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Natural and Cultural History of the Golfo Dulce Region, Costa Rica

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Veronika Mayer, Susanne Pamperl, Anton Weber,
Gerhard Aubrecht (scientific editors)

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Anton WEISSENHOFER, Werner HUBER, Veronika MAYER, Susanne PAMPERL,
Anton WEBER, Gerhard AUBRECHT (scientific editors)

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Outline of the geology of the Golfo Dulce region (Costa Rica) and its surroundings in Central America

Vista de conjunto de la geología de la región del Golfo Dulce (Costa Rica) y de sus inmediaciones en América Central

Otto MALZER & Markus FIEBIG

Abstract: This article is a brief review of the present knowledge on the Costa Rican geology. In the first chapter of this paper the main structural elements of the Central American land corridor are described. The second chapter focuses on the Golfo Dulce region and the area around the research station La Gamba. A short introduction to the regional geology is given and will help to understand the rocks and structures in the area. This work is meant to be a basis of and supplement to the wealth of biological scientific research carried out at the Tropical Field Station La Gamba.

Key words: Geological history, Geomorphology, La Gamba, Golfo Dulce, Central America, Costa Rica.

Resumen: Este artículo es una breve revisión del actual conocimiento sobre la geología de Costa Rica. En el primer capítulo de este trabajo se describen los elementos estructurales principales del corredor terrestre de América Central. El segundo capítulo se centra en la región de Golfo Dulce y en los alrededores de la estación de investigación La Gamba. Se entrega una breve introducción a la geología regional que ayudaría a comprender la estructura y las rocas de la area. Este trabajo está considerado como una base y complemento a la riqueza de investigaciones científias biológicas llevadas a cabo en la Estación de Campo Tropical La Gamba.

Palabras clave: Geología histórica, geomorfología, La Gamba, Golfo Dulce, América Central, Costa Rica.

Introduction

Central America forms a land bridge between the two American continents. The sedimentary and structural history of Central America has been investigated intensively in the last decades and an impressive list of publications (e.g. DENYER & KUSSMAUL 2003, DENYER et al. 2003, MALZER 2001), including some general tectonic, geomorphologic and geologic maps (DENYER et al., 2003) is available. This statement is also valid for Costa Rica as a whole and to a somewhat more limited degree to the Golfo Dulce region. Here, and in particular in the area of the biological research station "La Gamba", detailed geological work is still rare (e.g. SCHEUCHER et al., this volume; FIEBIG et al. 2007; BOSSEW et. al, in this volume). Further studies of local geoscientific problems, like the exact nature of Quaternary infill in young sedimentary basins are still necessary.

This article gives a brief summary of the geomorphologic development of Central America on the whole, of Costa Rica in detail, and an introductory overview of the Golfo Dulce Region.

Short overview of the tectonic structure and development of Central America

At an average distance of 100 km from the Pacific coast, a deep ocean trench with water depths between 3.000 and more than 5.000 metres is situated. This Middle America Trench (Fig. 1) marks the border between the North American, the Caribbean and the South American Plates in the north-east and the Pacific Cocos and Nazca Plates in the south-west. The trench is the morphological expression of a subduction zone in the earth's interior. In subduction zones, oceanic plates descend into the mantle of the earth. At the Middle America Trench, Pacific plates subduct under the American plate system.

The Central American landmass is structurally subdivided into several tectonic blocks. The Maya block in the north, comprising southern Mexico, the Yucatán peninsula and most of Guatemala, is part of the North American Plate. The Chortis block, Chorotega- and Choco blocks, adjoining southward, form the Central American land bridge. The boundary between the

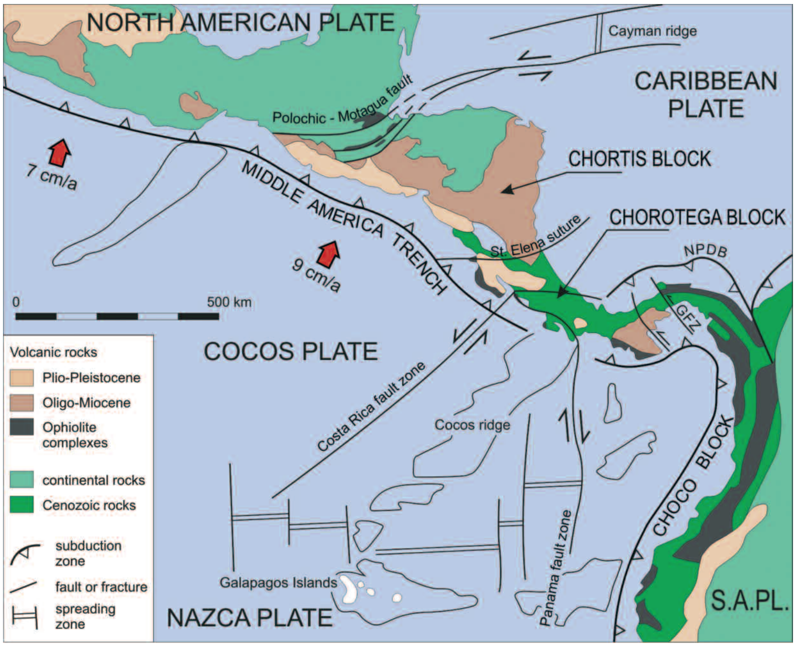

Fig. 1: Plate tectonics of Central America (modified after Berrage & Thorpe 1988, Malzer 2001). The complex tectonic situation of the Central American land bridge is explained in the text. Active subduction (e.g. in the Middle America Trench) and ocean floor spreading (between the Nazca and Cocos plates) cause very active geological processes on land (volcanism, earthquakes, land slides etc.).

North American Plate and the Chortis block is the transcurrent Polochic-Motagua Fault System. In the Caribbean Sea, the Cayman Trench is the continuation of this fault system and splits the Caribbean Plate from the North American Plate. The Costa Rica Fault Zone (CRFZ) and the Panama Fault Zone (PFZ) are important structural elements in the Pacific Ocean floor and on the Central American land bridge. The PFZ is the boundary between the oceanic Cocos and Nazca plates. In the southern part of Costa Rica, the PFZ splits into branches which control to a large extent the topography of the Golfo Dulce region.

The structural element which was crucial for the uplift and eventually the closure of the entire Central American land bridge is the Cocos ridge. It is nowadays an aseismic feature (no appreciable recent seismic or volcanic activity). Its width ranges from 200 to 300 km and the top of the ridge is up to 2.500 m higher than the surrounding Pacific Ocean floor. The Cocos ridge strikes SW-NE and represents the trace of the Galapagos hotspot below the moving Pacific Plate (Ranero & v. Huene 2000), a feature similar to the Hawaiian island chain. It consists of thick oceanic crust (basaltic lavas) and appears to interrupt the Middle America Trench.

The Gatun Fracture Zone (G.F.Z. in Fig. 1) is the boundary between the Chorotega and the Choco block and simultaneously the eastern limit of the so-called Costa Rica – Panama Microplate. This microplate was formed during the Miocene collision of Central America with the South American plate. It is bounded by the North Panama Deformed Belt (NPDB) in the north, the Middle America Trench in the south and the Panama and Costa Rica fault zones in the west.

Geological history and present-day configuration

The history of Central America begins with the fragmentation of the Pangaea super-continent in the Middle Jurassic. The opening of the North and later the Central Atlantic Ocean started about 160 million years (Ma) ago, resulting in the separation of North and South America around 120 Ma. The intrusion of large volumes of basaltic lava formed a plateau of oceanic crust where North and South America drifted apart (130-80 Ma). Afterwards, possibly as a consequence of the opening of the South Atlantic in Late Cretaceous, the stress regime between the two American plates changed from dilatation to compression. On land, the Santa Elena Suture (Fig. 1) resulted from these compressive forces. Also around 80 Ma, subduction of the eastern Pacific Ocean floor under a newly formed Caribbean Plate started. Subduction and related plate movement also triggered the formation of the transcurrent Polochic-Motagua Fault System. Along this fault system, present-day Honduras, southern Guatemala and northern Nicaragua were split off from the North American plate, rotated around the Maya Block and moved eastwards into their present position. This rotated landmass forms the northern part of the Central American land bridge and is called Chortis block. As a former part of the North American continent, this block possesses a metamorphic basement of Precambrian to Paleozoic age. Due to the rigid continental crust, the Chortis block displays intensive faulting and lateral shifting along NE-SW structures. Surface features like mountain ranges and basins follow the NE-SW trend.

Also after 80 Ma, intensive volcanism along the subduction zone has formed an island arc, which is now the backbone of the Central American land bridge, the Chorotega block. This block comprises the south of Nicaragua, Costa Rica and western Panama. It does not have a continental basement like the Chortis block but consists of Mesozoic oceanic lavas with interspersed deep-sea sediments (radiolarites, cherts, shales). Apart from these basaltic and rhyolitic rock masses, some mafic and granitoid intrusions exist (e.g. Cerro Chirripo in the Sierra Talamanca). During the Tertiary, 40-6 Ma, the basement was largely covered by shallow marine sediments deposited in backarc, forearc and short-lived inter-insular basins. The sediments generally contain some volcanic material.

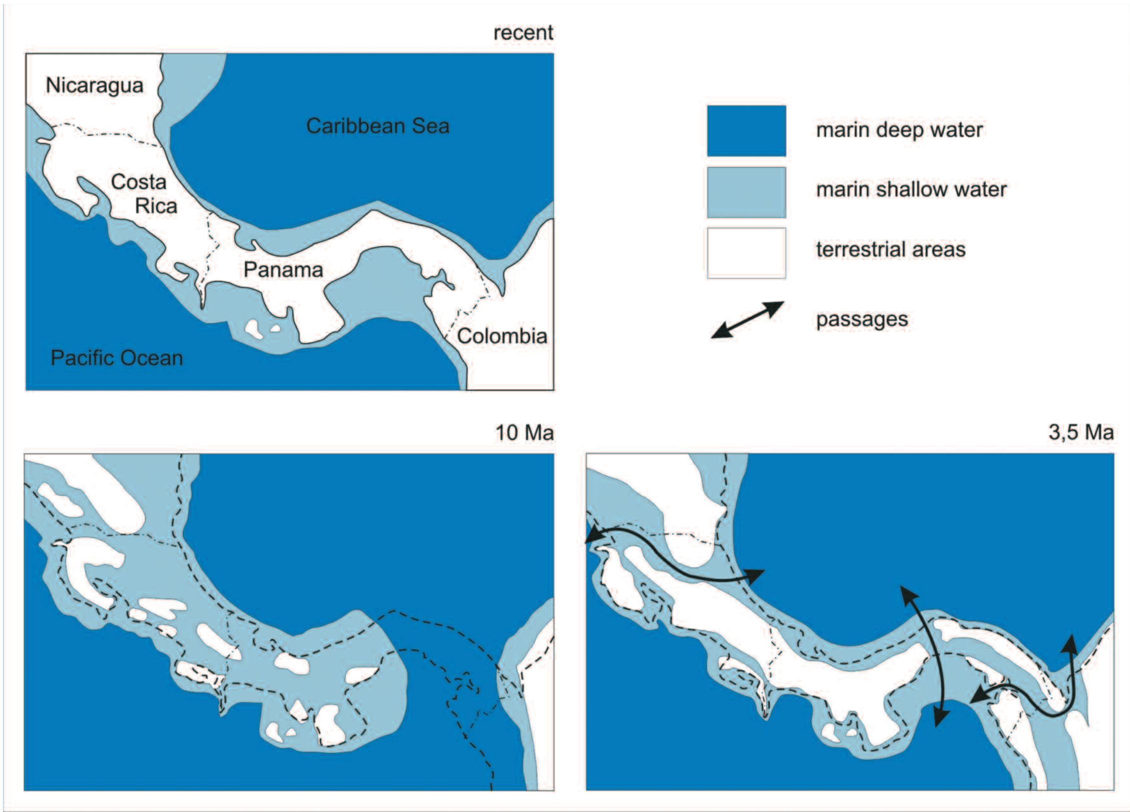

Fig. 2: The closure of the Central American Seaway (modified after Denyer et al. 2003) started during the late Miocene. When the closure was finished is still a subject of scientific discussions. Most probably the onset of migration of land mammals around 2.7 Ma marks the final closure.

Around 6 Ma, the Cocos ridge reached the Middle American Trench. The subsequent shallow subduction under the Caribbean plate caused folding and inversion of the southern Costa Rican forearc (today the Fila Costena) and backarc (today the Caribbean coast S of Puerto Limon) basin and rapid uplift. The subducting Cocos Ridge has also sealed this area from ascending magma and thus caused the conspicuous gap in the line of active volcanoes in southern Costa Rica.

The Choco block underwent a different tectonic development. In the late Miocene (around 13 Ma), the South American plate started to move against the Panamanian isthmus. The resulting compressive force has formed the North Panama Deformed Belt and has gradually created a stable island chain – here without the aid of a central volcanic range.

At some time between 3.6 Ma (Haug & Tiedemann 1998, Coates et al. 1992) and 2.5 Ma (e. g. Bartoli et al. 2005) this movement of southern America, assisted by the subduction of the Cocos ridge, almost completely closed the seaways between the Pacific and Atlantic Oceans (Fig. 2). Only after this closure, the development of the phenomenon of "El Nino" and other ocean surface circulation regimes which resulted in an intensification of the Northern Atlantic thermohaline circulation, was possible (Haug et al. 2001, 2005, but Ravelo et al. 2004). A connection with the onset of northern hemisphere glaciation is discussed (Bartoli et al. 2005).

Finally from 2.7 Ma, migration of land mammals started on a large scale (more than the "island bouncing" over the proto-Antilles, indicated since the Late Cretaceous). Especially during the glacial periods of the Pleistocene, when relatively arid, savannah-like habitats may have prevailed on the elevated parts of the land bridge and new lowland areas emerged because of sea level drop, northern land plants found favourable conditions for southward expansion. Examples for megafauna immigrants are mastodonts, horses, elephants and other fossil species (Alvarado 1994). In the latest part of the Pleistocene, modern man reached Central America coming from Asia, probably over the dry Bering Strait and through the then thawing North America.

During the Quaternary (2.5 Ma-Recent), large volumes of terrestrial sediments accumulated in the lowlands of Costa Rica (Fig. 3). Frequent volcanic eruptions of different types (Plinian, phreatomagmatic etc.) occurred during the Quaternary, producing thick pyroclastic sheets and other volcanic deposits (Alvarado & Salani 2004). Large landslides of avalanche-type debris occurred within the volcanic and sedimentary ranges. Offshore, in front of the Pacific coast, large quantities of sediment were deposited. Large submarine earthquakes triggered during the Quaternary and continuing today trigger tsunamis along the coast of Central America. (Alvarado et al. 2004).

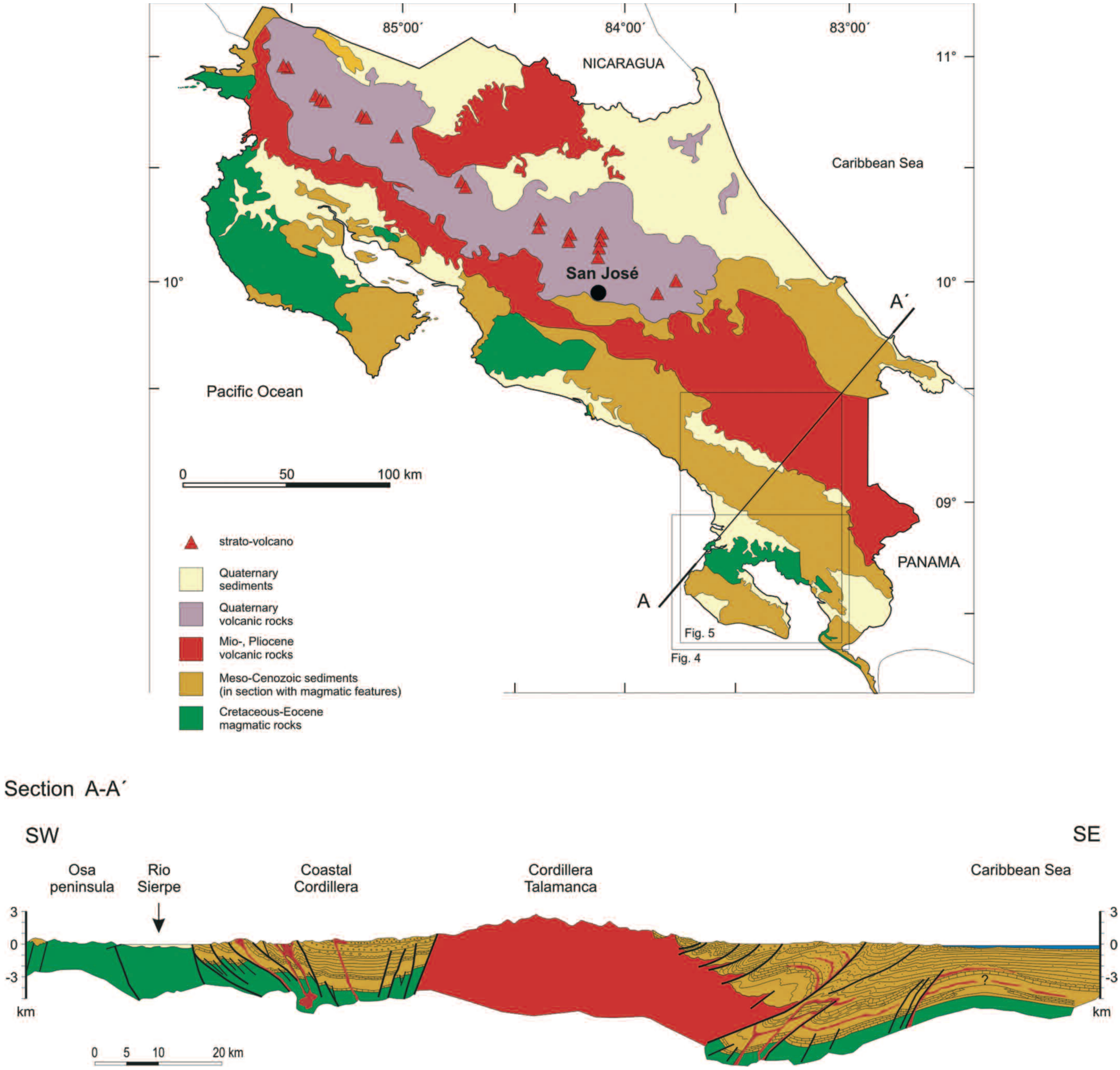

Fig. 3: Geological map of Costa Rica with section (modified after Denyer et al. 2003). The map is divided into general units, each representing chronologically and lithologically related rock-sequences in the field. In the section, the backbone of the Central American land bridge consisiting of Createceous to Eocene magmatites and Miocene-Pliocene volcanites is very conspicuous. – The map illustrates the widespread coverage by young sediments and volcanites.

The land bridge of Central America, however, increases its area not only by sedimentation but equally through ongoing tectonic movements. In 1991, one earthquake lifted 75 ha of reef surface over the sea level on the Caribbean coast near Cahuita.

Global sea level oscillations, as a consequence of the waxing and waning of the Pleistocene northern hemisphere ice sheets also significantly changed the coastlines of Central America. During interglacial sea level maxima, some of the ancient seaways of the Tertiary may have been temporarily reopened (e.g. the Rio San Juan valley on the border between Nicaragua and Costa Rica).

Pleistocene glaciations in Central America are documented by glacial landforms and deposits in the

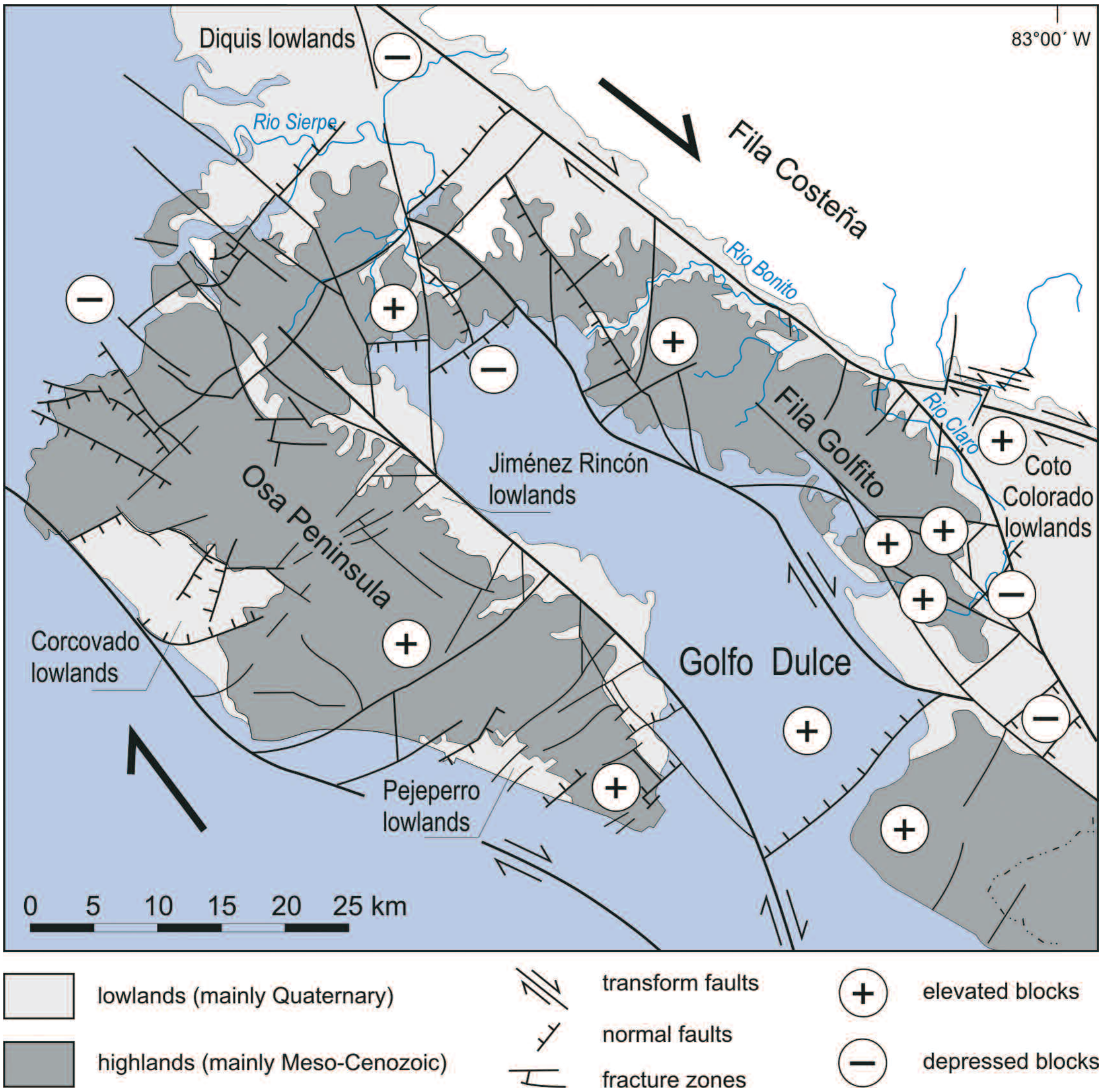

Fig. 4: Structural map of the Golfo Dulce region (modified after MALZER 2001). Several NW-SE striking transform faults dominate the general structure of the region, for example the subdivision into Fila Golfito, Golfo Dulce and the Osa Peninsula. Uplift or depression of singular blocks is additionally controlled by NE-SW striking secondary faults. Several river valleys, topographic situations and geological borders orientate as well on the underlying fault and fracture system.

Chirripo massive of southeastern Costa Rica. In the Valle de las Morrenas, there are traces of valley glaciers at least 4.6 km long (ORVIS & HORN 1999). Altogether, about 70 square kilommetres were glaciated in the Chirripo massif. Stable snowfields may have persisted above 3.300 m in the Cordillera de Talamanca, Cerro de la Muerte, Chirripo and Kamuk and on high volcanoes like Irazu (LACHNIET & VAZQUEZ-SELEM 2005).

Geology of the Golfo Dulce Region and the environs of La Gamba

The geographical limits of the Golfo Dulce Region are the Fila Costena in the northeast, the Rio Sierpe in the northwest, the Pacific Ocean to the west and south and the Rio Colorado to the east (Fig. 4 + 5). The main topographic elements are the deeply incised valleys and hills of the Fila Golfito (highest point 579 m), the Golfo Dulce basin and the Osa Peninsula (highest elevation 782 m). The marine inlet of the Golfo Dulce (GD) measures approximately 55 × 12 km. The shape is controlled by north-west-trending on-land extensions of the Panama Fracture Zone and their north-east-striking secondaries. A sill only 60 m deep forms the entrance in the south-east and limits water exchange between the 185-210 m deep gulf and the open Pacific. This restricted entrance has caused slightly anoxic conditions in the

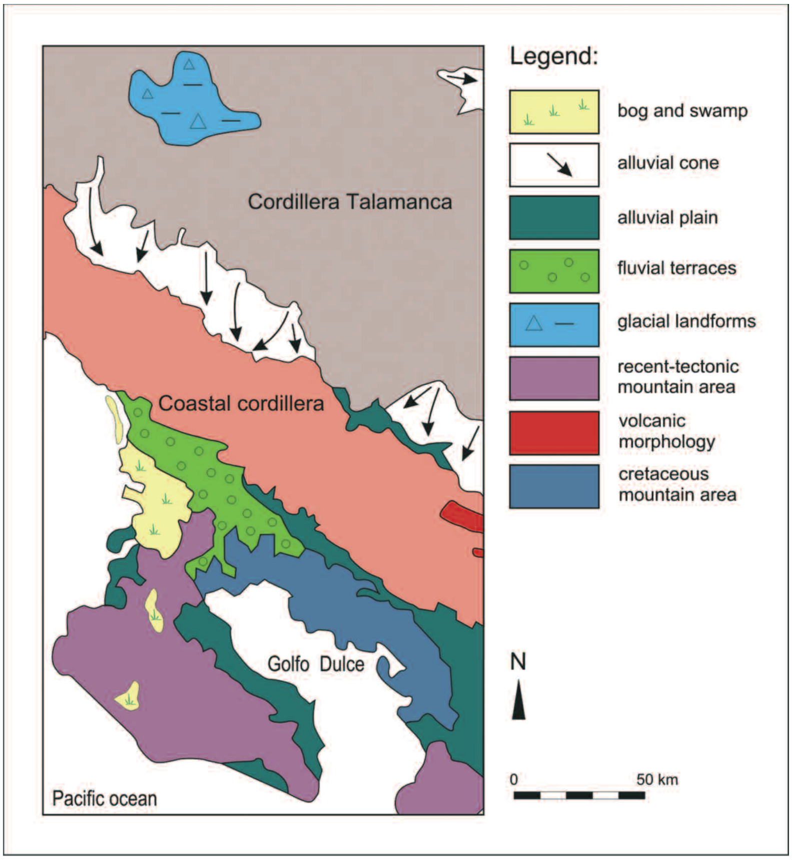

Fig. 5: Geomorphology of the Golfo Dulce Region (modified after Salzar Mondragon 2000). Glacial landforms developed in the past only in high lying parts of the Cordillera Talamanca. Fluvial terraces are widely spread in the Diquis lowlands (compare Fig. 4). While alluvial cones are found along the mountain ranges, alluvial planes and bogs form mainly coastal areas. Especially the Osa Peninsula is subject to intensive recent uplift and mountain building. The diverse geomorphology of the Golfo Dulce Region reflects the active geological processes on the Central American land bridge.

inlet. Bottom sediments are mainly turbidites, which enter the gulf via permanent channels in the sea floor. A number of small reefs flank the northeast coast between the Rio Esquinas mouth and the town of Golfito. The NW-trending Esquinas Fault (or Ballena – Celmira Fracture Zone (BCFZ) separates the Golfo Dulce region from the mainland. BCFZ and the equally NW-trending continuation of the Panama fracture zone and their NNE-SSW striking secondaries dominate the structure and morphology of the region. Fig. 4 provides an overview of the tectonic structure.

The Golfo Dulce region can be subdivided into three pacific "terranes" (Di Marco et al. 1995). Based on palaeomagnetic data, these terranes have been accreted to the Central American volcanic arc during the subduction of the Cocos Plate. The Golfito Terrane (GT) is situated in the north-east and the Rincon Block (RB) surrounds the Golfo Dulce. Both are composed of basaltic rocks and associated deep sea sediments. The Osa-Cano Accretionary Complex (OCAC) is situated on the external side of the Osa Peninsula.

The Osa-Cano Accretionary Complex has an age range from Late Cretaceous to Miocene (approx. 80-15 Ma). Rare sediment inclusions in basalts of the Rincon Block are Late Cretaceous to Eocene in age. The oldest sequence on the Golfito Terrane is latest Campanian (± 80 Ma), the second and the lower part of the youngest sequence belong into the Maastrichtian (± 68 Ma). The highest part of the Golfito Terrane sequence probably reaches up into the Paleocene in age. It carries sediments derived from an acidic (explosive) volcanism at its top.

An additional time constraint is provided by unconformable Pliocene sediment layers on top of the Osa-Cano Complex and of larger parts of the Rincon Block basalts on the Osa Peninsula. The Pliocene is only covered by Pleistocene sediments in large valleys and on the north coast of the Osa Peninsula. Such a young cover is missing in the north coast of the Golfo Dulce.

Overall, two fundamental periods of the structural development can be distinguished: an older pre-Cocos Ridge period (80-6 Ma) and a younger period characterised by the arrival, impact and shallow subduction of the Cocos Ridge (6 Ma-Recent).

The environs of La Gamba and the research station

About 3 km west of the "La Gamba" research station, a north-south striking steep fault separates the Golfito Terrane (GT) from the Rincon Block (RB). The village of La Gamba and the research station are situated on the Golfito Terrane which, as mentioned before, is composed of three stratigraphic units. It begins at the base with oceanic basalts and dolerites, followed by pelagic deep sea carbonates and fine clastics and is topped by a volcaniclastic complex. The deepest unit is mainly exposed along the coast of the Golfo Dulce (GD). The two higher parts adjoin to the north and west. The research station and the nearby Esquinas Lodge are located on the highest and probably youngest sequence, composed of light green, weathered whitish, tufaceous silt to mudstones. Because of dense vegetation and deep weathering, hard rock exposures are limited to river and road cuts and landslide sites.

The Rincon Block frames the Golfo Dulce basin on the north-west, west and south-west and includes the upper reaches of Rio Bonito and Quebrada Sardinal. It is characterised by a thick, uniform series of oceanic, tholeitic basalts with scarce intercalations of deep sea limestone and radiolarite. In this unit, pillow basalts, which are typical for submarine magma flows, have been described (Berrange & Thorpe 1988). Due to the greater resistance of these rocks to weathering and erosion, this terrane is more rugged and contains the highest elevations north of the Golfo Dulce basin (over 550 m). The basalt series of the RB are covered by younger sediments on the north flank of the Osa Peninsula. The steep, NW-SE striking fault boundary of the Rincon Block is exposed in several narrow valleys of north-flowing small rivers. South of this almost vertical fault, a very different sedimentary series, the Osa-Cano Accretionary Complex (OCAC), forms the central part and the Pacific flank of the peninsula. This complex represents (after DI MARCO et al. 1995) a melange of volcaniclastic matrix with embedded components with sizes from centimetres to hundreds of meters. Basalt blocks, deep sea limestone and chert, but also carbonates of shallow water origin are redeposited in this deep-sea unit. Good rock exposures are mainly along the Pacific coast and on the bottom of some interior valleys. Over most of the peninsula, except the northernmost corner, the strata of the Osa-Cano complex are overlain discordantly by young, fluvial to marine (turbiditic) clastics of the Pliocene Osa-Group. Along the north and northeast coast and in small, down-faulted basins (Laguna Corcovado, Laguna Pejeperro), poorly consolidated fine clastics of the Pleistocene Puerto Jimenez Group have been deposited. Basal conglomerates of the Osa Group are gold bearing. These placer-gold deposits are subject to numerous small gold mining operations.

According to ANCHUKATIS & HORN (2005) and BEHLING (2000), at least three eruptions of the Baru Volcano (NW Panama) have happened in the past 3.000 years (1440, 1080, 610 a cal. BP = 500, 900 and 1350 A.D.). The evidence stems from lake drillings in Costa Rica and Panama. FIEBIG et al. (2007) found young and unweathered volcanic ash minerals in surface soils around La Gamba. These minerals do not derive from the local subsurface but are wind blown exactly from Baru. An influence of this sub-recent volcanic activity of Baru on soil fertility, vegetation and possibly population density around La Gamba is likely. Pollen and charcoal evidence shows that southwestern Costa Rica has been occupied and its nature disturbed by humans for over 3.000 years (CLEMENT & HORN 2001: 425). After 2.500 years of varying (but generally increasing) human colonisation and intensity of forest clearing and burning, the post-Columbian population declined after 1500 A.D., enabling the forest to regenerate.

Conclusion

There is considerable information about the geology and geomorphology of Central America and Costa Rica available, but, as mentioned before, further studies on the local Quaternary history still need to be done. This future research work would provide a complement to the wealth of biological scientific research carried out at the La Gamba Station.

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Contents/Indice

PLANT BIOLOGY — BIOLOGÍA DE PLANTAS

Ecosystems and vegetation — Ecosistemas y vegetación

Plant diversity — Diversidad de plantas

Life forms — Formas de vida vegetal

Ecophysiology — Ecofisiología

Mammals — Mamíferos

Limnology — Limnología

PLANT-ANIMAL INTERACTIONS — INTERACCIÓNES DE PLANTAS Y ANIMALES

Pollination — Polinización

Ants and plants — Hormigas y plantas

HUMAN ASPECTS — ASPECTOS HUMANOS

History and development — Historia y desarrollo