneath the Rodalquilar calderas. This new phase of resurgence of the magmatic system is accompanied by a doming of the pile of volcanic material, the opening of fractures and the development of the hydrothermal system, which produced alteration of the rocks and the formation of mineral deposits. The age is younger than 9 million years. In this phase a series of very extensive fractures formed with a north-south orientation, that were partly infilled through mineralization.

Finally, all of the associated volcanic deposits were covered by marine carbonate sediments at the end of the Miocene (latest Tortonian and Messinian), forming the features of La Molata, Romeral, Molatilla, etc.

Domes formed on the ring-like margin of the caldera.

The Lázaras Ignimbrite corresponds to a tuff formed from pumice fragments (dark colours) in a matrix of fine ash (light colours).



La Molata carbonates on top of the ignimbrites of the Rodalquilar caldera.

13. Mining and metallurgical processes in Rodalquilar

Carlos Feixas

MINING IN RODALQUILAR

Exploitation of gold in Rodalquilar has been carried out by means of two very different methods, such that it relates to extraction as much as to the retrieval of precious metal.

Mining in the 19th century and at the start of the 20th century, was carried out by internal exploitation of high-grade quartz veins through means of shafts and galleries. On the other hand, mining took a new path from 1956 through the National Company ADARO, characterised by combined exploitation; interior workings with high grade material (over 5 g/ton), and cutting or quarries on the outside, with lower grade material (1 to 1.5 g/ton)> the mixture of these products allowed intermediate grades of 3 g/ton to be obtained, optimal for the type of extraction plant that was working it.

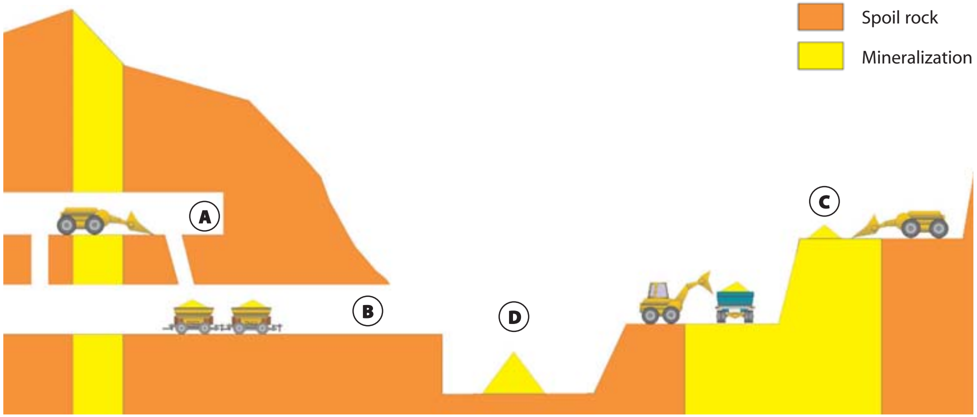
In the last decades of the 19th century and the start of the 20th century, the recovery of gold was carried out through means of smelting furnaces obtaining a lead blende rich in gold and silver. In the second half of the 20th century, recovery was carried out through the operation of electric furnaces, after concentrating by means of washing with cyanide solutions.

Opening of the track that connected the Cerro del Cinto mine workings with the grading and concentration plant. This infrastructure already meant an enormous advance that opened up the possibility of mechanising the quarrying system (Photo, Evaristo Gil Picón).

Mine entrance of 'Lode 340' during the period of maximum activity in the mining district of Rodalquilar. The photograph is taken roughly in the 50's decade (Photo, Evaristo Gil Picón).

QUARRYING METHODS

The extraction workings in the interior are achieved by following the auriferous lodes and exploiting raised chambers (A); the materials was removed by shafts and galleries (B). The outside workings were carried out on small, terraced, quarry benches (C). The minerals obtained in this way were mixed and piled up ready for transport to the treatment plant (D).



Cerro del Cinto quarry cuttings completed by ADARO in order to supply the treatment plant.

The darker structures correspond to the richest lodes (Photo, Juan M. Fernández).

METALLURGICAL METHODS

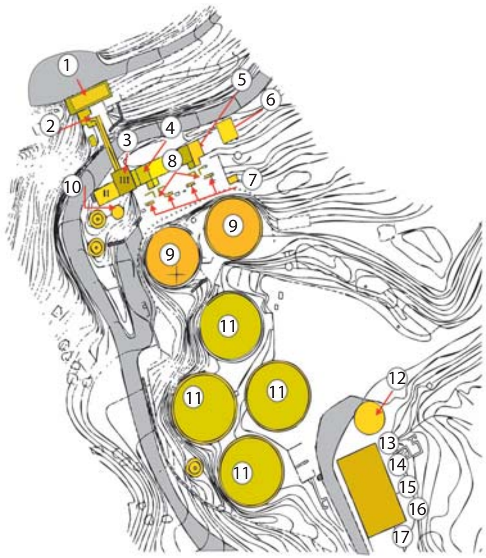
The quarried mineral was mixed in a storage shed (1), and afterwards subjected to initial crushing in a grinding machine (2), and secondly in a mill (3). Later it was classified in vibrating sieves (4 and 5). This product was submitted to electromagnetic separation (6), in order to eliminate metals other than gold. Afterwards it was milled in ball mills (7). The remains were classified in pressure washers (8) in order to separate the fines, without gold, and return the pieces with gold to the mills for grinding. The minerals concentrated in this way were mixed in two heavy tanks (9) with a solution of cyanide (10) in order to subject it to the following chemical reaction in a medium with pH 9 to 11:

$4 Au + 8 CNNa + O_2 + 2 H_2O \text{--->}$
$4 Na(CN_2 Au) + 4 NaOH$.

In 4 cleaning tanks (11) the mixture of mineral and cyanide is removed and ventilated in order to obtain the solution rich in gold, that is reclaimed in the tank (12). The cyanide solution is rinsed in tanks (13) and afterwards put through a filter. Immediately following the ventilation continues under a partial vacuum by means of pumps in tanks (14) and, straight afterwards, is added to zinc dust in a tank (15, 16) in order to activate gold precipitation in the following reaction:
$2 NaAu(CN)_2 + Zn \text{--->} Na_2Zn(CN)_4 + 2Au$.
This process is known as "Merril Crowe".

The precipitate in the tanks comes from a process of retrieval through precipitation by means of zinc dust, with zinc content of between 10 and 40%; it is put through an electric heater for drying, where the last traces of humidity are removed. The dry product is precipitated by acid washing and the precipitate is removed through filtration. The gold is obtained by fusion in an electric furnace.

OPERATIONAL RECONSTRUCTION ACCORDING TO THE METALLURGICAL PROCESSES IN THE ACTUAL INSTALLATIONS OF RODALQUILAR



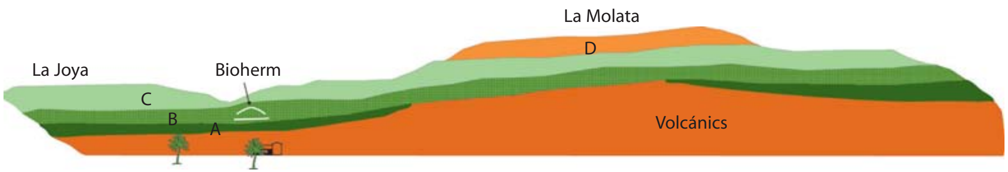
Photograph from an era when the mining installations of Rodalquilar were working. The photo dates from the 50's decade (Photo, Evaristo Gil Picón).

System of cleaning tanks in operation (Photo, Evaristo Gil Picón).

14. The Post-volcanic sediments of La Molata de las Negras

Juan C. Braga - José M. Martín

In La Molata de Las Negras sedimentary rocks are present that record the geological history of the Cabo de Gata region since the volcanic activity. Above the volcanic basement a series of sedimentary units may be observed that correspond to deposits formed in a small basin (an inlet or bay), connected with the Mediterranean, and presently emerged, uplifted above the present sea level. The presence of coral reefs and oolitic limestones indicates that during the formation period of units B, C and D (Messinian), the climate of the western Mediterranean was warmer than at the present day and similar to that of tropical latitudes at present.



UNIT A

Consists of bioclastic limestones; rocks composed of the remains of bryozoan skeletons, bivalves, red algae, starfish, sea urchins and foraminiferans. These organisms lived in the small marine basin of Las Negras, joined to the Mediterranean in the Upper Tortonian-Lower Messinian, around 7 million years ago. The organisms whose remains form these rocks are similar to those that today live, and produce sediment, in the marine platform surrounding Cabo de Gata. The climate in the region during this period would have been similar to present or slightly warmer. A small proportion of theses rocks comprises clasts and grains coming from the erosion of the volcanic relieves.

Field view of bryozoans and fossil bivalves that formed the limestone of Unit A.

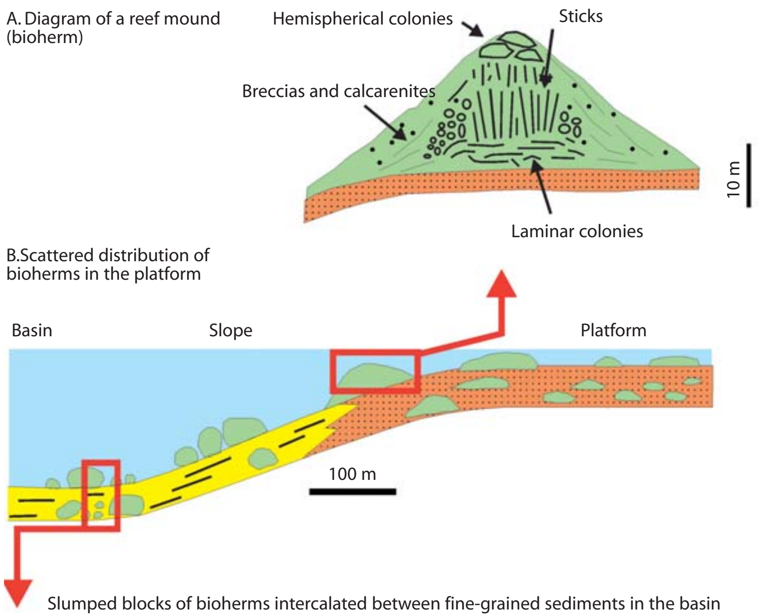
The remains of calcareous algae and bryozoans that presently live on the seafloor of the Cabo de Gata platform produce a sediment similar to that which formed the limestone of Unit A.

UNIT B. CORAL REEFS

TAfter deposition of the bioclastic limestones there was a stage of uplift and deformation of the basin seafloor, in such way that before the following unit (unit B) was deposited, the bioclastic limestones were inclines and underwent erosion (observed in the panorama and view point from the central part of the hillside).

In Unit B, formed during the Messinian around 6 million years ago, coral reefs stand proud in the form of isolated pinnacles (bioherms), such as that which stand out in the panorama, easily appreciable from this perspective. These reefs are mainly formed through the in situ accumulation of the calcareous skeletons of corals belonging to several genera (Porites, Tarbellastrea and Siderastrea). Between the coral colonies and around the pinnacles, algae and invertebrates lived, whose skeletons also contributed to the formation of carbonate sediment. Blocks derived from these reefs, such as that observed to the left of the large pinnacle, fell down slope and became mixed with the marls and mud that were being deposited in the sea offshore, in deeper regions, situated towards our left. Marls formed through the settling of silt from suspension in seawater, and through the accumulation of the skeletons of planktonic micro-organisms such as foraminifers, unicellular algae, and at times diatoms.

DISTRIBUTION AND STRUCTURE OF BIOHERMS IN THE REEF STRUCTURE

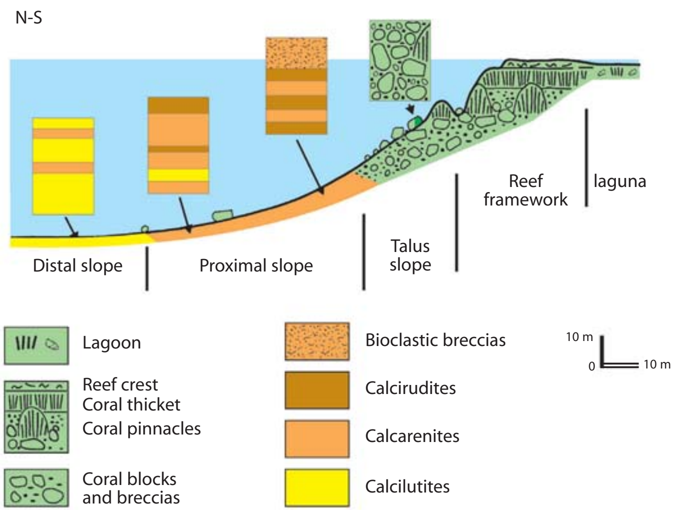


Tarbellastrea coral colony, one of the components of the Unit B bioherms.

UNIT C

Corresponds to a fringing reef that was advancing from our right towards our left. Here the corals are almost exclusively Porites and the coral colonies are surrounded by foraminifers and encrusting red algae; that in turn are covered by stromatolites, that is to say, carbonates that are precipitated (or bound) by the action of micro-organisms, mainly cyanobacteria. Towards the sea (towards the left), the reef gave way to a slope where debris coming from its destruction accumulated. The grain size of this debris is segregated downslope, in a way that it continually becomes finer. Between the reef debris, other organisms grew, such as calcareous green algae (Halimeda) and bivalves.

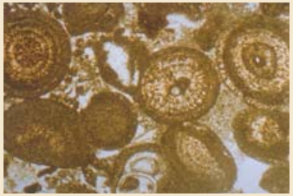
DIAGRAM SHOWING ONE PHASE OF REEF GROWTH



UNIT D

Rests on an erosion surface that had an effect on the reef (Unit C) and removed a large part of its deposits. This erosion surface is the expression of the Messinian desiccation of the Mediterranean at this locality, known as the salinity crisis. Its age is end Messinian (around 5.5 million years ago).

Unit D is fundamentally formed from stromatolites and oolitic carbonates. The latter are made up of microscopic, spherical particles, called ooliths, with an internal structure of concentric layers of calcium carbonate. Oolites are presently forming in the shallow, agitated waters of tropical seas. Stromatolites are domes or irregular constructions formed by miilimetre-thick (or less) layers of carbonate.



Microscopic view of ooliths that formed the carbonates of Unit D.

Field view of stromatolites, with their typical laminated structure.

15. Bentonites of cabo de Gata

Carlos Feixas

GENESIS AND NATURE OF BENTONITES

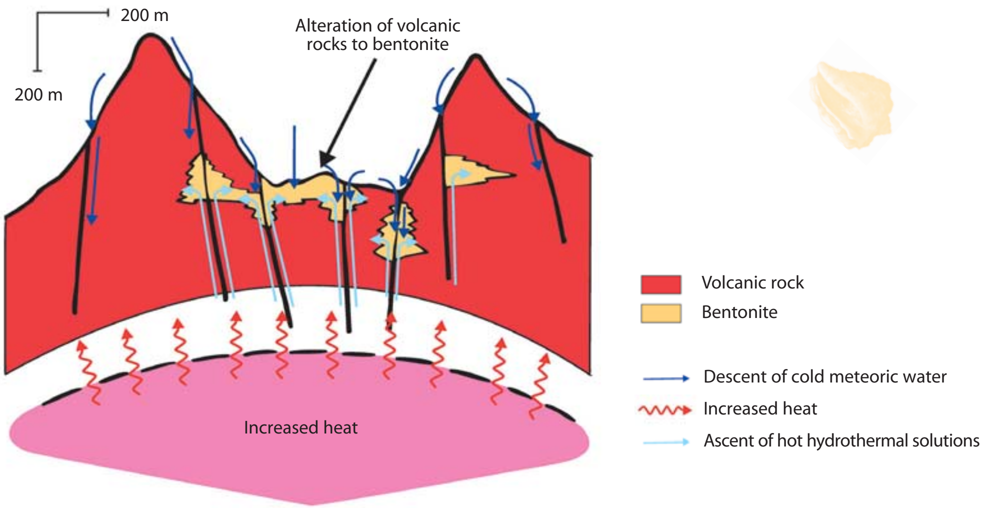
Bentonite is a rock composed of minerals from the clay group. Their internal structure of superimposed layers of different chemical composition defines their key characteristic: their capacity to absorb a quantity of water several times greater than their own volume. This is produced through storage of fluid in the spaces that exist between the different layers.

Bentonites originate from the alteration of volcanic rocks, also through processes of hydrothermal alteration (rise of hot solutions through fractures) or also through weathering alteration (due to the action of meteoric water).

The special composition of the Cabo de Gata volcanic complex means that within it the greatest concentration of bentonite deposits in Spain formed. In fact, they constitute the only exploited industrial minerals that exist within the Natural Park.

The Cabo de Gata bentonites are by nature around 75% to 95% Calcium-Sodium-Magnesium types, and the rest of the rock consists of other types of clays and small quantities of other minerals originating from volcanic rocks. They display various colours, from reds, greens, yellows and blacks, to whites. The deposits have an irregular and stratified morphology.

SIMPLIFIED DIAGRAM OF BENTONITE FORMATION

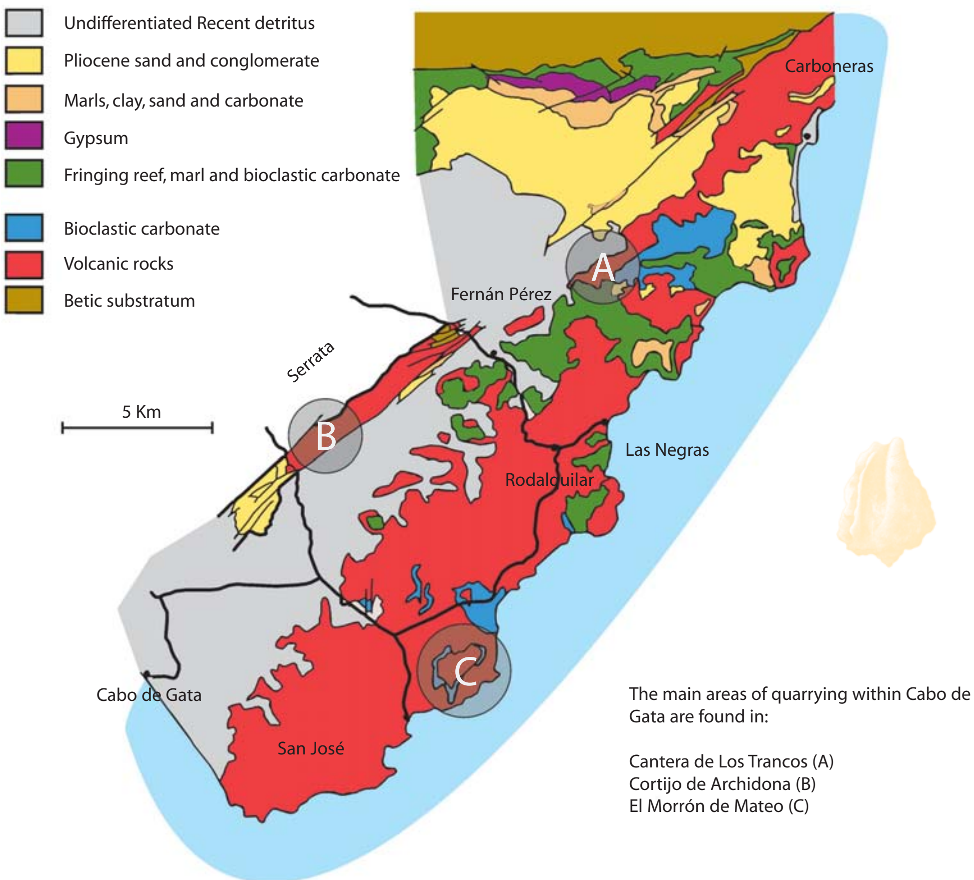


15. Bentonites of cabo de Gata

Bentonite quarry exploited in an intermittent fashion in the Serrata de Níjar. The bentonite masses that display some colouration hold less commercial interest than those that are white.

Quarrying of white bentonite in the area of Morrón de Mateo.

DISTRIBUTION OF QUARRYING. GEOLOGICAL MAP OF THE CABO DE GATA AREA



The main areas of quarrying within Cabo de Gata are found in:

Cantera de Los Trancos (A)
Cortijo de Archidona (B)
El Morrón de Mateo (C)

15. Bentonites of Cabo de Gata

Bentonite mining is carried out through an open cast quarry method. In a modern quarry the following activities are undertaken:

- *Conditioning and preparation*
  The discovery of productive layers takes place with the help of excavating machines or mechanized tractors.

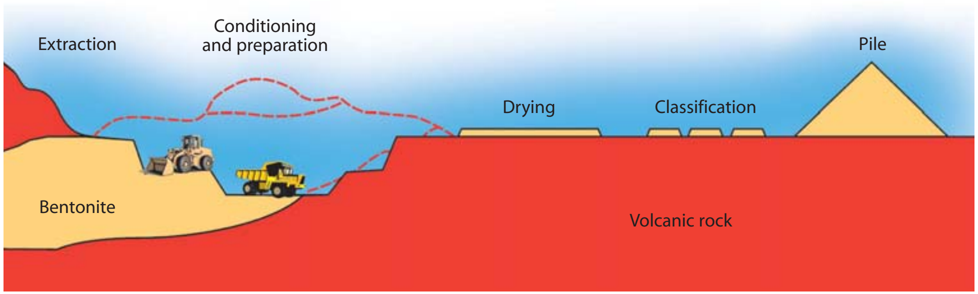
- *Extraction*
  Once the surface is cleaned off, quarrying is carried out by cutting down benches lengthwise along the face, with a height of about 10 metres and a length close to 50 metres.

- *Drying and classification*
  The material quarried in this way is spread out across large areas or "heaps", cleaned of impurities and classified by qulaity according to the use for which it is destined.

- *Storage*
  The dried and classified material is stored in large uncovered piles ready for transport to treatment plants or for direct sale.

The mineralized body might be covered by non-mineralized rocks that need to be removed for quarrying.

Los Trancos quarry is the principal bentonite mining concern in the park. The extent of the quarry benches can be observed, taking the lorries as a scale.



USES AND APPLICATIONS

Bentonite clays, due to their physical properties, are utilised in many industrial fields.

- In the smelting industry they are used, along with siliceous sand, to prepare the mould of manufacture parts, in that they are capable of fusing together the sand, without altering the composition of the cast.

- Addition to cements allows mortars to remain fluid for a longer period of time, for which its use is essential in special cements.

- As an integral part of drilling mud. Due to its addition, the viscosity of the drilling mud increases and is capable of pulling out broken components more easily. Additionally, it is capable of covering and keeping the walls of the borehole intact when drilling of the borehole finishes.

- Its addition to powdered irons minerals means that they can be recovered in a profitable way from smelting.

- Their capacity for absorbing water and ionic exchange means that they can serve as cleansing aids and fertilizers, also as discolourants and clarifiers of wines and oils.

- Properly compacted it is an excellent impermeable material, used to this end for holding back and securing residues in storage containers and potentially contaminant substances.

Characteristic field view of bentonite clays: white-coloured powdered masses, greasy to the touch and very plastic.

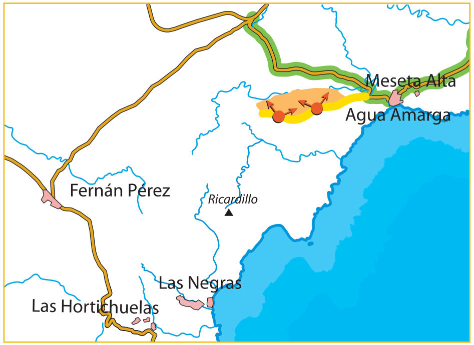
16. Marine sediments of Cañada Méndez (Agua Amarga)

Juan C. Braga - José M. Martín

In the outcrops of Cañada Méndez, exceptionally exposed carbonate sediments generated in temperate and shallow marine platforms, with temperatures and salinities identical to the modern Mediterranean, are exposed. They are located directly on top of volcanic rocks 9.6 million years in age. At the very base of the sediment succession, just above the volcanics and immediately beneath the carbonates, sand of volcaniclastic character appear (that is to say, supplied by erosion of the same volcanic rocks) with a few marine fossils (essentially the remains of shells).

Two different carbonate units are represented. The lower stands out here as the most important, known informally as the red unit due to its characteristic colour. It is Lower Tortonian in age, roughly 9 million years old.

These carbonates are bioclastic in nature. They consist of the abundant, highly fragmented remains of calcareous marine organisms typical of shallow marine environments (0 to 100 m deep), such as bryozoans, red algae, bivalves, echinoderms, brachiopods, benthic foraminiferans, barnacles, gastropods and solitary corals, clearly visible in hand specimen and/or by microscope. Ordered internal sedimentary structures are extremely abundant in the carbonates, such as lamination, cross-stratification, etc., reflecting their transport through the action of waves and by currents on the same marine bottom.



Fragments of typical carbonate producing organisms in the platform environment.

16. Marine sediments of Cañada Méndez (Agua Amarga)

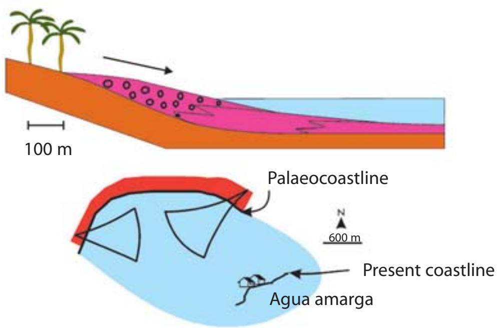
SEDIMENTARY RECORD, PALAEOGEOGRAPHICAL EVOLUTION AND SEDIMENTARY MODEL OF THE AGUA AMARGA BASIN

The sedimentary record in this area allows us to reconstruct the palaeogeography of the Agua Amarga Basin during the Lower Tortonian based on the interpretation of its distinct environments of deposition. Its palaeogeography was essentially that of a small bay, open towards the south, with a small submarine high (ridge) situated right at its entrance, especially notorious for determining episodes in its history. The basin was filled by different packages of sediments in successive phases.

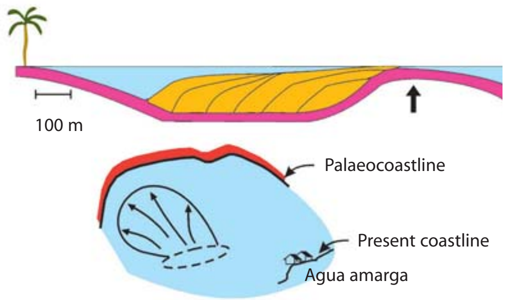
PHASE 1: In the initial phase ramblas reached the bay, extending into the sea in the form of submarine fans. The underlying volcaniclastic sands correspond to deposits of the distal part of these sand fans, coming from the destruction of volcanic relieves.

Platform carbonates are positioned immediately above. By means of the dominant sedimentary structures it is possible to differentiate four units in the interpreted section:

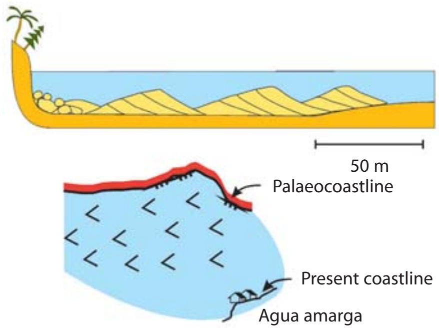
PHASE 1



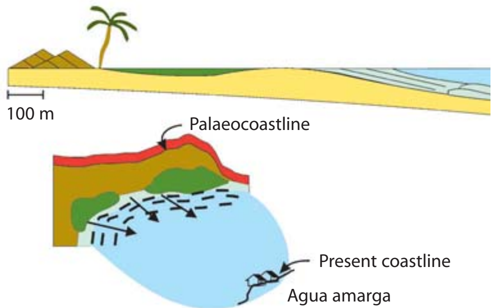
PHASE 2



PHASE 3



PHASE 4



Taken from Betzler et al., 1997

16. Marine sediments of Cañada Méndez (Agua Amarga)

PHASE 2: A lower unit in which the most characteristic features are layers of cross-stratification (of rectilinear appearance, Photo A), separated by very low-lying (almost horizontal), sharp and continuous surfaces. They are the deposits of storm-generated fans, deposited on the protected side of a high or submarine volcanic ridge located to the south.

PHASE 3: An intermediate phase with abundant trough cross-stratification (in curves, Photo B). They are interpreted as marine dunes that migrated parallel to the coast.

PHASE 4: An upper phase in which the most characteristic sedimentary structures are low-angled parallel lamination (Photo C), this corresponds to typical beach sediments. Laterally, and superimposed on the previous deposits, a last unit composed of fine sands with high-angled, poorly-developed, and/or unconsolidated muds without evident sedimentary structures (Photo D). These are interpreted as coastal aeolian dunes and lagoons, respectively.

PHOTO A. Field view of layers with tabular cross-stratification, tied to storm fans.

PHOTO B. Field view of trough cross-stratification produced by the migration of sub-aquatic dunes.

ACTUAL PANORAMA OF THE INTERPRETED FIELD SECTION

INTERPRETATION OF THE OBSERVED PANORAMA

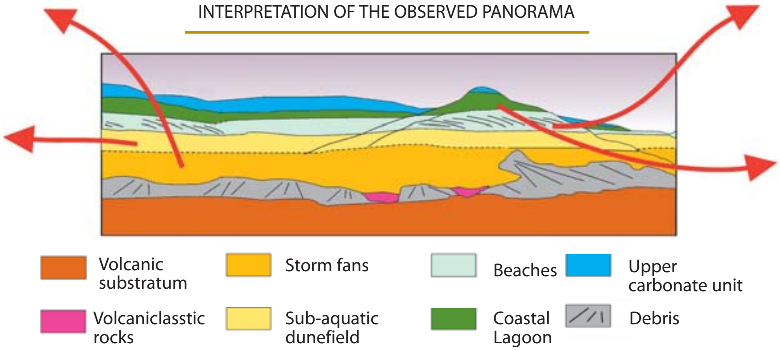


PHOTO C. Low-angled parallel lamination corresponding to episodes of beach progradation.

PHOTO D. Mud levels (soft sediments) formed in coastal lagoons.

17. The Quay at Agua Amarga

José Vicente Coves - José Antonio Gómez

The extensive development of mining activity during the 19th century and first decades of the 20th century in Almería Province furnished the existence of a mining railway network of which only the vestiges are preserved at the present day. One of the routes is that from Lucainena to Agua Amarga. Across the Natural Park parts of the railway can still be seen and are preserved, and the mine workings quay at Agua Amarga although very deteriorated. This constitutes, along with Rodalquilar, one of the 2 most interesting archaeo-industrial elements of the Natural Park.

Locomotive LUCAINENA (Nasmyth Wilson 464/95), one of the machines used on the mineral transport line from Lucainena to Agua Amarga. The photo dates from the end of the 19th century (Photo, Col. J.M. Sánchez Molina).

The plans of work were decided, in March 1894 the project wording was finalised and signed off by D. Cayetano Fuentes, and on the 18th of February 1895 the concession was granted by royal order. This was for an economic railroad, without any government grant and for a period of 99 years. Nevertheless, in September 1894, work on the construction of the railway had already started, and, one month later, the Biscayan company announced the purchase of 63,000 oak sleepers.

The works were progressing and, by the middle of 1895, the quayside-unloading bay had been completed. Finally, in March 1896 the work ended. In May the first shipment of minerals accumulated in the Agua Amarga storage facilities boarded the steamboat ALBIA.

GENERAL VIEW OF LUCAINENA - AGUA AMARGA

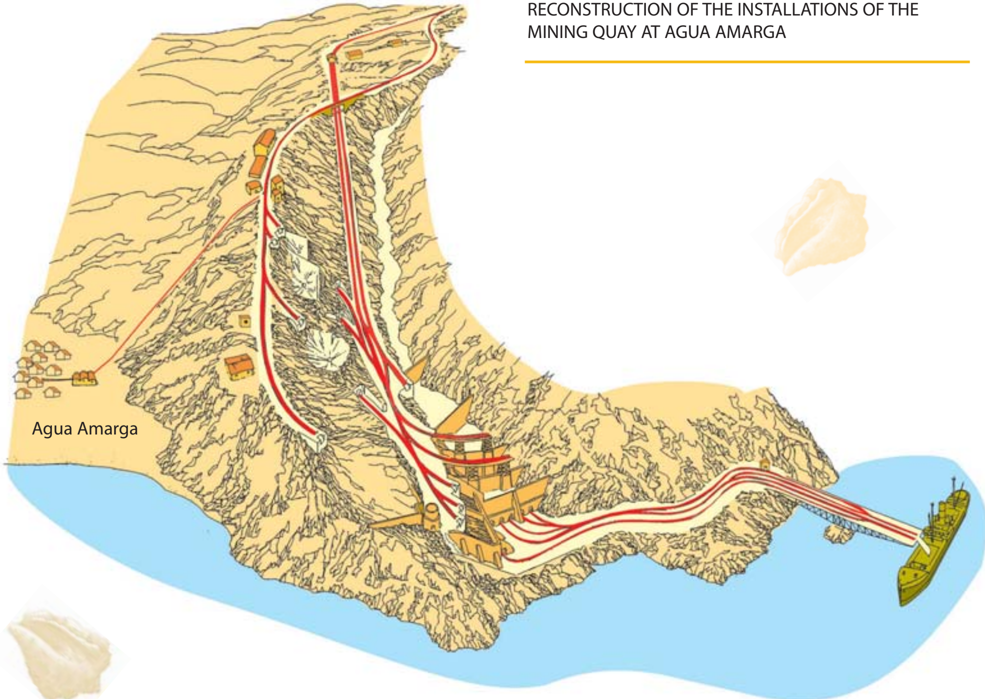
The cost of installing the railway was 3,500,000 pts, the mineral storage area was credited with a cost of 60,000 pts and the quay 265,000 pts. The total investment for establishment was around 3,675,000 pts with an average investment cost of 100,000 pts/km.

In 1901 the transport of minerals by railway was attributed a cost of 0.025 pesetas per ton per kilometre, and the loading cost was 0.123 pesetas per ton.

17. The Quay at Agua Amarga

Although the mining venture company maintained a good level of activity in the first decade of the 20th century, in the second the second the marked started to no longer be favourable. In the years that followed the First World War, a grave iron industry crisis which took place in Europe and Spain, meant a tough trial for national mining of iron. In 1919 and 1920 the Agua Amarga storage facilities were completely full of a mineral that no one bought. These difficulties were compounded by competition from North-African mines, salary rises that started to be introduced around this date, and included the loss of personnel due to the strong migratory movement recorded in Almería Province during this period.

The company endured a marked decline until in 1931, and faced with the impossibility of exporting its iron, it was forced to temporarily suspend operation of the railway. Operation was sporadically renewed, but in 1930, with the state of civil war, the situation worsened. During the three years of struggle the mines and railway remained in the hands of its own workforce, although without great activity. In 1939 transport by rail was restarted until activity finally ceased in 1942, the date in which the steamboat Bartolo loaded for the last time in Agua Amarga. A little later the mining installations and railroad started to be dismantled. The locomotives, the bridges and the railway were taken apart and transported in lorries to Almería.



RECONSTRUCTION OF THE INSTALLATIONS OF THE MINING QUAY AT AGUA AMARGA

Present state of the mining installations in the mineral working quay of Agua Amarga. To the right a general view of the installations can be observed: in the background the Sierra Alhamilla, place of iron exploitation and origin for the transport network; in the foreground, the large inclined plane through which the wagons carrying minerals could descend to the silos. On the left, the remains of the said 'silos' used for mineral storage prior to final loading (Photographs, M. Villalobos).

The boat BARTOLO receiving the last cargo shipped out of Agua Amarga from the Lucainena mines. With it, a page in the history of mining in Almería closed.

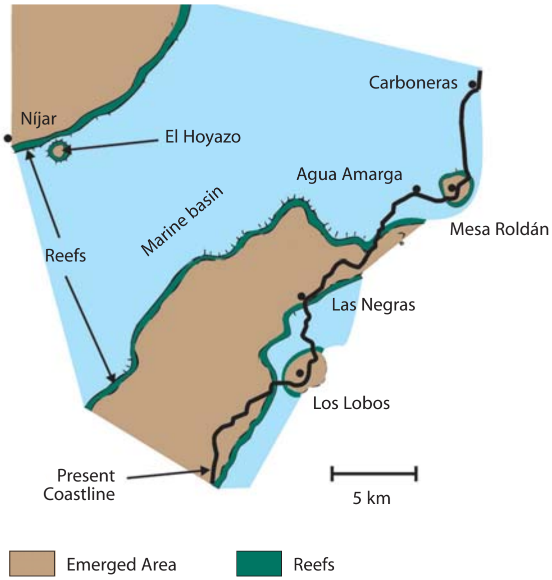
Locomotive LUCAINENA (Nasmyth Wilson 464/95), one of the machines used on the mineral transport line from Lucainena to Agua Amarga. The photo dates from the end of the 19th century (Photo, Col. J.M. Sánchez Molina).

Juan C. Braga - José M. Martín

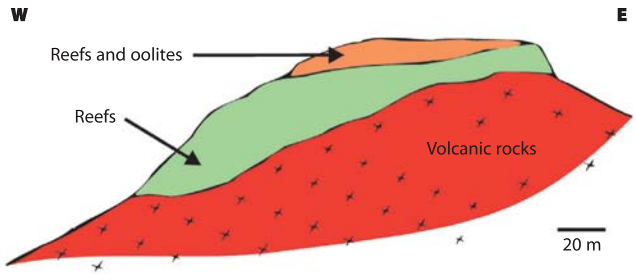
GEOLOGICAL INTERPRETATION

The Mesa de Roldán relief feature is essentially a volcanic dome that formed about 8.7 million years ago. However, the roof of Mesa de Roldán, the upper platform that gives this hill the shape of a mesa, owes its structure to the formation of coral reefs and other sedimentary deposits above the volcanic dome in more recent periods. Two sedimentary units may be distinguished.

PALAEOGEOGRAPHY OF THE CABO DE GATA VOLCANIC AREA DURING THE DEPOSITION OF THE REEF COMPLEX



INTERPRETATIVE GEOLOGICAL SKETCH OF THE PANORAMA



LOWER SEDIMENTARY UNIT
THE REEFS

The lower sedimentary unit is constructed from the remains of coral reefs. As in other places within the region, during the Messinian, around 6 million years ago, corals utilised the raised seafloor that constituted the volcanic dome to install themselves and form a reef. The calcareous skeletons of the corals just as happens in modern tropical seas (Photo A), finished constructing a rigid structure of carbonate rock. In the Mesa de Roldán, the coral constructors belong to the genera Porites (Photo B) and, to a lesser extent, Tarbellastrea and Siderastrea. Other organisms such as red algae, encrusting foraminiferans, bivalves, gastropods, serpulid worms, etc. (Photo C), contributed with their skeletons to the reef construction or the accumulation of carbonate sediment.

Calcareous corals in modern tropical seas construct coral reefs similar to those that formed in the region 6 million years ago.

The remains of bivalves contribute to the formation of reefal deposits.

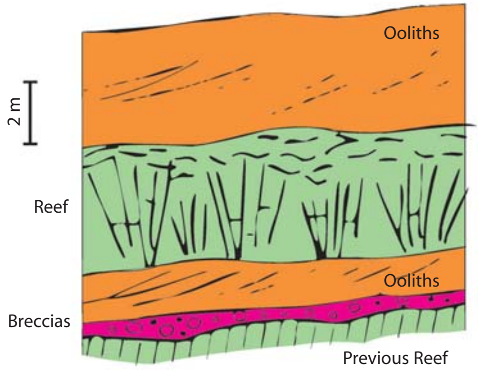
Corals of the genera Porites are the main constructors of Messinian coral reefs in Almería.

UPPER SEDIMENTARY UNIT
THE PATCH REEFS

Above the lower sedimentary unit there is an erosion surface, and, above it, a new sedimentary unit is present. The latter, also Messinian in age, but younger (around 5.5 million years) is again constructed from coral reefs along with some particulate carbonate sediments that are called oolites (lower figure). Here the reefs have only a small dimension, patches a few metres wide with a height of 1 or 2 metres, formed by corals of the genera Porites (Photo D) and well-developed micritic coatings of microbial origin (Photo E). These reefs grew surrounded by oolitic sediments. This type of oolitic sediment consist of small carbonate particles with a spherical shape and an internal structure of concentric laminations (Photo F). At present, ooliths, as the particles are known, are formed in shallow, agitated, tropical seas.

The oolitic carbonates as much as the coral reefs testify that in the western part of the Mediterranean, on the southeast Iberian peninsula, during the Messinian around 5.5 million years ago, at the end of the Miocene, a tropical climate prevailed, similar to that now found in lower latitudes, closer to the equator.

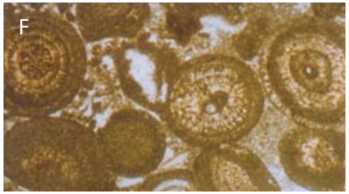
Since that period until the Present, the climate in the region has followed a general trend of cooling, although this tendency has suffered strong fluctuations, especially during the last 2 million years.



Patch reefs and oolitic limestones appear in the upper unit.

Coral colonies of the genera Porites (vertical sticks), surrounded by micritic carbonate coatings (white hue), that constitute the patch reefs of the upper unit.

Micritic carbonate coatings encrusting the upper part of patch reefs at the same time as the coral colonies were periodically living.



Microscopic image of oolitic sediments. These particles, ooliths, constitute the bulk of sediments in the upper unit.

19. The Hoyazo de Níjar

Juan C. Braga - José M. Martín

The Hoyazo de Níjar hill is a locality of great geological interest. This relief feature, with a circular form, that stands out in the extensive plain of the Campo de Níjar, in fact constitutes a small volcano whose crater emerged as an island in the archipelago of small volcanoes emplaced in this area around 6 million years ago.

At the base of the Sierra Alhamilla relief, where the coastline was located during this period, and surrounding the volcanic crater of El Hoyazo, fringing reefs composed of the coral Porites and typical of warm waters developed. The reef which capped and surrounded El Joyazo is magnificently conserved, exhibiting the complete reef structure.

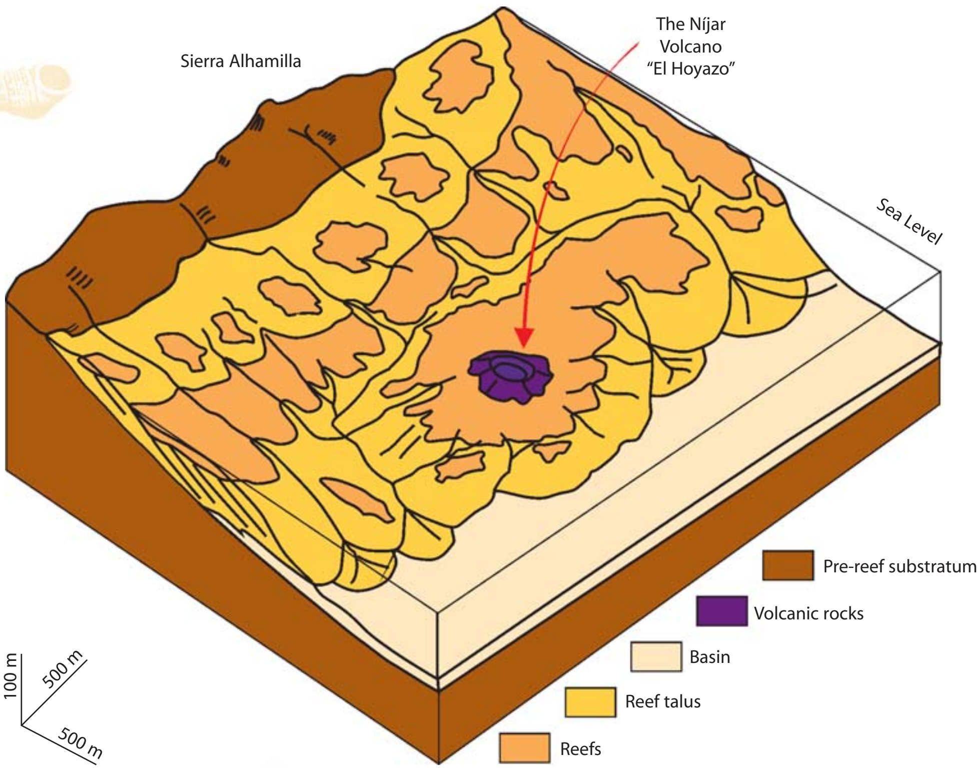
The Hoyazo de Níjar volcano is also known for an abundance of garnets, minerals that make up almost 1% of the volcanic rock. The origin of the garnets in the volcanic rock is related to the existence of schists rich in the same semi-precious mineral at depth, which were carried upwards towards the surface in volcanic eruptions. The garnets are desirable when they form well-shaped crystals, like jewels. In the case of El Hoyazo, people came to benefit as such in the 19th century.

Later on, through the decades of the 50s and the 60s in the 20th century, they were quarried as an abrasive product, due to their great durability. They were mined in the sediments of the Rambla de la Granatilla, which formed a small alluvial fan at the exit of El Hoyazo, in whose sediments the very resistant garnets had accumulated, coming from the destruction and erosive washing of volcanic material. It may be regarded, as such, as a typical secondary source or "placer deposit".

Exterior view of the small atoll of fringing reefs on top of the volcanic cone. At this point, fluvial erosion by the Rambla de la Granatilla has dissected the carbonates, facilitating access to the interior of the structure (Photo, M. Villalobos).

DIAGRAM OF EL HOYAZO DE NIJAR

C. Dabrio



Interior view of Hoyazo de Níjar. The interior depression is carved into the ancient volcanic crater. The upper capping level corresponds to the reefal carbonates, that are supported externally upon the volcanic relief in the form of a small atoll (Photo, M. Villalobos).

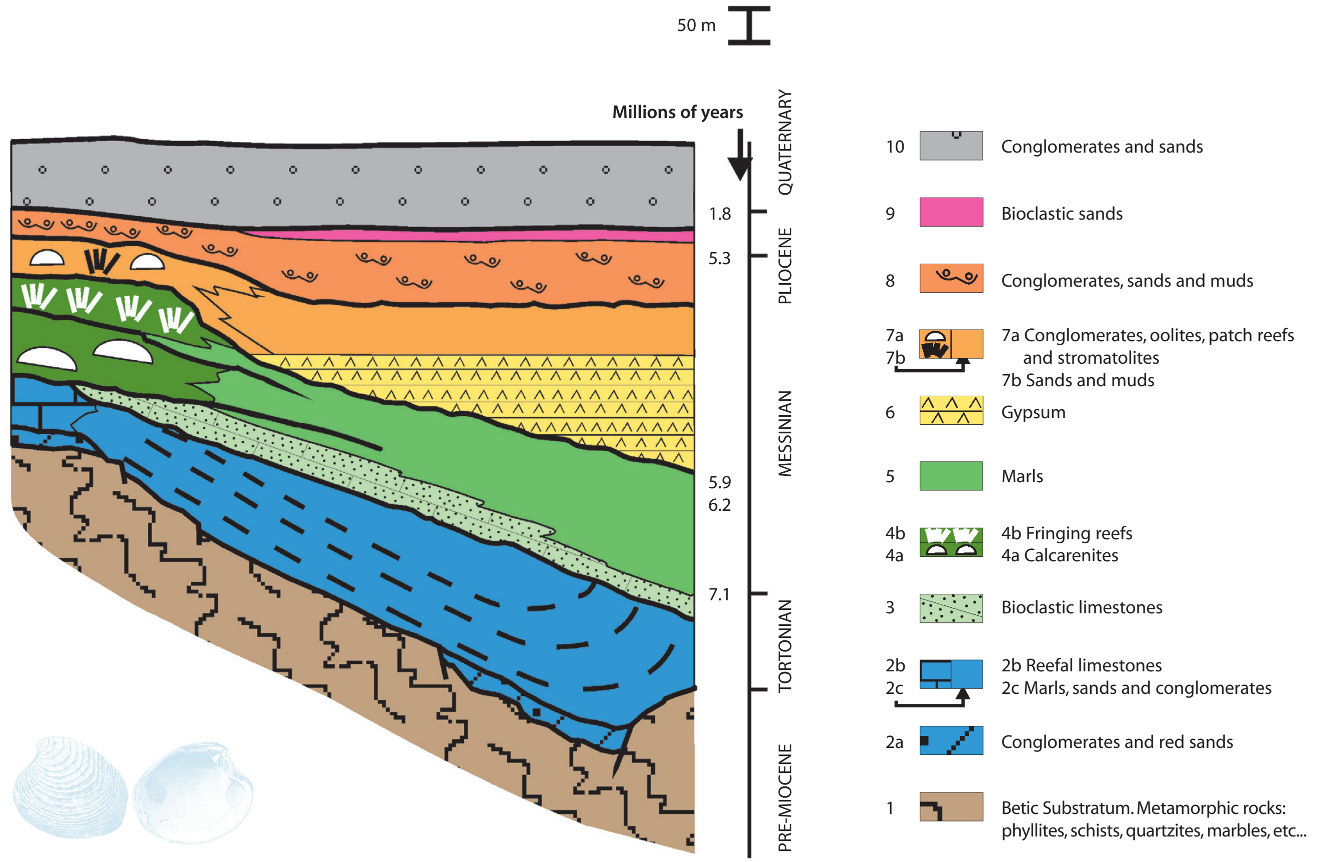
Detail of the reef carbonates (Photo, M. Villalobos).

The Sorbas Basin

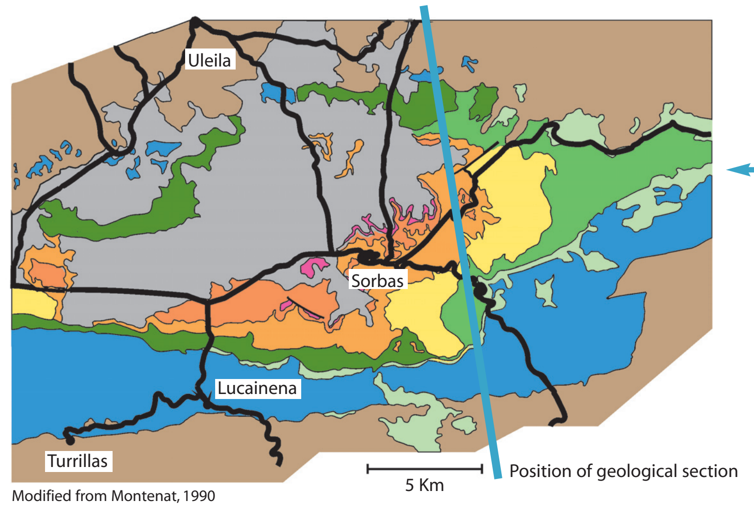
Geological Features

Geological Features and Evolution

STRATIGRAPHY OF THE SORBAS BASIN

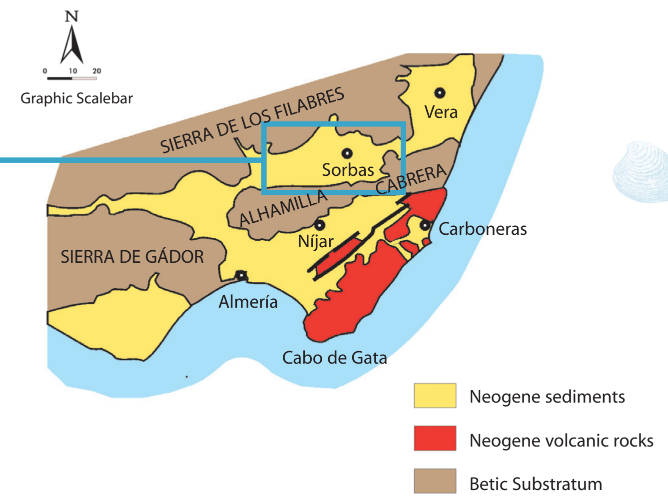


GEOLOGICAL MAP OF THE SORBAS BASIN

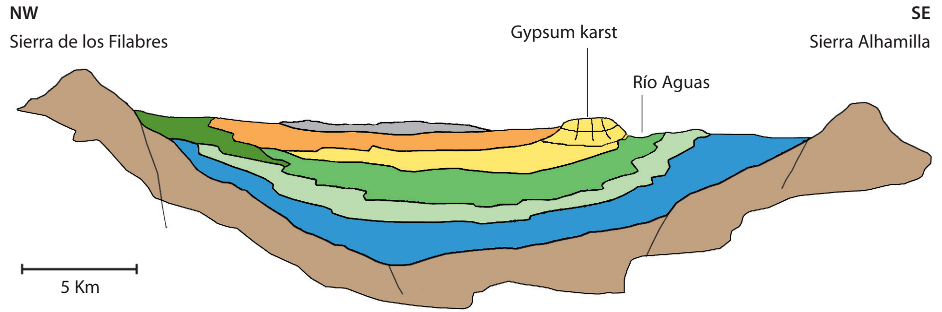


Modified from Montenat, 1990

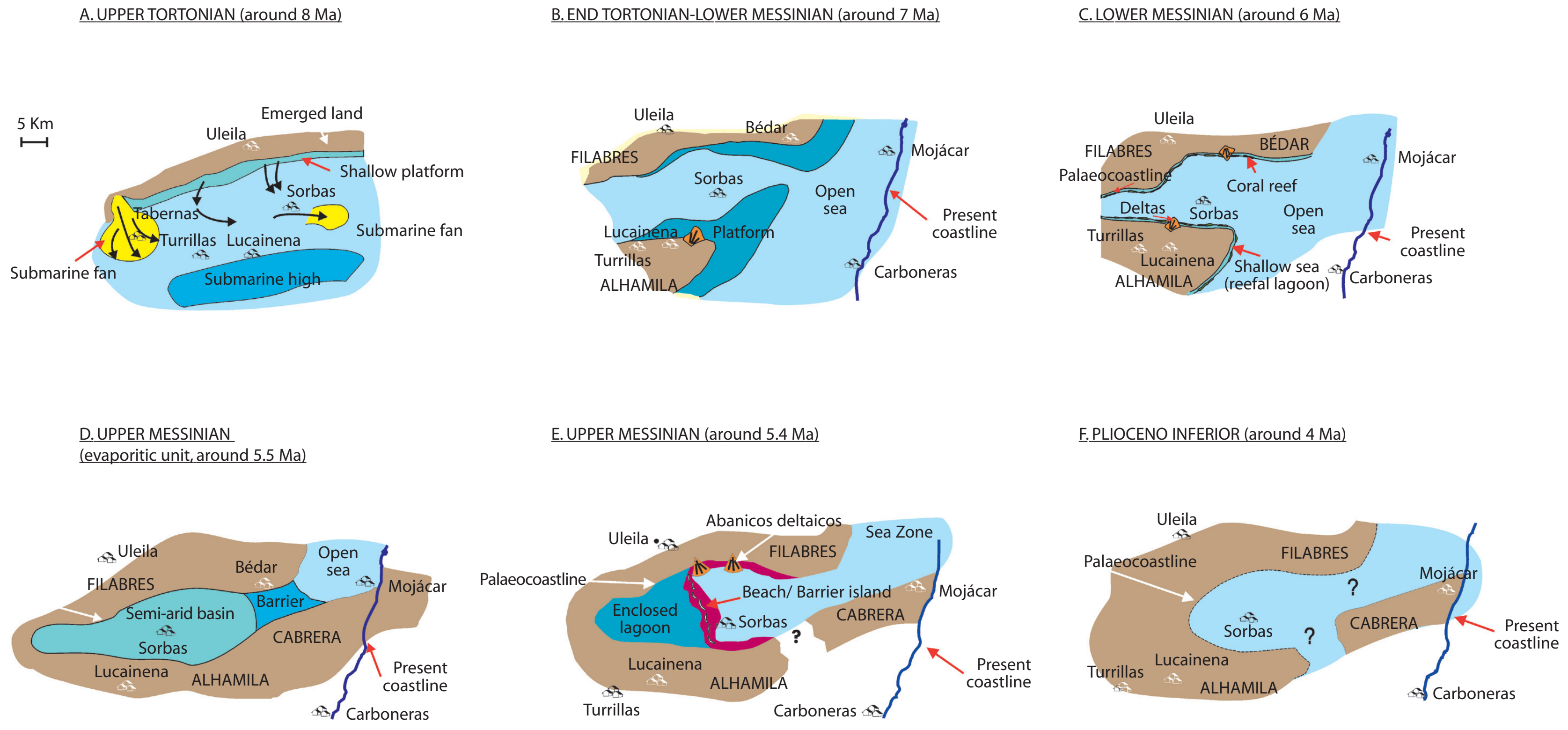
GEOLOGICAL CONTEXT OF THE SORBAS BASIN



GEOLOGICAL SECTION

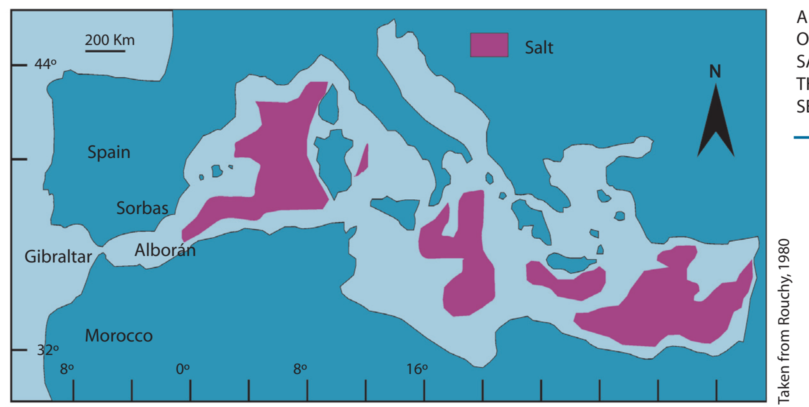


PALAEOGEOGRAPHICAL EVOLUTION OF THE SORBAS BASIN FROM THE UPPER TORTONIAN (8 Ma) TO THE LOWER PLIOCENE (4 Ma)



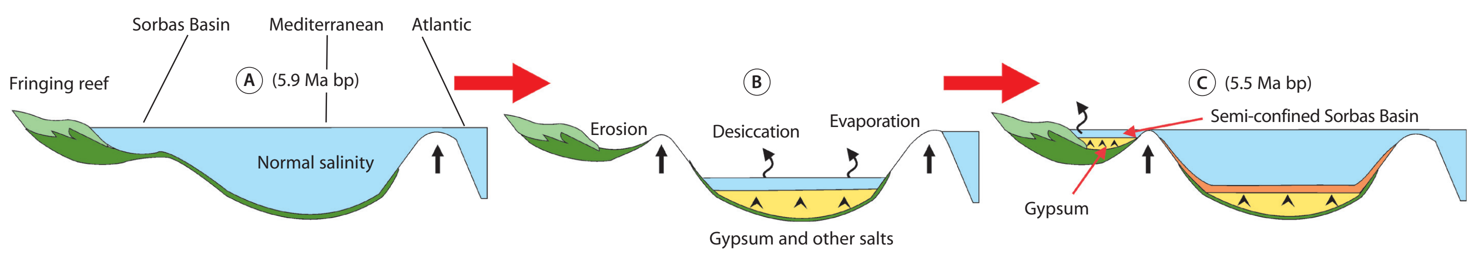
Juan C. Braga - José M. Martín

Around 5.5 million years ago (in the Messinian) the Mediterranean dried up through closure of its communication with the Atlantic Ocean due to tectonic uplift, and masses of evaporites (gypsum and salt) were deposited in its central and deepest region. The thickness of accumulated salt (mainly sodium chloride) exceed 1500 m in some places. In relation to this phenomenon, important deposits of gypsum (hydrated calcium sulphate) were also deposited in the Sorbas Basin, which locally exceed 130 m in thickness and that outcrop over an area of nearly 25 square kilometres.



AEREAL DISTRIBUTION OF MESSINIAN SALT DEPOSITS IN THE MEDITERRANEAN SEA

SEDIMENTARY INTERPRETATION FOR THE SORBAS GYPSUM IN A MEDITERRANEAN CONTEXT



Situation prior to the deposition of evaporites, with the formation of reefs along the margins and marly-muddy sediments in the basin.

Evaporite deposits in the centre of the Mediterranean result from this disconnection with the Atlantic, and drying out.

Evaporite deposits in the interior of the Sorbas Basin.

Juan C. Braga - José M. Martín

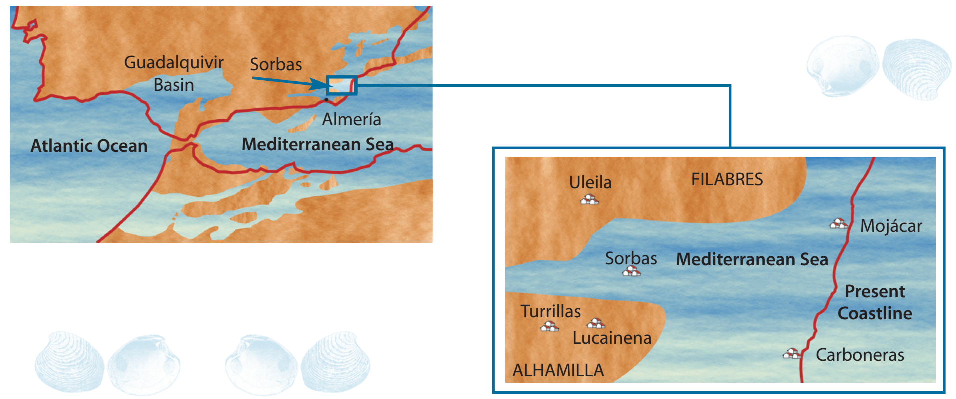
The Sorbas Basin constitutes an intermontane basin of singular geological interest for the study and understanding of palaeogeographical and palaeoenvironmental changes occurring on the Mediterranean coast during the last 8 million years, and its relationship to the geological evolution of the Betic Cordillera.

Eight million years ago (in the Upper Miocene), the configuration of land emerged and submerged beneath the sea along the coastal zone of Almeria was similar to present, but not identical: the sea spread across the Sorbas Basin, dry land today, up to the foothills of the Sierra de los Filabres, in whose margin reefs of fossil corals from this age remain as testament, closely marking the position of the ancient coastline. On the slopes, submarine fans deposited thick and extensive sediments that the rivers stripped out from the emergent relief. The later emergence of Sierra Alhamilla and Sierra Cabrera configured a long and narrow intermontane marine basin between these new relieves, to the south, and Los Filabres, towards the north, where the deposition of marine sediments continued: this is today called the Sorbas Basin.

At the end of the Miocene (around 5,5 million years ago, during the Messinian) an enhanced process of desiccation of the Mediterranean Sea caused the marine Sorbas Basin to become practically dry, with a very shallow depth subjected to strong evaporation. In these circumstances a package of gypsum almost 100 metres in thickness was deposited: the Sorbas gypsum. Afterwards, the sea reoccupied its level, continuing the accumulation of marls and detrital sediments above the gypsum, up until, around 3.5 million years ago (in the Pliocene), the coastline progressively retreated until reaching its present position.

The final retreat of the sea meant that the marine sediments became exposed to the action of erosive agents. The removal of the upper sedimentary layers left the highly soluble gypsum subjected to the continuous action of water, which progressively dissolved it. Therefore, one of the most important gypsum karst landscapes in the world for its size, worth and beauty started to form.

DISTRIBUTION OF EMERGED LAND AND SEA 6 MILLION YEARS AGO



Geological Features and Evolution

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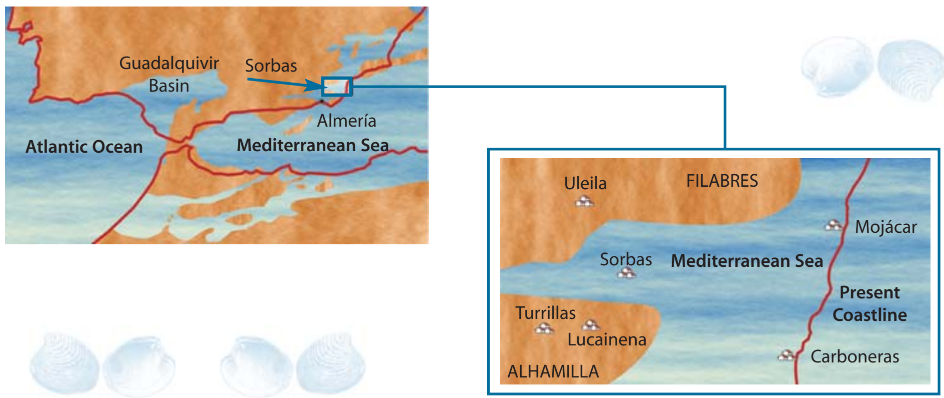
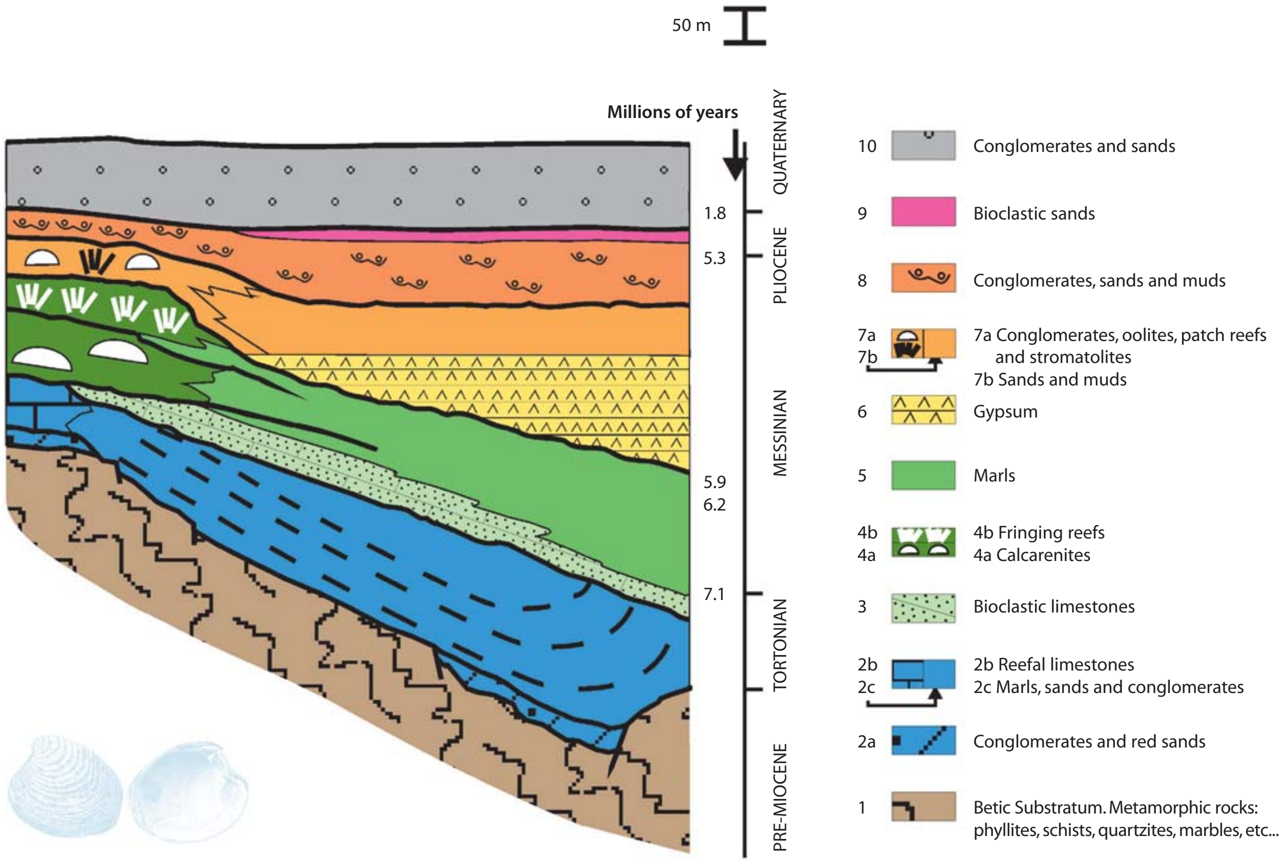
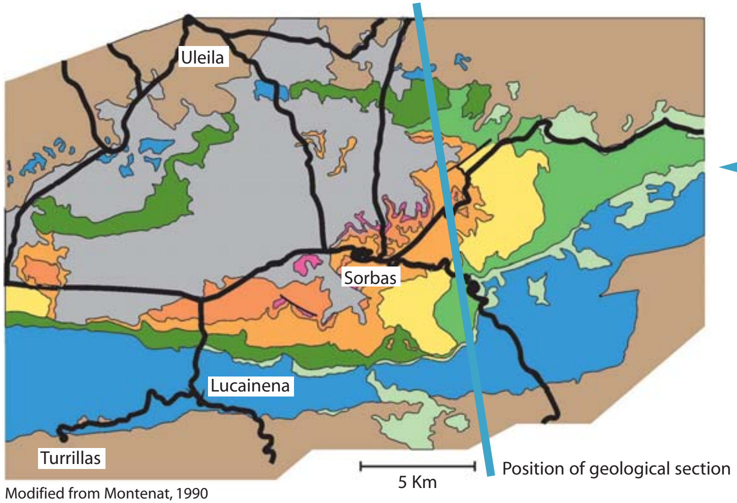


STRATIGRAPHY OF THE SORBAS BASIN



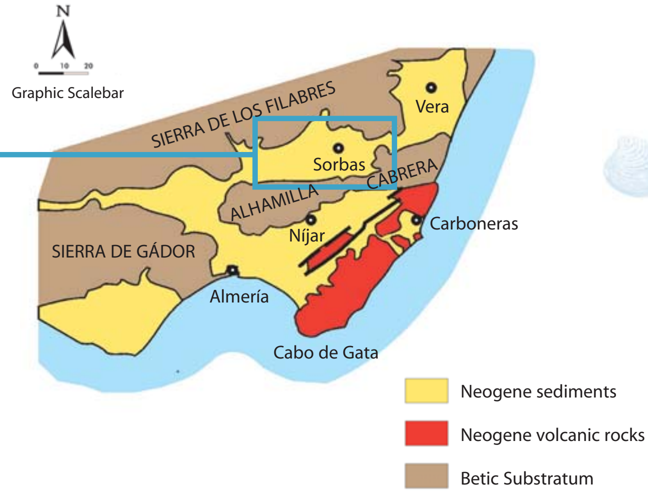
Geological Features and Evolution

GEOLOGICAL MAP OF THE SORBAS BASIN

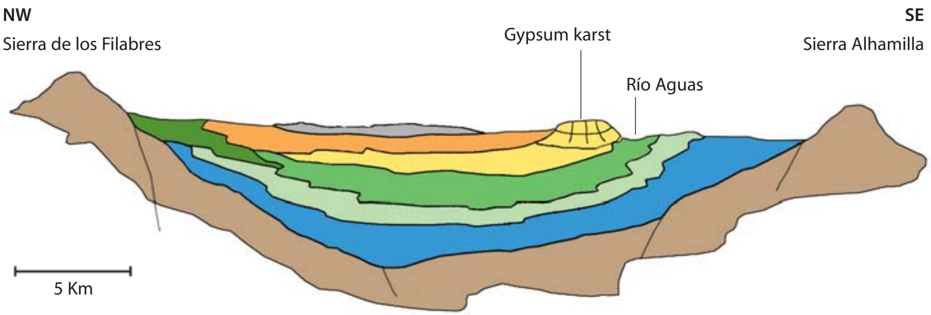


Modified from Montenat, 1990

GEOLOGICAL CONTEXT OF THE SORBAS BASIN

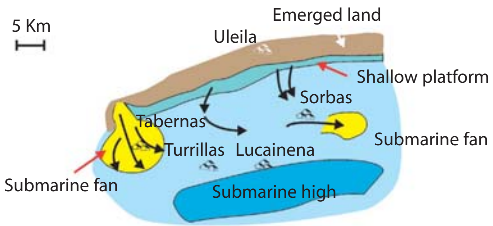


GEOLOGICAL SECTION

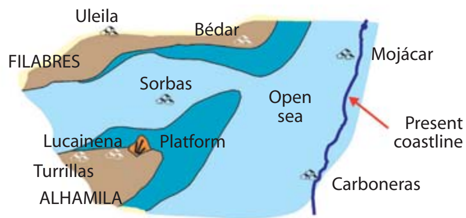


PALAEOGEOGRAPHICAL EVOLUTION OF THE SORBAS BASIN FROM THE UPPER TORTONIAN (8 Ma) TO THE LOWER PLIOCENE (4 Ma)

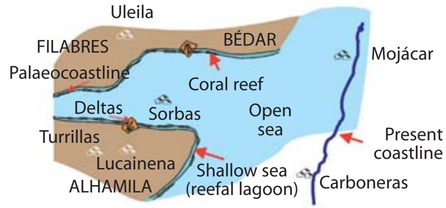
A. UPPER TORTONIAN (around 8 Ma)



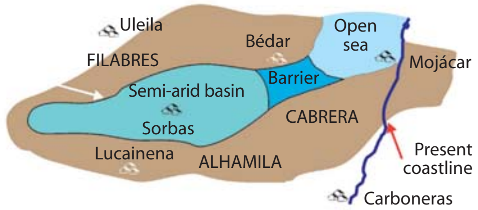
B. END TORTONIAN-LOWER MESSINIAN (around 7 Ma)



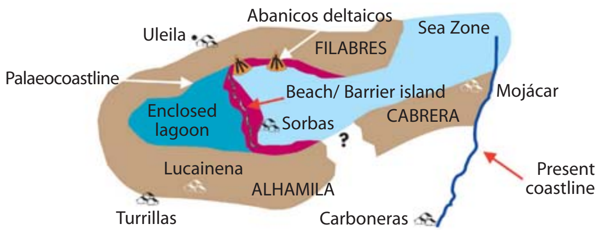
C. LOWER MESSINIAN (around 6 Ma)



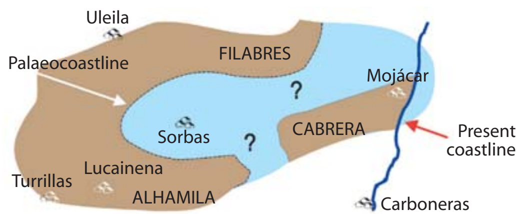
D. UPPER MESSINIAN (evaporitic unit, around 5.5 Ma)



E. UPPER MESSINIAN (around 5.4 Ma)



F. PLIOCENO INFERIOR (around 4 Ma)



Juan C. Braga - José M. Martín

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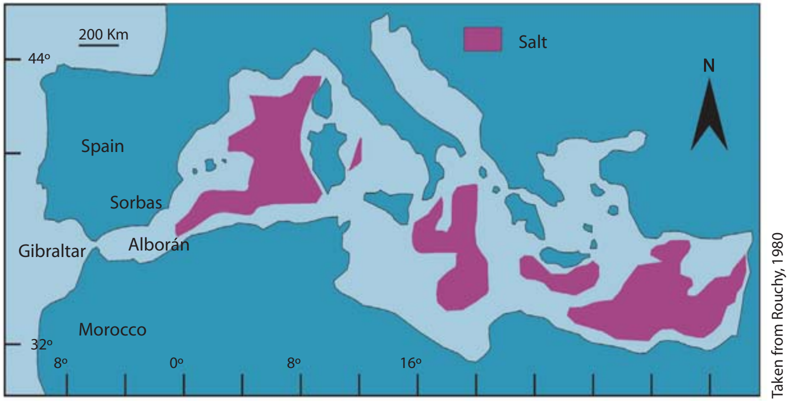

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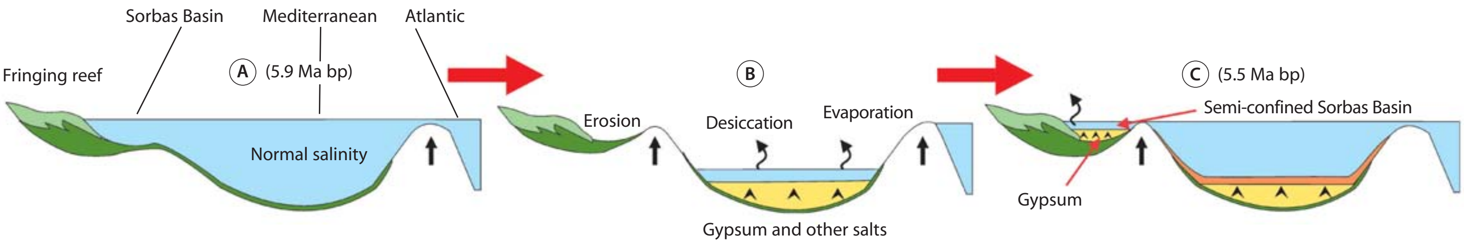
SEDIMENTARY INTERPRETATION FOR THE SORBAS GYPSUM IN A MEDITERRANEAN CONTEXT



Situation prior to the deposition of evaporites, with the formation of reefs along the margins and marly-muddy sediments in the basin.

Evaporite deposits in the centre of the Mediterranean result from this disconnection with the Atlantic, and drying out.

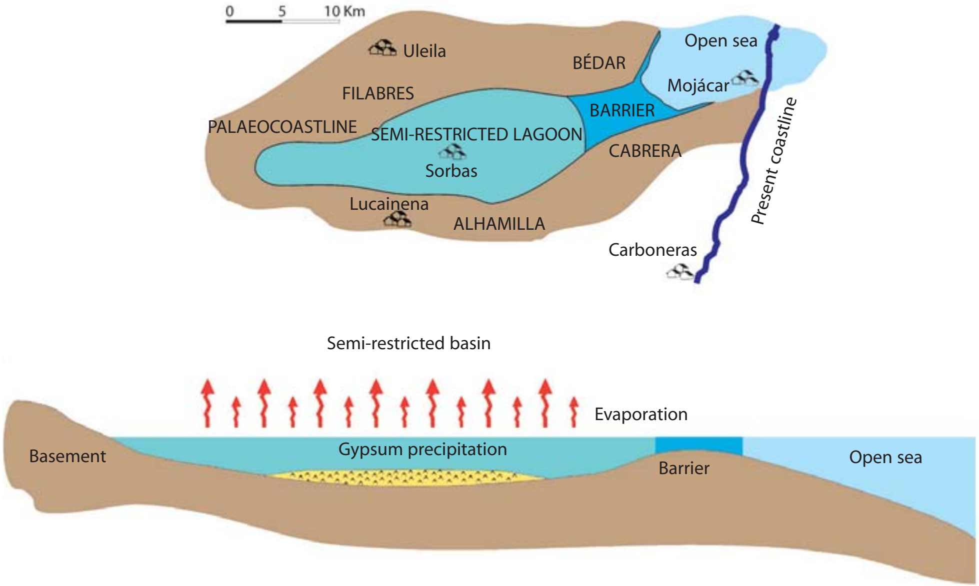
Evaporite deposits in the interior of the Sorbas Basin.

Origin of the Sorbas gypsum

The gypsum deposits in the Sorbas Basin were not, however, strictly contemporaneous with the deposition of evaporites in the centre of the Mediterranean, but somewhat later.
This deposition took place during the reflooding phase of the Mediterranean, upon refilling with new water, presumably coming from the Atlantic and invading a broad semi-restricted depression, that at the time occupied a large part of what today constitutes the Sorbas Basin.

The Sorbas gypsum was deposited in an evaporitic basin, of restricted character, closed towards the west and separated from the open sea by a submarine barrier located at its most easterly end, created through uplift of the Sierra Cabrera.

PALAEOGEOGRAPHY OF THE SORBAS BASIN DURING GYPSUM DEPOSITION (5.5 Ma bp)

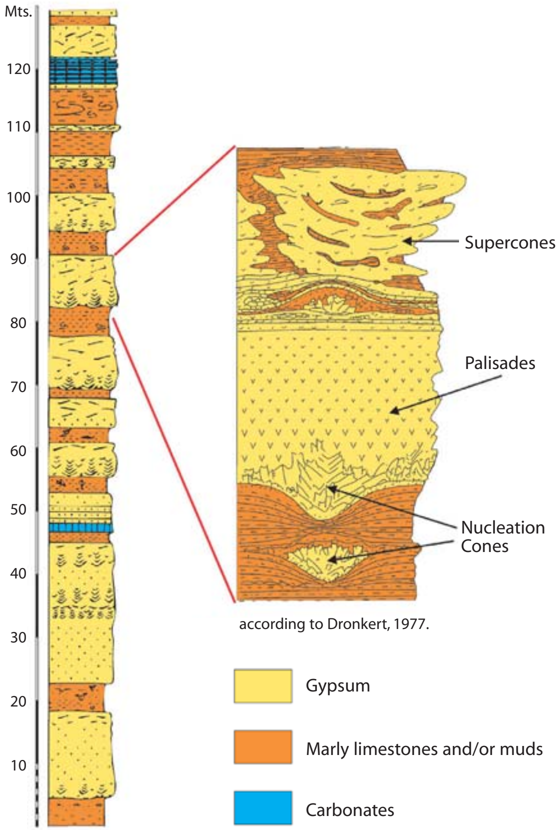


In detail, the evaporite sequence of Sorbas consists of banks of gypsum, of up to 20 m thickness, separated by marly-limestone intervals and/or carbonates. The thickness of the gypsum banks diminishes towards the top at the same time as that of the non-evaporitic intervals increases. The latter, at least in the higher part, possess a marine character, in that they incorporate the remains of the calcareous skeletons of marine organisms and record the different episodes of basin inundation.

In the highest banks of gypsum in the sequence a very spectacular growth structure of arborescent character evidently forms, known as supercones (also called cauliflowers), that are interpreted as resulting from competition between the growth of gypsum and the deposition of contemporaneous muddy sediments.

STRATIGRAPHICAL COLUMN OF THE SORBAS EVAPORITE SEQUENCE AND DETAILED STRUCTURE OF THE GYPSUM BANKS WITHIN THE SUCCESSION

Taken from Dronkert, 1976



Field view of the gypsum banks.

Detailed field view of the gypsum supercones.

Field photograph of the gypsum banks from the upper part of the evaporite sequence.

Karst: the slow dissolution of the rocks

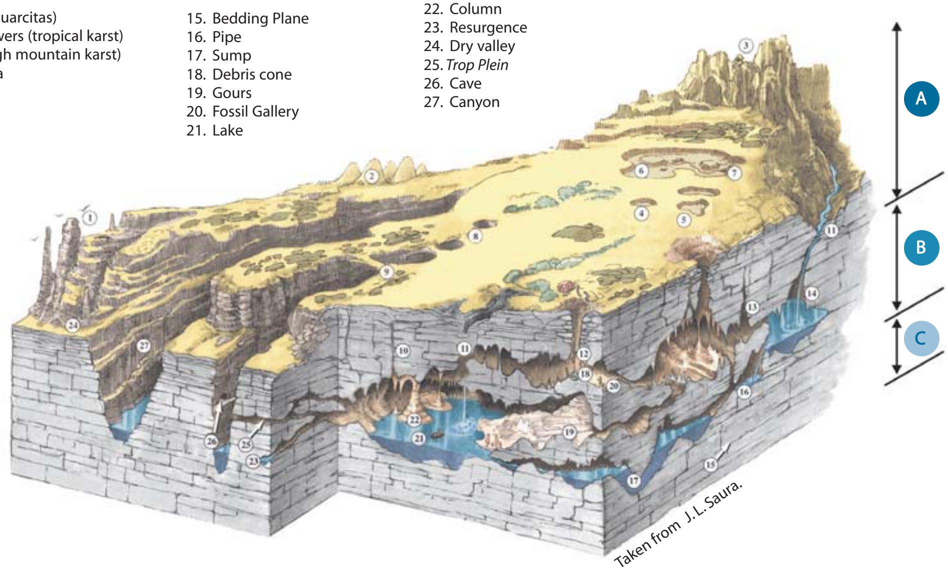
M. Villalobos

Rainwater and groundwater are capable of dissolving soluble rocks in a slow process that takes thousands of years. The resultant landscape, known as karst or karstic landscape, is very peculiar. It is characterised by the presence of abundant closed depressions at the surface (dolinas, potholes, etc.) and a complex subterranean drainage system (cavities).

Karstification of gypsum is an infrequent phenomenon in nature. The greater part of known karst are limestones. The Sorbas karst is the most important gypsum karst in Spain, and one of the four best known examples in Europe. Additionally, it has a very high scientific and didactic value in a world context.

FEATURES IN KARST LANDSCAPE

1. Tepuys (Karst en cuarcitas)
2. Pitons, Stacks ,Towers (tropical karst)
3. Lapiés/Karren (high mountain karst)
4. Dissolution Dolina
5. Uvala
6. Polje
7. Ponor
8. Collapse dolinas
9. Rock bridge
10. Joint
11. Sinkhole
12. Pothole
13. Chimney
14. Cascade
15. Bedding Plane
16. Pipe
17. Sump
18. Debris cone
19. Gours
20. Fossil Gallery
21. Lake
22. Column
23. Resurgence
24. Dry valley
25. *Trop Plein*
26. Cave
27. Canyon



Zone of recharge (photo J. M. Calaforra).

Zone of transfer (photo J. M. Calaforra).

Flooded Zone (photo J. M. Calaforra).

How is the gypsum karst of Sorbas formed?

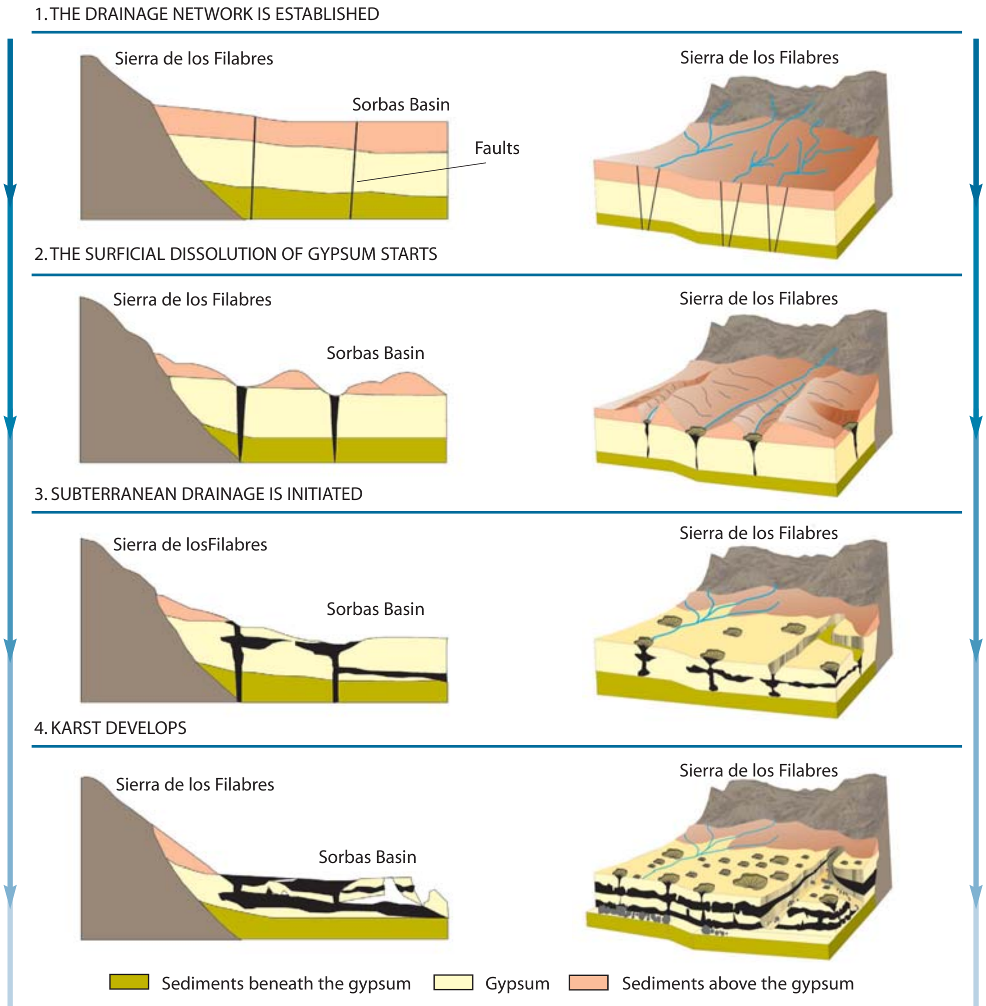
J. M. Calaforra

1. The gypsum is originally covered by other sediments, on top of which the incipient drainage network starts to install itself.

2. The drainage network erodes the upper sediments until exposing the gypsum in very localised places where the first dolinas originally start to be dissolved.

3. The gypsum is becoming exposed to a greater extent at the surface through time. A multitude of dolinas develop that favour the entrance of water into the interior.

4. The general entrance of water into the gypsum mass promotes its slow dissolution, creating a complex subterranean network of galleries.



Landscape and surface features

M. Villalobos

A multitude of small depressions pepper the surface of the karst. These are the dolinas. They result from the dissolution or collapse of the surface layers of the gypsum.

An escarpment cliff delimits the entire southern margin of the gypsum outcrop.

The extensive plain, the escarpment cliff and the valley are the most characteristic elements of the surface landscape.

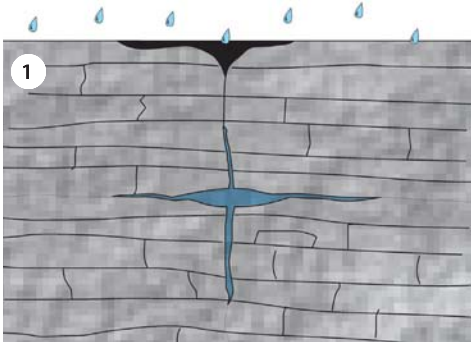
Above the gypsum rock an extensive karstic plain is fashioned.

Large gypsum blocks tumble down from the cliff covering the marl slope. These are called block falls.

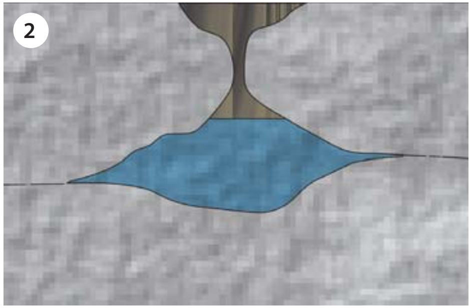
The Río Aguas cuts down towards the south into soft marly sediments giving rise to a broad valley.

Dissolution features: chambers and galleries

J. M. Calaforra - M. Villalobos



Rainwater penetrates into the rock interior, starting to dissolve the gypsum.

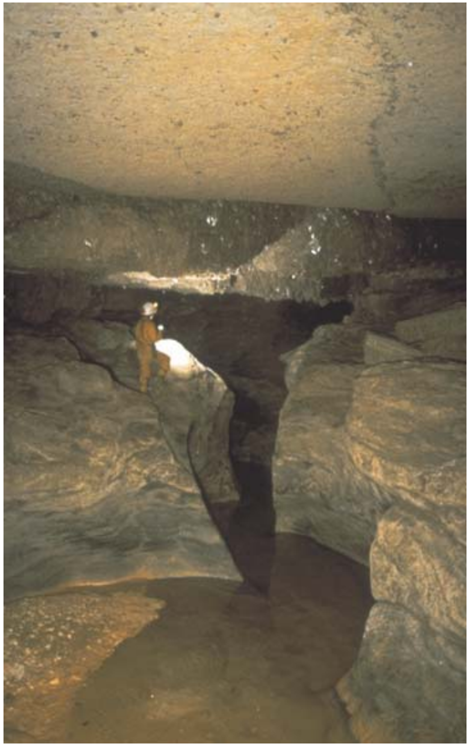


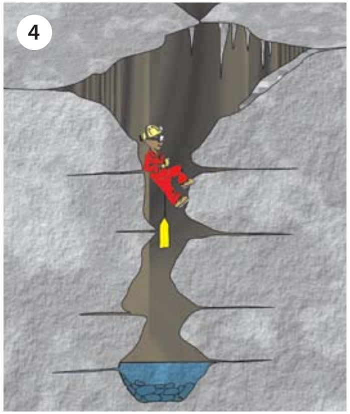
Dissolution progressively enlarges the initial channel.

The water penetrates through to the lower layers. The initial crystallization features start to form.

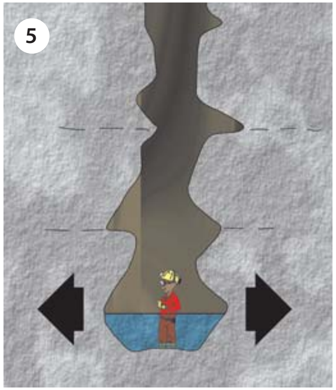
(Photo J. Les)

The water infiltrates, slowly dissolving gypsum rock, generating a complex network of subterranean galleries. Chambers are formed from galleries through the dissolution of the walls, and by the fall of blocks from the walls and roof.

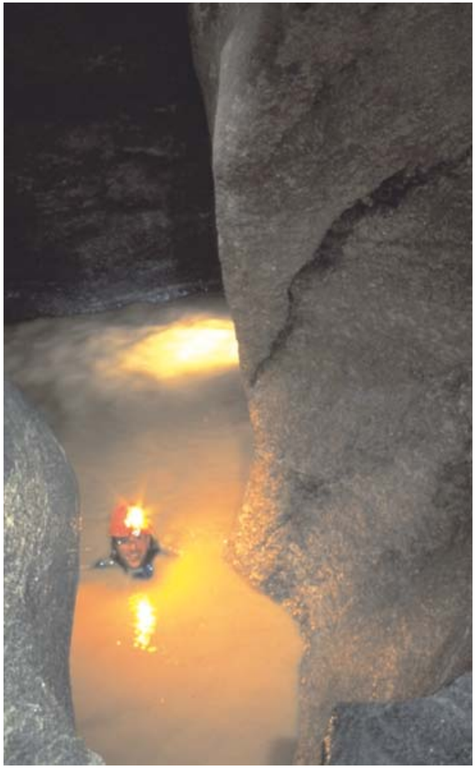




Slowly meanders are excavated, on occasions they are very long.



Only the lower section is permanently flooded.

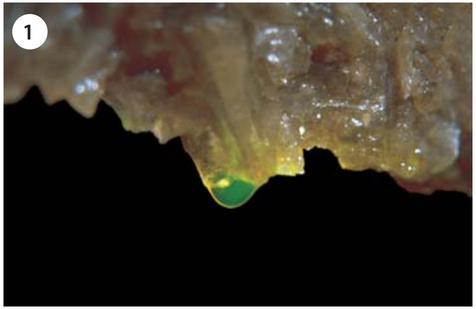


4

5

Crystallization features: speleothems

J. M. Calaforra - M. Villalobos



Water circulates through the incipient galleries and chambers, infiltrating and dissolving the gypsum rock.

Gypsum is saturated in this slow process so that it then precipitates in the form of small crystals.

The roof, walls and floors of chambers and galleries are coated with a multitude of gypsum crystals in fanciful designs and colours.

Water infiltrates dissolving the gypsum, is saturated and crystallizes in extremely delicate forms. These are the speleothems.

It has taken hundreds of thousands of years, millions at times, in order for nature to sculpt them. Respect them, never touch them, and be careful not to damage them by accident. They have an incalculable value, but only here where they were born, they have no value elsewhere.

Stalagmites.

Columns.

Mamelones.

Rings.

Stalagmite mounds.

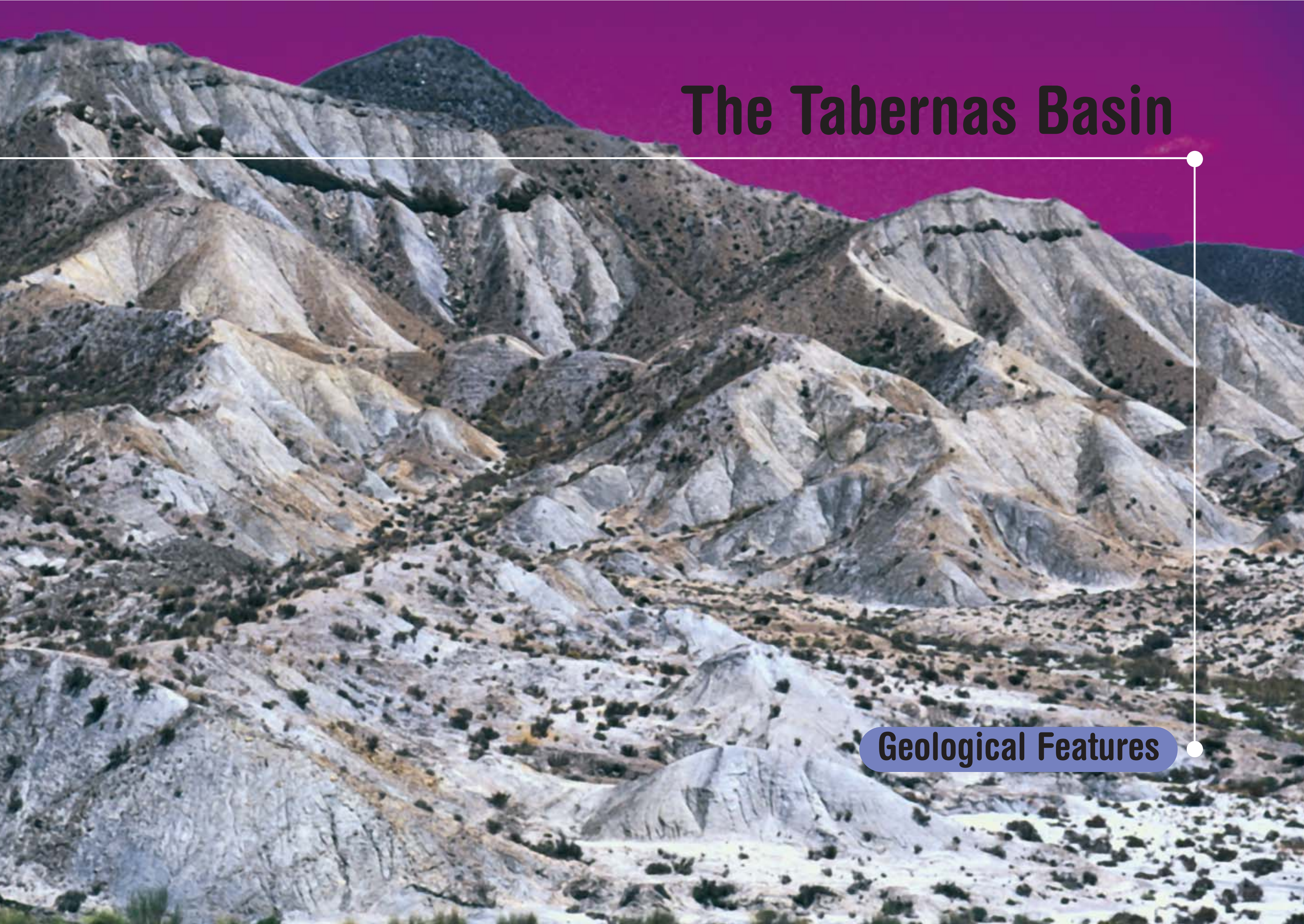
Curtains.

Corals.

Balls.

The Tabernas Basin

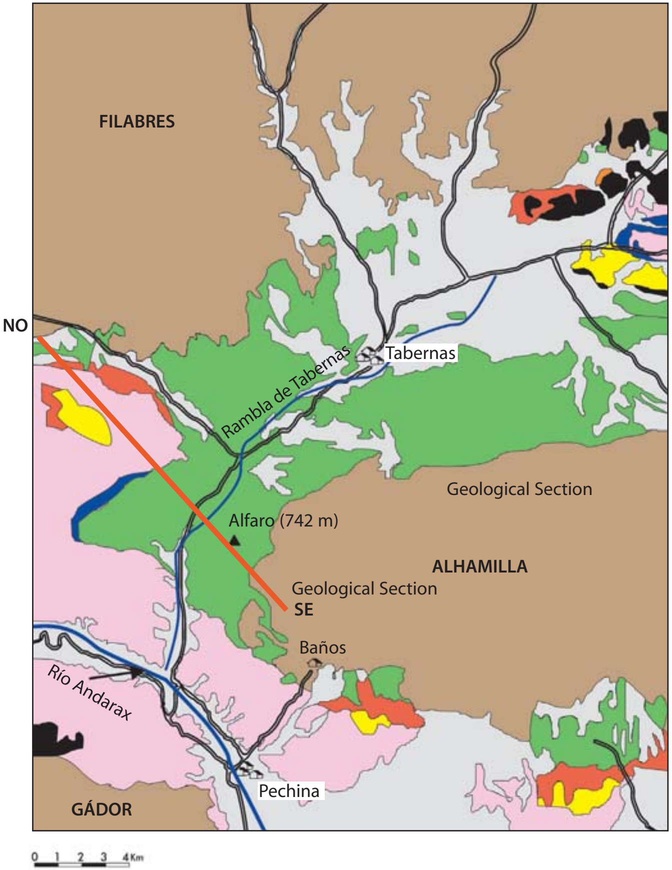
Geological Features

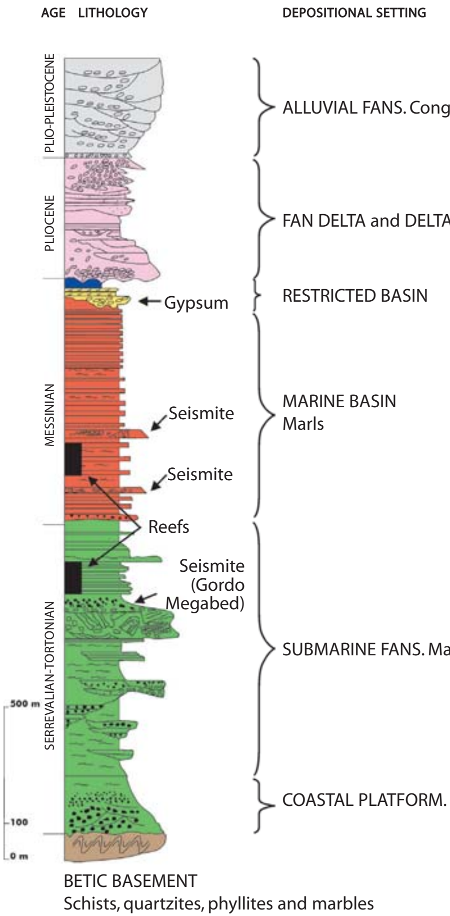


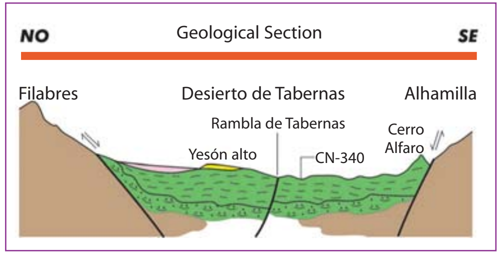
J. C. Braga - José M. Martín

SIMPLIFIED GEOLOGICAL MAP AND STRATIGRAPHICAL SUCCESSION FOR THE TABERNAS BASIN

Taken from Weijermars et al, 1985







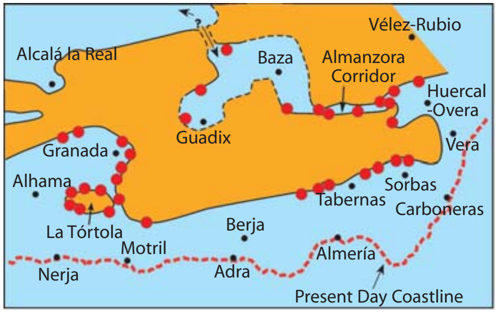
About eight million years ago (in the Miocene) the configuration of emerged and submerged land around the littoral margin of Almería was similar to that of today, but not identical: the sea extended through the territory of the Tabernas Desert up to the foot of the Sierra de los Filabres in whose borders fossil coral reefs of this age formed, reliably marking the position of the ancient coastline. In the slopes of this ancient sea, submarine fans deposited a thick and extensive sedimentary package that the rivers eroded from the emerging relief. This material, comprising alternations of marl and sand, are amongst those which have, to a great part, fashioned the eroded landscape of the Tabernas Desert.

Later, some 7 million years ago (in the Upper Miocene), the Sierra Alhamilla was uplifted, closing a narrow and elongated, marine intermontane basin between this new relief, to the south, and los Filabres, to the north.

In this depositional environment, marine at times, lagoonal for others, the deposition of limestones, marls, muds and sands, and enclosed gypsum, continued up until around 2 million years ago (in the Pliocene, almost at the start of the Quaternary), when the sea ultimately retreated, leaving the sediments exposed to the action of erosive agents.

DISTRIBUTION OF EMERGED LAND 8 MILLION YEARS AGO

1



● Reefs

Braga, Martín and Quesada

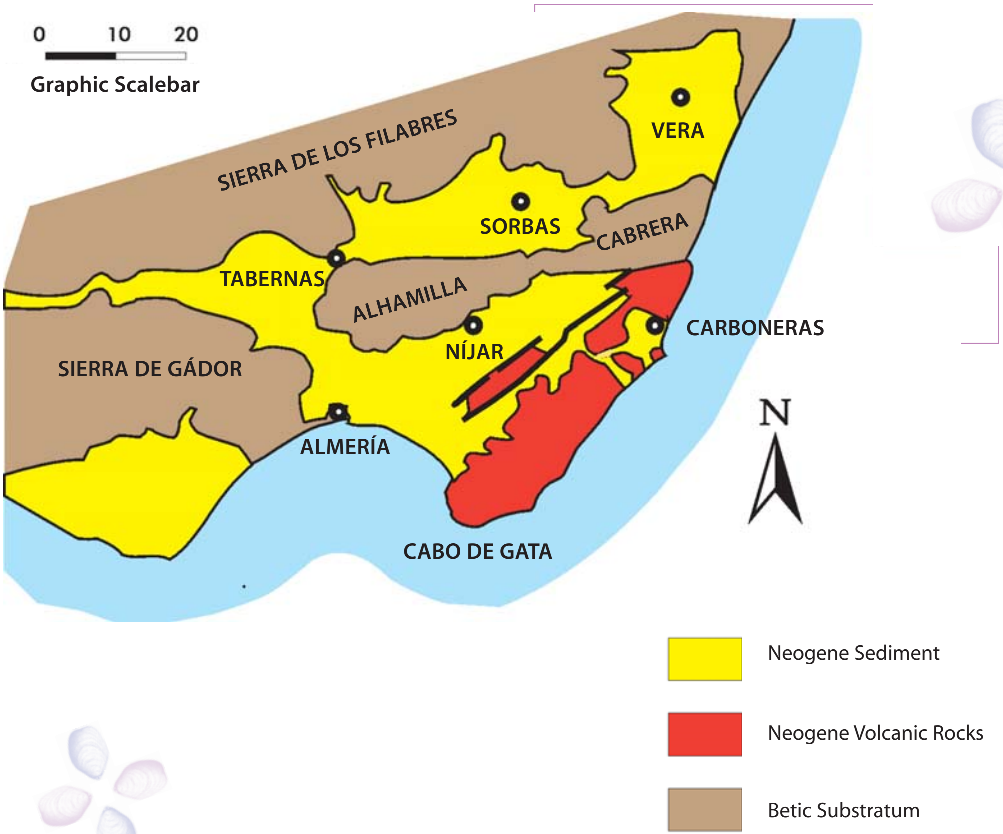
DISTRIBUTION OF EMERGED LAND 7 MILLION YEARS AGO

2

DISTRIBUTION OF EMERGED LAND 4 MILLION YEARS AGO

3

The Tabernas Basin has been configured since then as a long and narrow depression (approximately 20 km in length and 10 km in maximum width) between the Sierra de los Filabres and the Sierra Alhamilla, situated to the west of the Sorbas Basin and in continuation with it.



THE ERODED LANDSCAPE

The soft nature of the sediments that have filled the Tabernas Basin from 10 to 8 million years ago, the slow and continual uplift of the sierras that border it, and the arid yet stormy climate that has characterised this territory for a good part of the more recent Quaternary, have conditioned the model for one of the most spectacular erosive landscapes in continental Europe.

A geological landscape reminiscent of Africa that has captured the attention of geologists, naturalists, geomorphologists, photographers and film producers for generations: the Tabernas Corridor, the most southerly desert in Europe. This spectacular erosive landscape is not, therefore, attributable to human action, but to the concurrence of a series of geological factors and its own natural evolution, upon which the peculiarity of being one of the most important scientific and educational places for the study and comprehension of the natural phenomena of erosion and desertification in the Mediterranean Basin has been conferred.

The temporary and torrential character of precipitation generates a rambla type of fluvial system, normally dry, but which discharges a great amount of sediment and water in an almost instantaneous manner during strong storms. Within them the riverbeds are very broad and well-fitting, with steep and vertical sides, although they generally appear dry.

In the soft and readily eroded foothills, the stream produces grooves, which grow towards rills and runnels, and terminate in furrows separated by sharp crests. This landscape is given the name 'Badlands', alluding to its difficulty for being worked or put into agricultural production.

Turbidite sequences in the Tabernas Desert .

Eroded landscape of the Tabernas Desert.

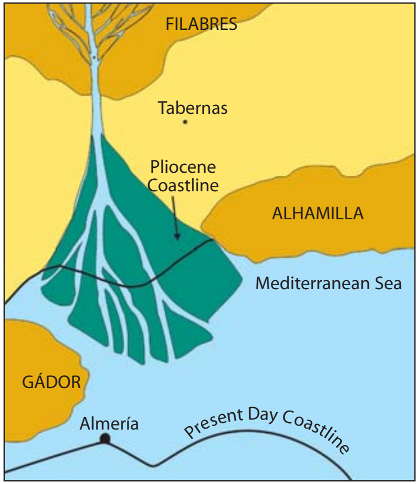
Evolution of the Drainage Network

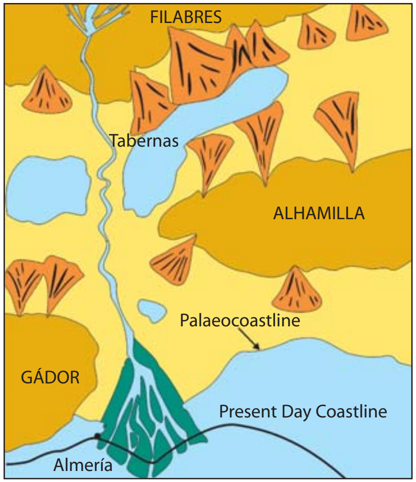
Antonio Martín Penela

4 MILLION YEARS AGO

The eroded landscape of the Tabernas desert is a consequence of the geological evolution of the region over the length of the last 4 million years, and more specifically, of its tectonic and climatic evolution in the past 150,000 years.

In the Lower Pliocene, about 4 million years ago, a fall in sea level took place simultaneously with a strong uplift of the adjacent relieves, Sierra Alhamilla, Sierra Gador and Sierra de los Filabres, already emerged and with some elevation. As a consequence, broad surfaces of the region became emergent and important fan deltas developed that collected water coming from the Sierra de los Filabres. One of these is the precursor of the modern River Andarax, that already occupied a similar position, although its river mouth (outlet) is somewhat displaced to the north, towards the position of La Rioja.





2 MILLION YEARS AGO

During the latter stages of the Pliocene, around 2 million years ago, the elevation of the mountainous relives and the fall in sea level continued, since then practically all of the Province of Almería has become emerged.

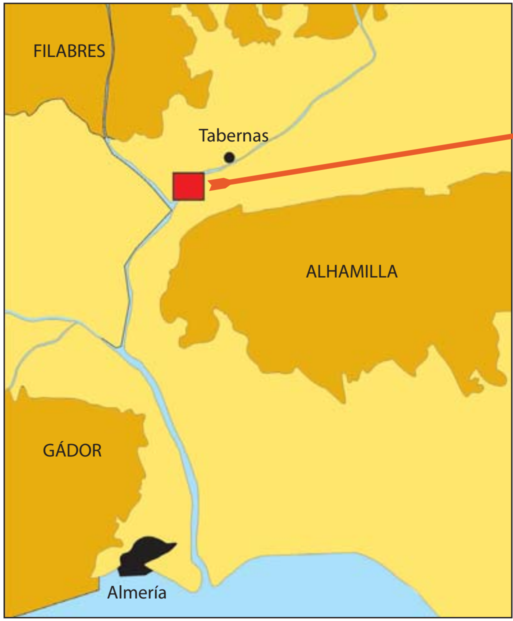
In this period, areas subjected to erosion and areas of sedimentation were differentiated. The latter were represented by small lakes installed in the most low-lying zones, and alluvial fans in those that material coming from the recently-formed mountainous massifs was deposited.

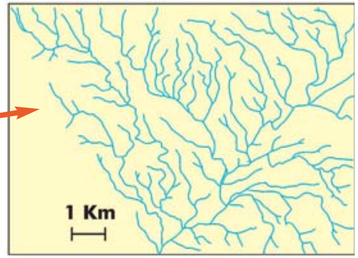
The main drainage during this period were made up of a fluvial system of close appearance to the modern River Andarax, which was forming an important delta in its outlet to the Mediterranean.

THE PRESENT DAY

The establishment of more arid climatic conditions in the Upper Pliocene, led to the total desiccation of lacustrine areas and almost total inactivity in the alluvial fans. It is since this period when erosive processes clearly became dominant in the region, initiating the sculpture of the modern landscape and the development of the fluvial network, which deeply excavated the Neogene and Quaternary sediments in the Tabernas Basin. The Andarax River continued as the principal river, in which all the water from the basin is drained, even if in reality the water and sediment carried by it to the sea is quite scarce.

Since the late Pleistocene, at a time when the modern configuration of the fluvial network was initiated, the factors that have allowed its strong incision, the development of badlands, and its general evolution have been: tectonics, the nature of the material, weak and easily-eroded lithologies, and the climatic conditions.





Distribution of streams in a section of the Rambla de Tabernas. The high drainage density (increased number of streams per unit of surface area) is typical of gullied areas.

Characteristic features of the present-day erosive sculpture in the Tabernas Desert.

Ramblas

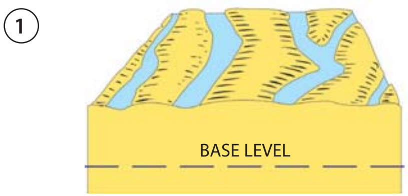
Antonio Martín Penela

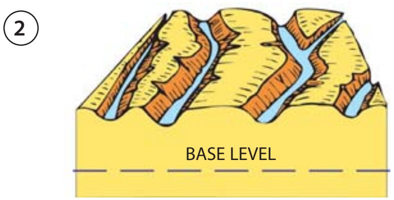
Ramblas constitute the main arteries of the drainage network in the Tabernas Basin. Through these the transport, and also the deposition, of particles coming from the erosion of the basin and the surrounding sierras is achieved.

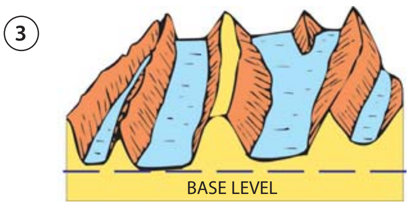
They comprise braided fluvial systems, characterised by the development of numerous sandy bars between which multiple channels are initiated during flood periods. The flow of water in the riverbed is ephemeral, in the majority of cases, circulating only water from surface currents originating as a result of storms. The erosive processes in the ramblas take place during floods, excavating laterally along the length of its margins.

During the last 100,000 years the ramblas have evolved, deepening and widening their river beds, starting to form valleys almost 100 metres deep and river courses whose width exceeds a hundred metres. This important development of rambla valleys is a consequence of a combination of factors such as progressive uplifting of the region, the arid and stormy climate, the soft and erosive nature of the material.

The rivers of the Tabernas Basin are continually down-cutting, trying to reach their equilibrium with the base level of the sea. The occasional torrential precipitation and sparse vegetation cover allows an intense water-bourne erosion that unleashes an intense processes of incision, with a dense drainage network of dendritic type, and abrupt and unstable hillsides.







At the end of the Pleistocene incision of the fluvial network was initiated. The ramblas adopt a meandering morphological pattern.

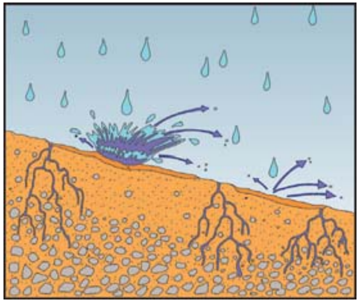
In the Holocene the rivers excavated deeply in order to reach their equilibrium with base level. It produced a generalised incision of the river courses.

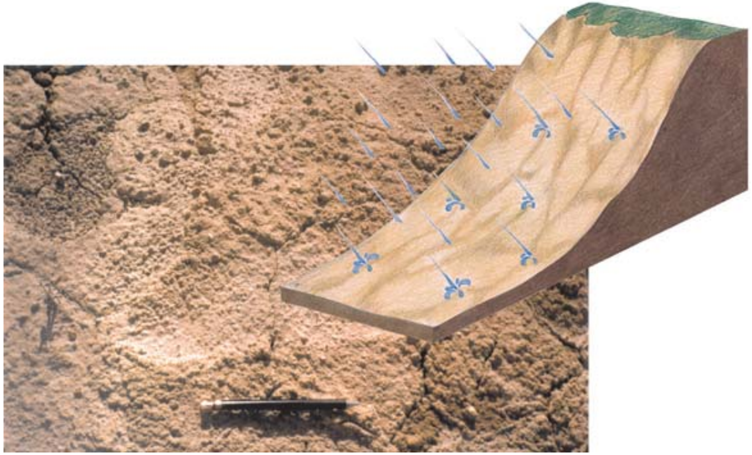
Mechanisms of erosion in the desert: currents

Antonio Martín Penela

RAINDROP IMPACTS

Raindrops tear away particles of the ground that are transported down slope by saltation. This process hardens the surface.

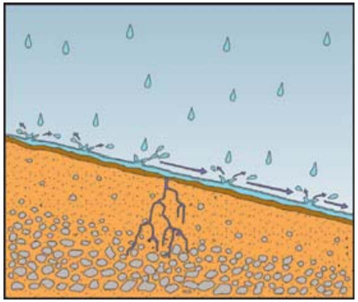


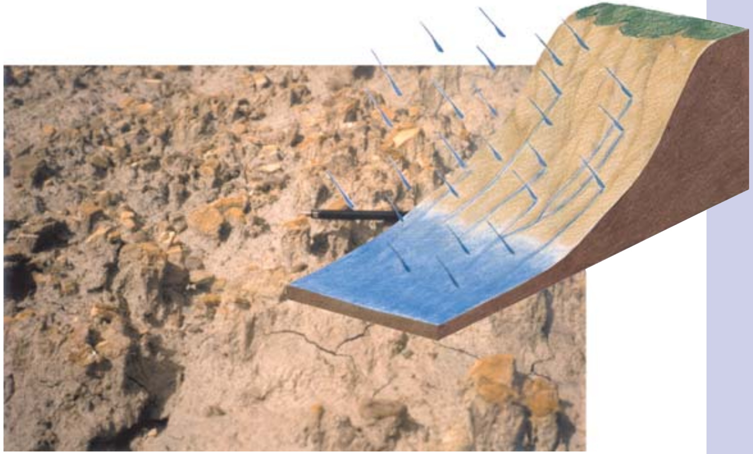


Ground encrusted by the effects of raindrop impacts.

SHEET EROSION

Hardened ground favours the initiation of sheeted flows, helped by the slope, that remove and entrain the material.



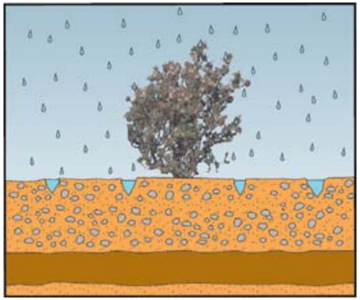


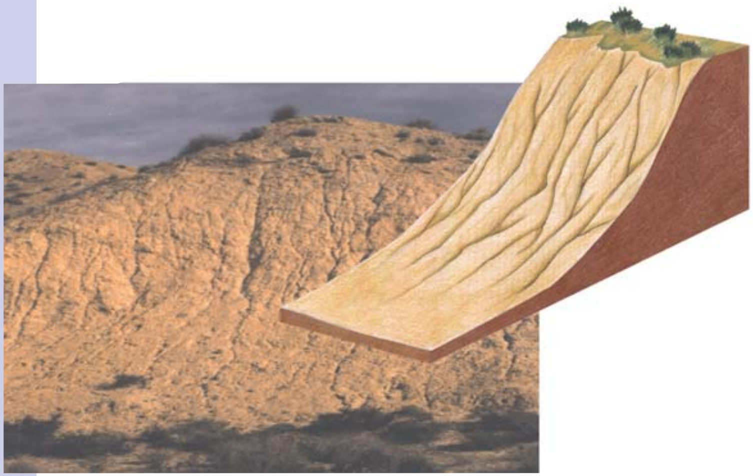
Fairy Chimneys : Small mounds of ground protected from sheet erosion by more resistant fragments of rock.

Mechanisms of erosion in the desert: currents

RILL EROSION

The flow is channelised forming furrows or 'rills'.

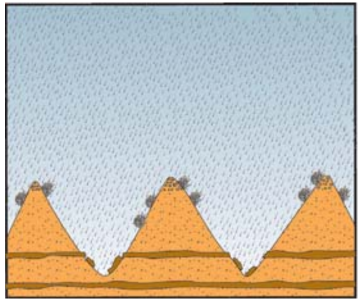




Erosive rills upon slopes are one of the characteristic features of soft hillsides in semi-arid regions.

GULLIES AND BARRANCOS

Deepening of the rills increases the capacity for excavation by concentrated flows, increasing the process until rills are created and barrancos as well.



Typical eroded landscape of gullies, known as 'Badlands'.

Mechanisms of erosion in the desert: evolution of slopes

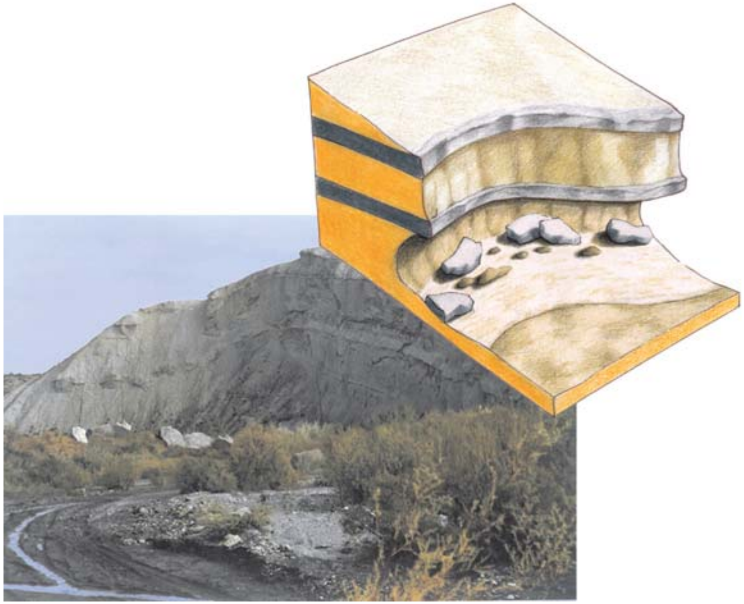
A. Martín Penela

LEDGES FROM THE RETREAT OF SLOPES

Erosion of the softest material forms unstable cornices in the harder material above it, which topple down due to gravity.

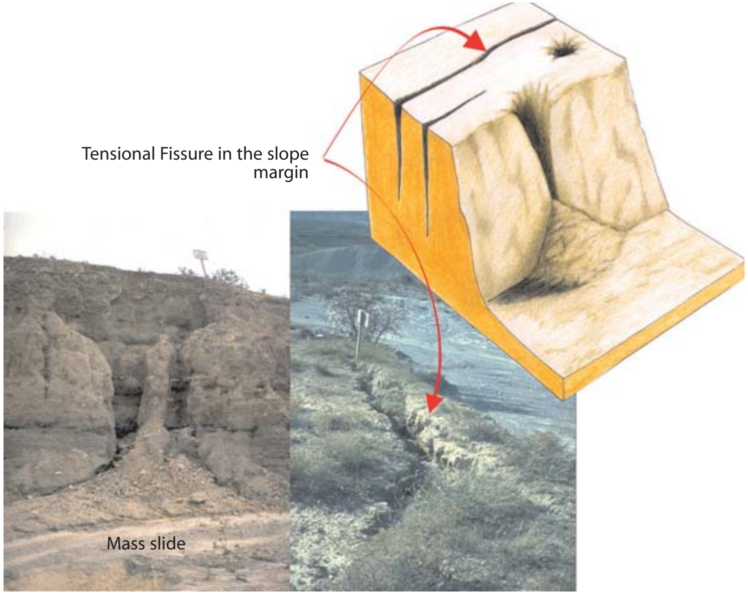
UNDERMINING BY BASAL UNDERCUTTING

Lateral erosion of the slope base in meandering areas causes instability and, afterwards, block falls from above.



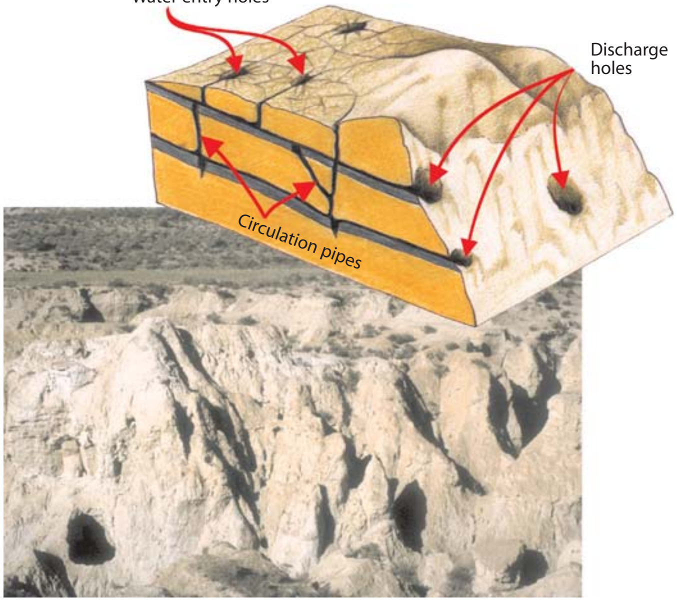
MASS SLIDES

Fissures parallel to the slope allow partial slumping and the collapse of vertical tunnels.

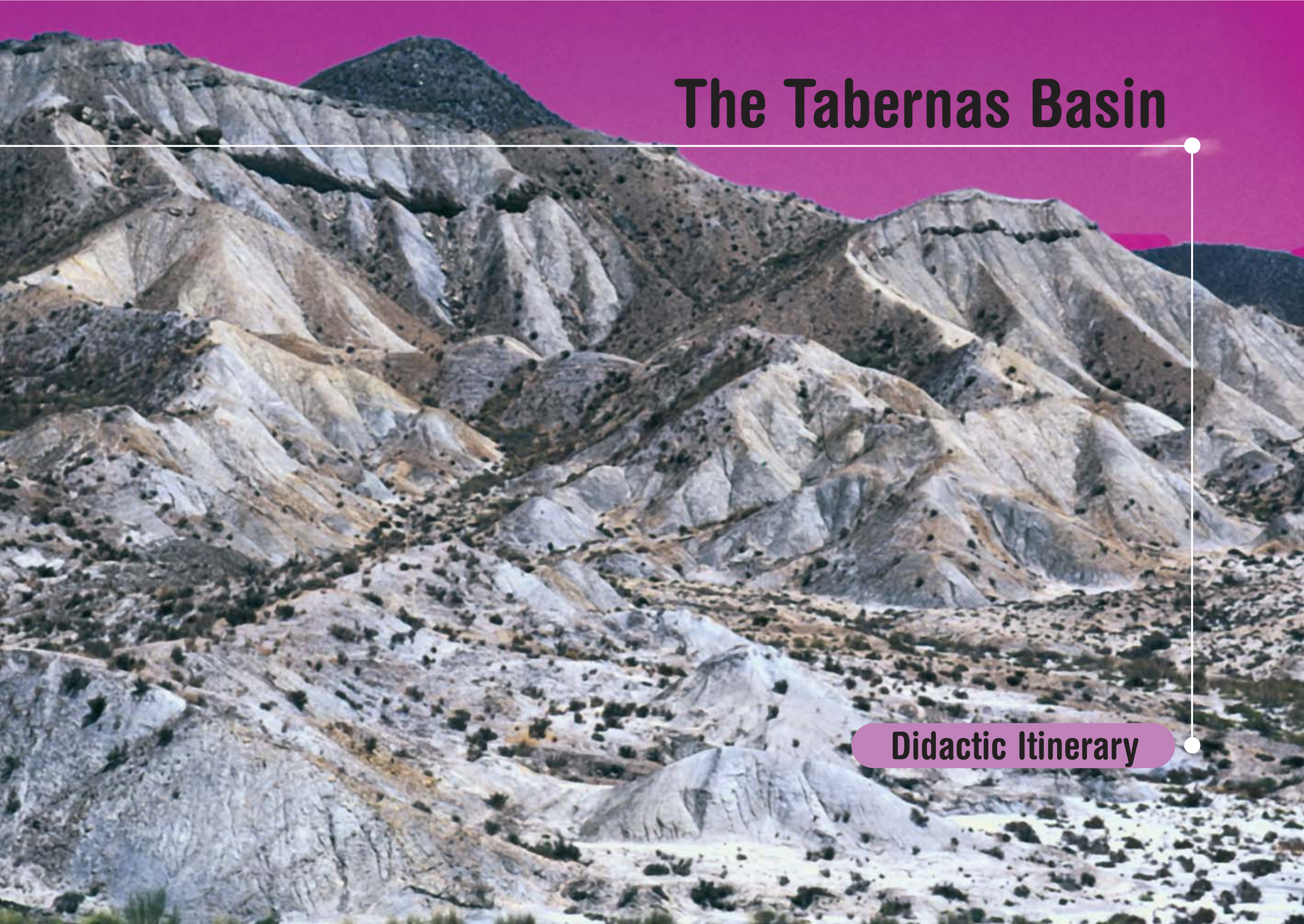


EROSION IN TUNNELS (PIPING)

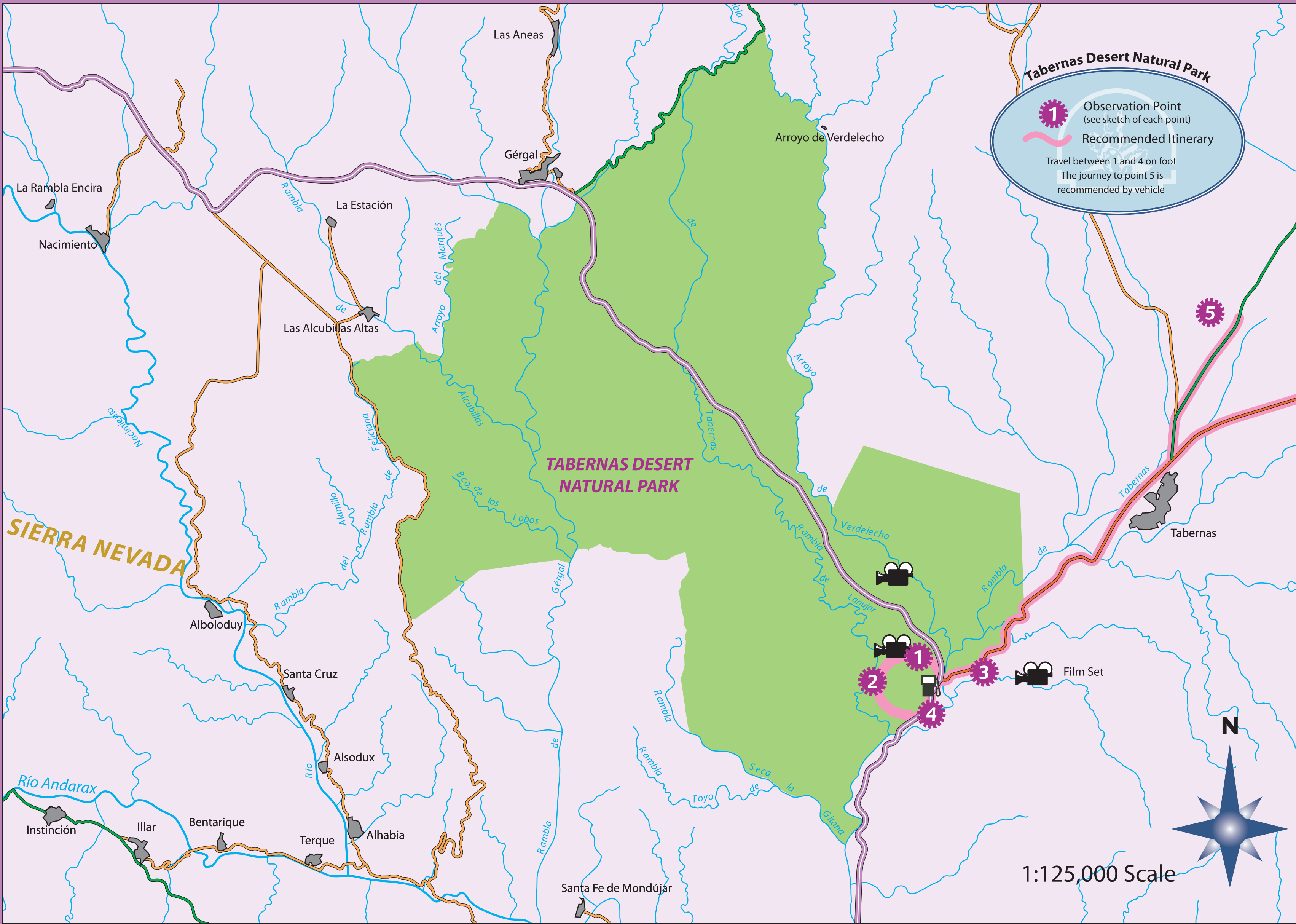
Water penetrates into the ground and generates a network of collectors through which material is removed. The pipes grow progressively and the relief ends in collapse giving rise to pseudokarstic morphologies.



The Tabernas Basin



Didactic Itinerary



Tabernas Desert Natural Park
Observation Point
(see sketch of each point)
Recommended Itinerary
Travel between 1 and 4 on foot
The journey to point 5 is
recommended by vehicle
TABERNAS DESERT
NATURAL PARK
SIERRA NEVADA
Las Aneas
Gérgal
Arroyo de Verdelecho
La Rambla Encira
Nacimiento
La Estación
Las Alcubillas Altas
Alboloduy
Santa Cruz
Alsodux
Río Andarax
Instinción
Illar
Bentarique
Terque
Alhabia
Santa Fe de Mondújar
Tabernas
Film Set
N
1:125,000 Scale

1. The turbidite succession of the Tabernas submarine fan

Juan C. Braga - José M. Martín

TURBIDITES

One of the most significant sedimentary features of the Tabernas Basin is the existence of a thick package of detrital sediment deposited around 8 million years ago (in the Tortonian) at the bottom of the sea, at several hundred metres of depth, in a slope setting, at the foot of the slope and on the submarine plain. Two different types of deposits are distinguished:

a) Those of submarine fans, situated at the foot of the slope and associated with turbidity currents, known as turbidites.

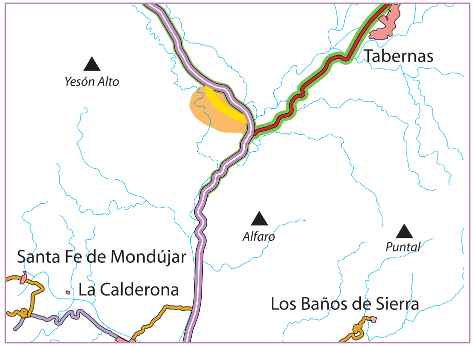
b) Mass failures on the slope, caused by seismic movement (earthquakes) of great magnitude, known as seismites.

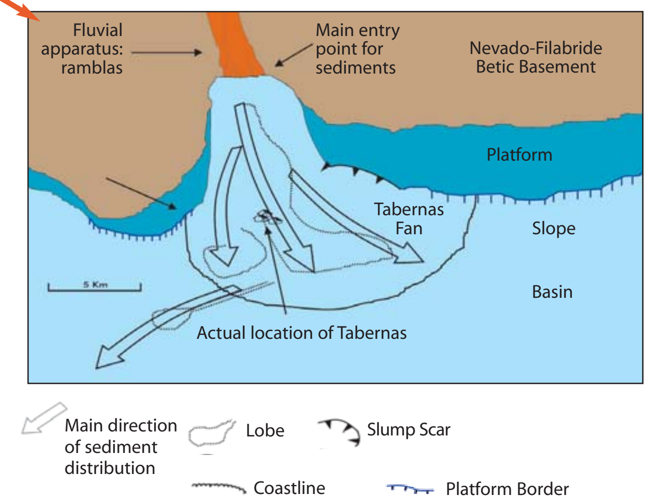
Upon this sedimentary unit characterised by the alternation of decimetre layers of sandstone and marl, the characteristic erosive sculpture ('Badlands') of the Tabernas Desert has been fashioned to a great extent.

8 million years ago (during the Tortonian) the Tabernas Basin had not been differentiated as such, since the relieves that delimited it to the south did not exist, like they do at present; the uplifting of the Sierra Alhamilla was initiated afterwards, around 7 million years ago.

PALAEOGEOGRAPHY OF THE TABERNAS BASIN AROUND 8 MILLION YEARS AGO (TORTONIAN)

With information taken from Kleverlaan, 1989

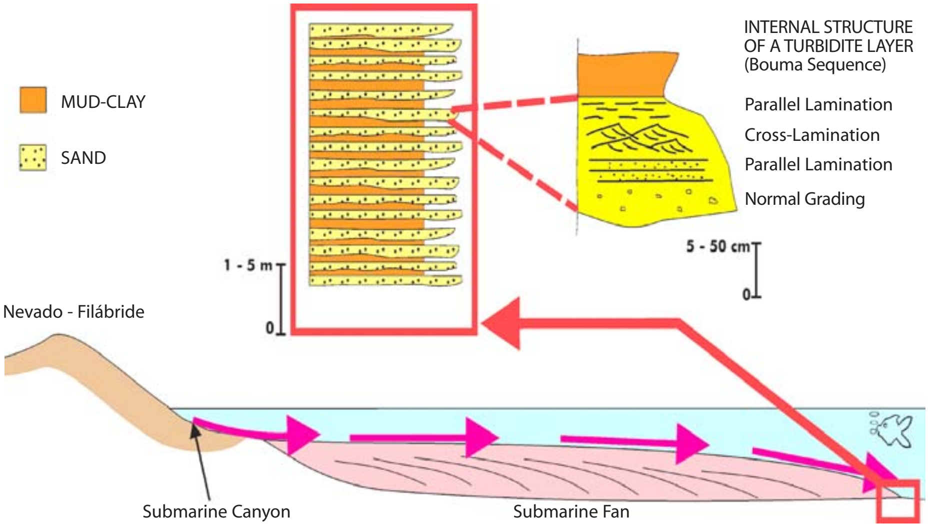




The Tabernas Submarine Fan occupied an area of some 100 km^2 extent. In it one can differentiate the most distinctive elements such as feeder channels, with a conglomerate fill (with clasts of up to several cubic metres), and lobes, that are built as mounded deposits at located at the exit of channels, consisting of sand and mud. The source area of all these sediments is the Sierra de los Filabres, located on the northern margin.

1. The turbidite succession of the Tabernas submarine fan

The turbidite succession that we observe in the Barranco del Poblado Mejicano corresponds to the external zone of the Tabernas Fan and consists of sand layers linked to turbidity currents (suspension of sand and mud with a density of between 1.5 and 2 g/cm^3), intercalated with fine sediments of mud and clay size. Both types of sediment are present in decimetre thick layers. Turbidite currents come from the upper part of the fan, and/or emergent area, or from the platform situated well away from here. The sediments that they transport are essentially deposited in the lobes and at the margin of the fan. The clay and mud layers are deposits that are formed at the bottom of the marine basin between every two turbidite layers.



In response to differential erosion, the turbidite layers, which are laterally very continuous, stand out in the landscape. The succession is actually found to dip towards the north, as a consequence of the later uplift of the Sierra Alhamilla, although the original (very gentle) inclination of the stratified succession was in exactly the opposite sense. The turbidite layers, in detail, consist of sand whose grain size progressively diminishes upwards, and some mud in its upper part. Its deposition is extraordinarily rapid. The most granular (sandy) intervals were deposited over a period of a few hours. The finest (muds) take as much as a few weeks. On the geological timescale deposition of the turbidite may well be considered as almost instantaneous. The frequency of repetition of this process within this zone was approximately one turbiditic event every 700 years. The sediment that is intercalated between the turbidite layers (clay-mud) was, however, deposited very slowly from suspension, in intervals of time from hundreds to thousands of years for each layer.

Fan margin succession. Alternation of hard layers of sandstone turbidites and soft layers consisting of muddy sediments.

SEISMITES

Throughout the turbidite succession observed in the barranco levels of seismites are intercalated within it. Internally they are composed of two types of material: (a) a conglomerate, at the base, with clasts (sometimes up to several cubic metres) encased in a sand and mud-sized matrix, and (b) a sand, in the higher part of the layer, of turbiditic character (up to several metres in thickness). The origin of these layers is tied to slumping of material in the marine platform slope, induced by earthquakes. The poorly-consolidated sediment that exists there, is easily mobilised through the shock produced by a seismic disturbance. If the shock is of sufficient intensity it slides, towards the frontal slope, at the same time disrupting and mixing with the fluid, generating a density flow that is afterwards going to give rise to a basal conglomerate deposit. The upper turbidite corresponds to sand that is lifted into suspension in the roof of the density flow, that is deposited immediately afterwards. Seismites correspond to instantaneous events on the geological timescale. Many of them have a considerable extent, and are suitable as correlation levels (guide levels). Their expanse gives an indirect estimate to the intensity of the earthquake that was generated.

At times in these slides only deformation folds are produced in the layers, without the sediment affected becoming disrupted, generating structures known as 'slumps'. In reality a complete transition exists between several situations, in that many slumps, if they continue through the sliding process, end up by breaking up and generating a breccia (intraformational breccia), whose clasts frequently exhibit irregular geometries, in a recurved form, corresponding to the remains of folds.

Deformation of layers produced by sliding: Slumps

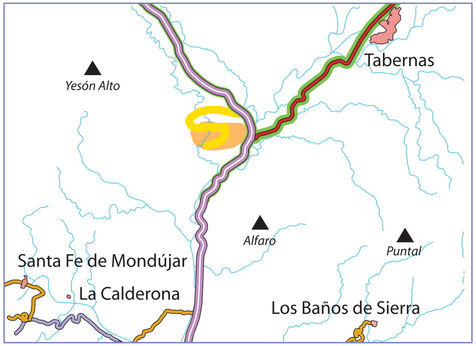
One of the most characteristic levels in the Tabernas Basin, interpreted as a seismite, is known as the 'Gordo Megabed', whose thickness reaches up to 40 metres (Kleverlaan, 1989).

2. The Las Salinas Travertines in the Tabernas Desert

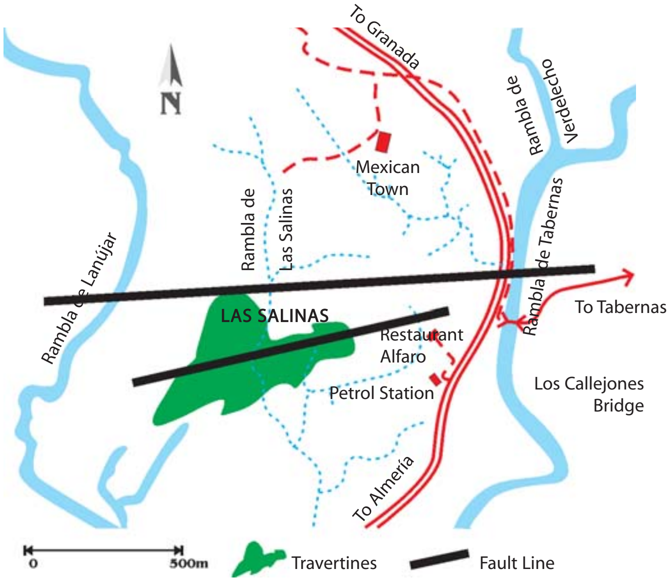
A. Mather - M. Stokes

One of the most surprising, and at the same time poorly known, aspects of recent geological processes that can be observed in the Tabernas Desert is the presence of Quaternary travertine formations from different areas within it. One of the zones where the better and most spectacular development is acquired is located in the place known as Las Salinas.

The precise age of these formations is uncertain for the moment. The process is active at present and most probably it was already in operation during the Pleistocene.



LOCATION OF THE LAS SALINAS TRAVERTINES IN RELATION TO FAULT LINES



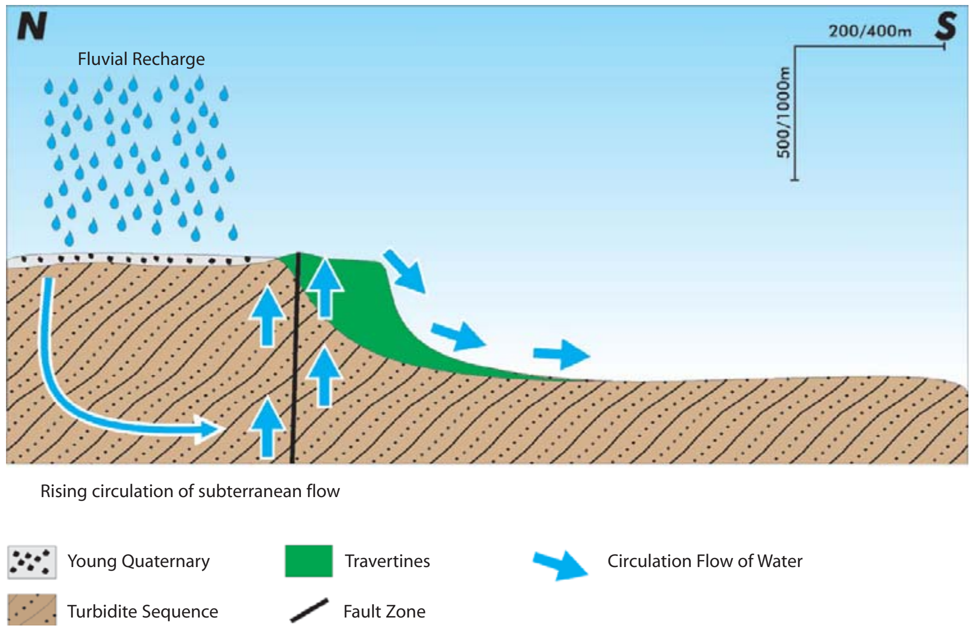
Travertines are a type of natural limestone rock, formed from the precipitation of carbonates out of surface and subterranean water. Modern travertines are developed in very localised zones associated with active streams, at springs in fluvial water courses, and in general, at whatever position a change in the velocity of flowing water is produced, so that the degasification and consequent precipitation of calcium carbonate is favoured.

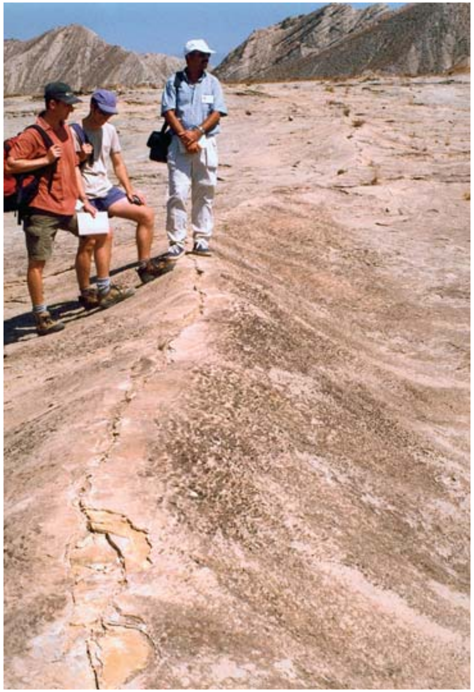
2. The Las Salinas Travertines in the Tabernas Desert

At Las Salinas it seems clear that its present-day operation is due to the circulation of water, of both pluvial and subterranean origin, at a certain depth that ends up appearing at the surface due to a series of rather important fractures with an approximate east-west orientation.

Thanks to this line of tectonic disturbance, a very slow and continuous stream of water flows out, with a large saline concentration owing, probably, to the washing of saline material from the area of Yesón Alto and to progressive concentration within water from capillary rise.
The carbonate precipitated due to the slope creates typical travertine deposits with laminated and concretionary structures.

IDEALIZED SECTION OF TRAVERTINE GENETIC PROCESSES IN LAS SALINAS, IN RELATION TO THE DISPOSITION OF GEOLOGICAL FRACTURES AND THE CIRCULATING FLOW OF WATER





Surface crest of the fault zone associated with the formation of travertine deposits (Photo, M. Villalobos).

Detail of the internal structure of the travertines (Photo, M. Villalobos).

Detail of travertine deposits and salt pseudostalagtites in the accretionary curtain (Photo, M. Villalobos).

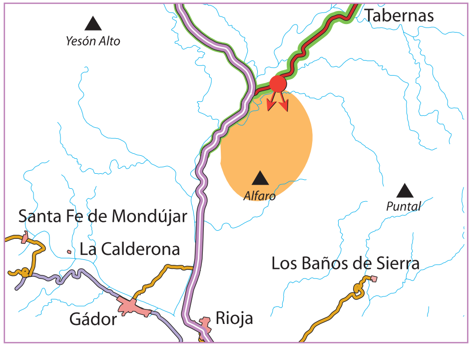
General view of the travertine accretionary curtain (Photo, M. Villalobos).

3. The Escarpment landforms of the Cerro Alfaro District

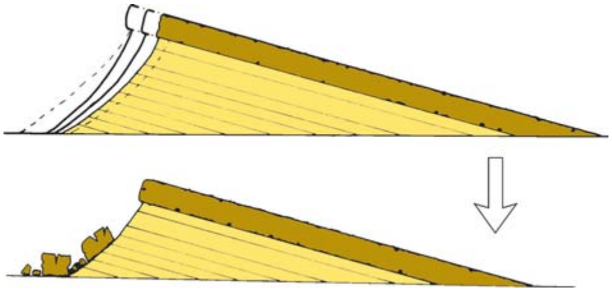
M. Villalobos

A very characteristic morphology in the erosive landscape of the Tabernas Desert are escarpment landforms, especially visible in the Cerro Alfaro district. These consist of inclined layers of hard material, normally sand and/or conglomerate, that protect the much weaker underlying material, usually marls, from erosion.

In the specific case of the Tabernas Desert, the most visible and spectacular examples have the peculiarity that the sense of inclination of the layers (towards the north) is reversed with respect to the original deposition of the layers (towards the south), that is to say, that they have been uplifted from the south and inclined towards the north. This inversion must be seen as due to uplifting of the Sierra Alhamilla, just as reflected in the accompanying figure.

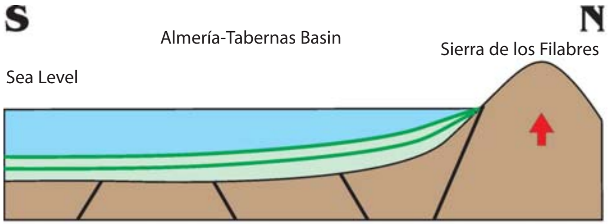


EVOLUTION OF AN ESCARPMENT LANDFORM, WITH A LAYER OF HARD MATERIAL INCLINED ABOVE A PACKAGE OF WEAK MATERIAL THAT IS ERODED LATERALLY



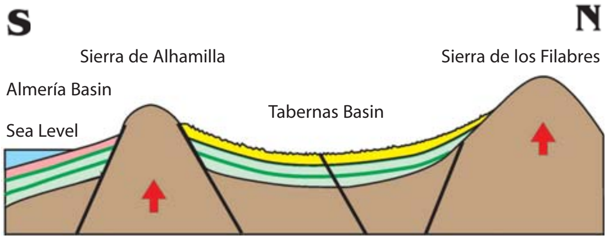
3. The Escarpment landforms of the Cerro Alfaro District

INTERPRETATIVE SECTION FOR THE ESCARPMENT LANDFORMS IN THE CERRO ALFARO DISTRICT IN RELATION TO THE EVOLUTIONARY HISTORY OF THE BASIN AND UPLIFT OF THE SIERRA ALHAMILLA



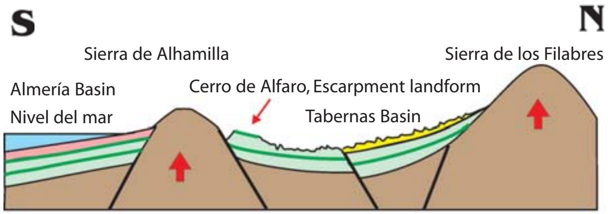
AROUND 8 MILLION YEARS AGO

In the period that existed between15 and 6 million years ago (Serravallian – Messinian), the sea washed against the foot of the Sierra se los Filabres. Numerous submarine fans, a continuation of the rivers that drained the sierras, fed sediments into the marine basin, depositing a thick series of turbidites, alternating layers of weak, marl sediments and tough sands and conglomerates.



AROUND 2 MILLION YEARS AGO

Approximately 7 million years ago, at the end of the Tortonian, tectonic readjustment had caused emergence of the Sierra Alhamilla block, separating the Tabernas Basin towards the north of the Sierra Alhamilla from the Almería Basin towards the south. They continued to be marine for a significant period of time, up until around 4 million years ago. Uplift of the sierra elevated and brought up turbiditic material already deposited, reversing the inclination of the layers. The post-Messinian deposits were markedly different in these basins.



PRESENT DAY

Since 4 million years ago (Upper Pliocene and Pleistocene) the environment in these basins has been virtually continental. Erosive agents have acted upon exposed material in the basin, especially in Tabernas, forming the erosive landscape that we can observe. The harder layers of the turbidite series create the typical landforms of dipping escarpments, also in a reversed sense to that in which they were deposited.

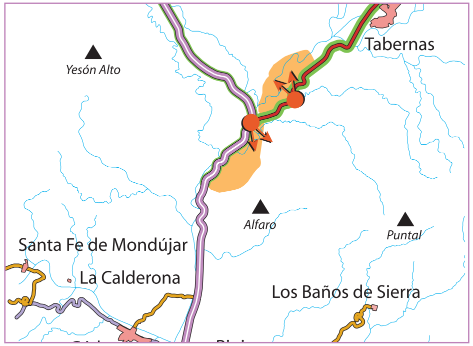
- Post-Messinian deposits of the Almería Basin
- Post-Messinian deposits of the Tabernas Basin
- Serravallian-Messinian deposits of the Almería-Tabernas Basin, hard layers in dark green, softer layers in light green
- Betic Substratum; Nevado-Filábride and Alpujárride complexes

4. Tunnel Erosion (Piping)

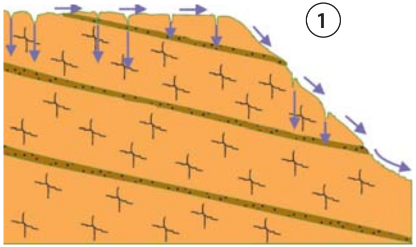
Antonio J. Martín Penela

Tunnel erosion (also known as 'piping') constitutes a peculiar erosive mechanism which may achieve an important development in semi-arid regions. The resulting landforms, of great scenic beauty, are known as 'pseudokarst' or mechanical karst. In the Tabernas Desert they are superbly represented.

It originates from the movement of concentrated flows of water that circulate through poorly consolidated material, producing a washout that gives way to the formation of tubular conduits (tunnels or pipes).

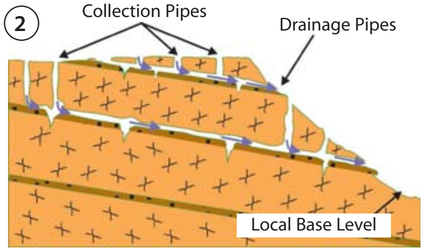


DIFFERENT STAGES OF TUNNEL EROSION



Tunnel erosion is initiated through part of the rainwater permeating into the ground through fissures and cracks on the surface.

Fissures and cracks in the surface.



Collection pipes on a slope, oriented in association with fractures.

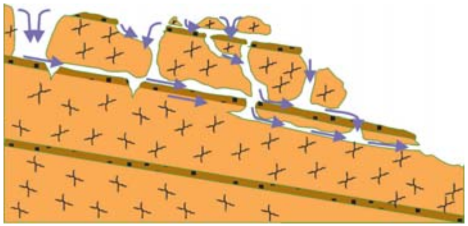
The removal of solid particles through the drainage orifices produces an increase in the size of the existing macropores and fissures, creating more or less complete, continuous channels, that come from the collection pipes or sinkholes through to the drainage pipes. These tunnels can have a diameter between 10 and 40 cm, and a few metres of length.

Drainage pipe close to local base level.

4. Tunnel Erosion (Piping)

DIFFERENT STAGES OF TUNNEL EROSION

3

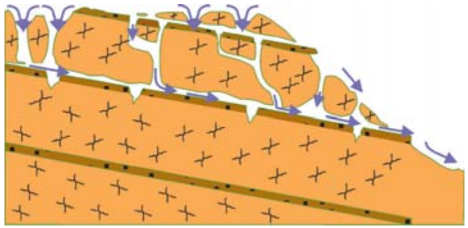


The channels grow progressively until they are made unstable. Partial or total collapse of the walls and roof occur when they are flooded with intense rainwater, causing an excess of weight in the overhangs. The phenomenon may also occur after a significant drought, through the intense cracking of the material, producing a sudden fall.

Large sized collection pipes or sinkholes, originating from the coalescence of several vertical collection pipes with the collapse of their walls.

Failed and abandoned drainage pipe, resulting from the descent of the tunnel network towards local base level.

4



Progressive development of the tunnel network, accompanied by many collapses through part of it. A system of barrancos is initiated in which numerous failed channels and blind valleys with U-shaped sections, are still preserved, that rapidly evolve into V-shaped sections. Altogether, a net retreat of the slope takes place.

Weathered pseudokarstic morphology which evolves towards a system of gullies.

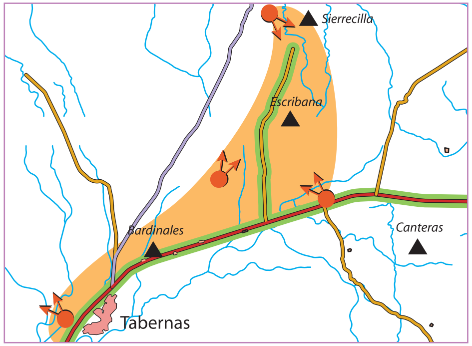
5. The Quaternary alluvial fan-lake system

A. M. Harvey

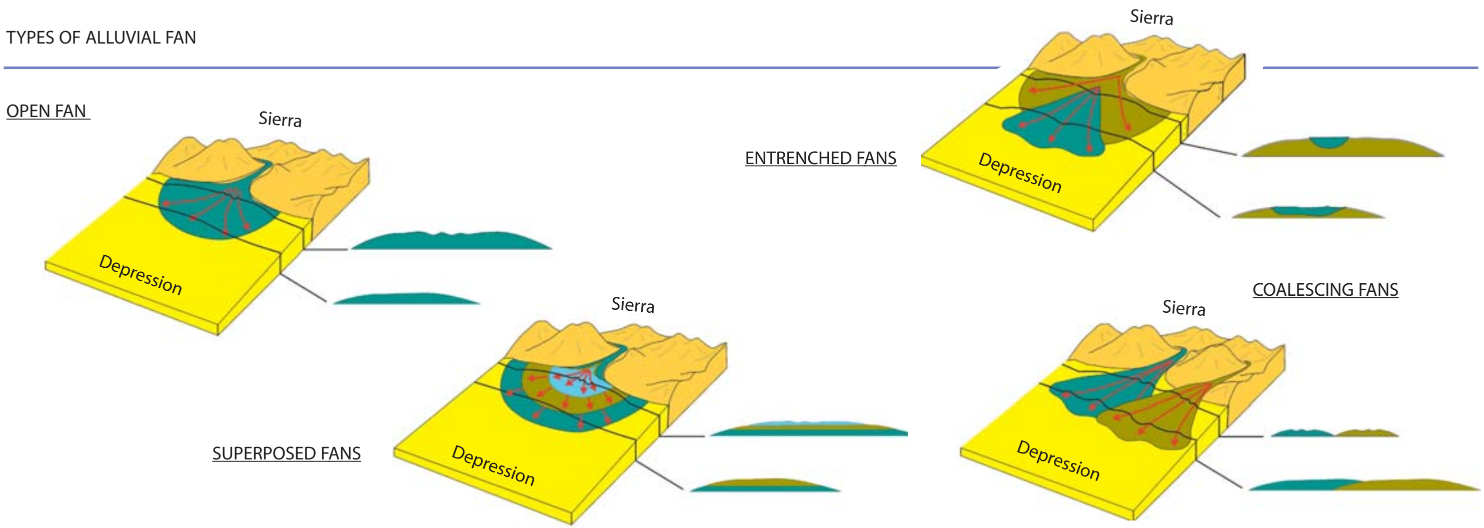
One of the most visible and characteristic features in the recent sculpture of the Tabernas Desert are alluvial fans.

The development of alluvial fans takes place at a break of slope produced at the contact between a more or less mountainous front and a small sedimentary trough. In this morphological setting, when the confined river or rambla courses of the mountainous zone reach the sedimentary basin, with much lower slope, they suffer a sharp reduction in their capacity to transport bedload, generating extensive deposits in the form of a fan.

The lateral superposition of fans in the same front generates a system of coalescing fans. In alluvial fans, the coarsest material is deposited in the more proximal zones (closer to the relieves), while the finer, less-heavy sediment, may be carried to the more distal zones (furthest from the relieves). In the more distal, practically planar parts of the fan, marshy or swampy zones are frequently formed, and include small lagoonal basins that are filled by sediments.



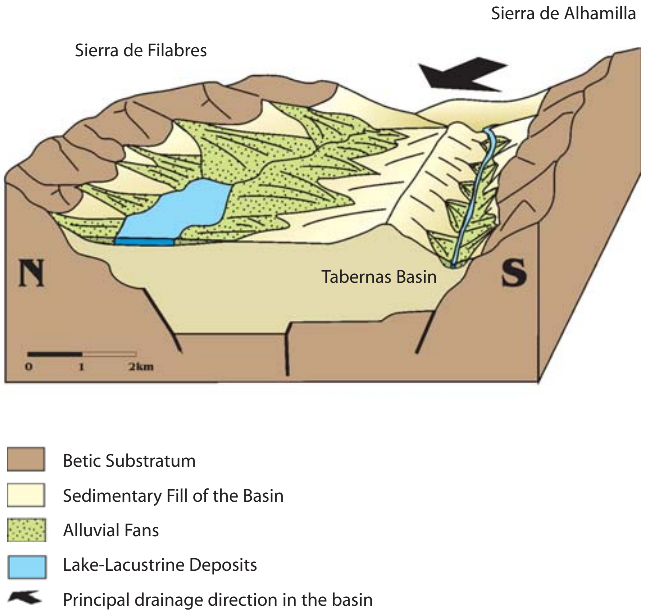
TYPES OF ALLUVIAL FAN



Although alluvial fan morphologies are frequent and obvious throughout the desert zone, in the vicinity of the Tabernas District, it is possible to distinguish an ancient yet still functioning alluvial fan system, that at present feeds into the main drainage of this area, the Rambla de Tabernas, an artery for the removal of sediment and water alike, that are discharged from the fluvial network in the eastern sector of the basin.

View of the lacustrine deposits (photo J. C. Braga).

IDEALIZED SCHEME OF THE ALLUVIAL FAN-LAKE SYSTEM DURING THE PLEISTOCENE IN THE EASTERN SECTOR OF THE TABERNAS BASIN

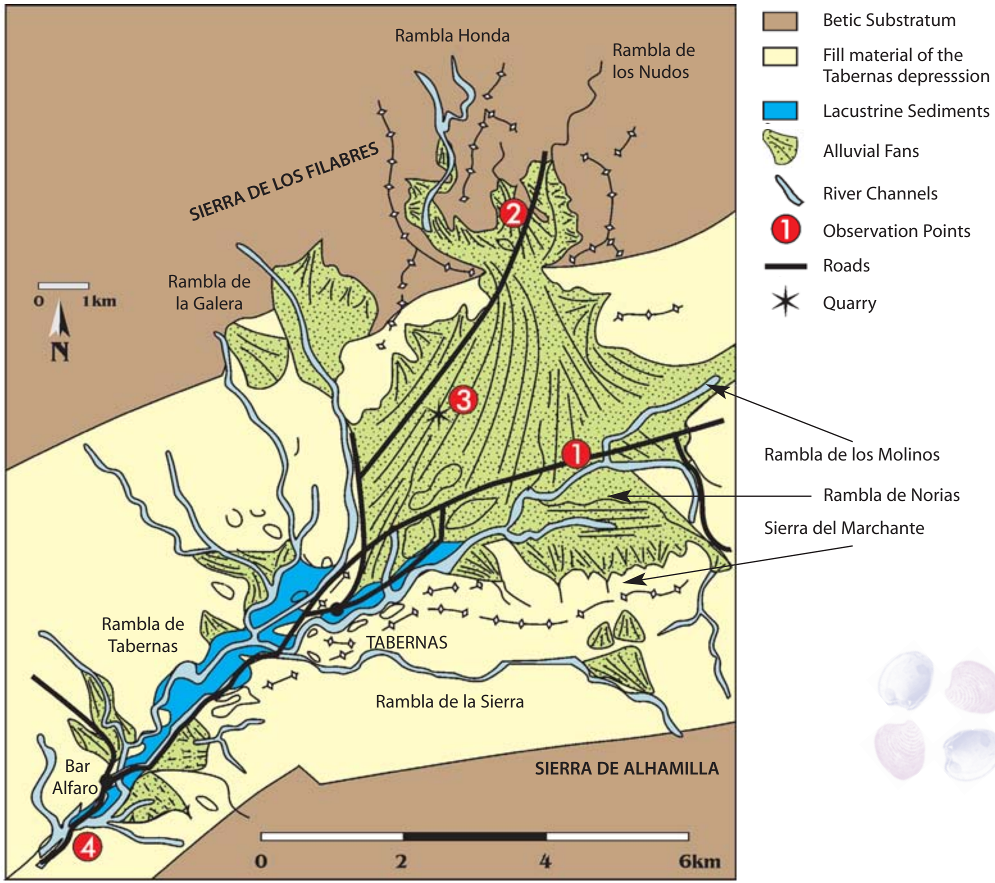


5. The Quaternary alluvial fan-lake system

The fans started to function during the Pleistocene, after an erosive period that stripped out the upper part of the sediments in the basin.

During the operation of these alluvial features, the basin drainage remained interrupted for some time, generating a lacustrine zone in which around 20 metres of sediments were deposited. These deposits are visible in the vicinity of Tabernas and the Los Callejones bridge (at the junction of the motorway with the old Murcia road).

QUATERNARY DEPOSITS OF THE ALLUVIAL FAN-LAKE SYSTEM IN THE TABERNAS AREA



In the map several places used for field observations are located

1. General view of coalescing alluvial fan deposits in Rambla Honda
2. Coarse river sediments typical of the more proximal part of the alluvial fan, in relation to the supply front from the Los Filabres relief
3. Finer sediments characteristic of distal deposits (visible in the quarry area)
4. Lagoon sediments visible in close vicinity to the Alfaro petrol station