GEOMORPHOLOGY AND GEOLOGY OF SAN ANTONIO DEL SUR, GUANTÁNAMO, CUBA: ITS CONTRIBUTION IN PRODUCING LANDSLIDES.

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ABSTRACT

The current geomorphology of San Antonio del Sur has many different and complex features conditioned by: the Caribbean-North America inter-Plate zone, climatic conditions and paleoclimatic oscillations during the Quaternary period. In general, the current landforms were created by a combination of horizontal and vertical movements, being more frequents the first ones until the Middle Eocene, as from which the vertical movements prevails mainly with strike-slip faults. These landforms present gravitational forms that have generated different types of landslides in the study area.

This paper presents the geomorphology and geology of San Antonio del Sur area, making emphasis in the causes that produce landslides. The different geomorphological complexes, the genetic landforms and subforms are explained besides the different lithologies. It is discuss the different hypothesis of the geomorphological evolution in the study area and the gravitational forms that produce landslides.

Due to climatic, tectonic and lithological factors, the study area has different landforms from the coast (at southern part) to the north. In this way, seven geomorphological complexes were defined: the coastal hills, the terrigenous hills, the limestone hills, the metamorphic hills, the alluvial valley, the accumulational slopes and the Caujery depression. The evolution of the area can explained using two models: one for the Caujery Valley and one to explain the coastal hills and the Baitiquirí pound-shape bay. The reason to use two models is because both areas has developed independent landforms due to different causes that are explained in the paper. The principals' landslides are located (in order of importance) in the Caujery Scarp, in the coastal hills and in the accumulational slopes at northern of Baitiquirí. It is outstanding the Jagueyes landslides in the Caurjery Scarp, recognized as the biggest in Cuba. Among the most common landslides are the rotational landslides, translational landslides, rock falls, topples and debris flows.

Introduction

The geomorphology has strong influence in producing landslide. The conditions from which many landslides are activated can be determinate by the current landforms and its descriptions. It may provoke, some times, large disasters where many casualties and economic losses may happen. In Cuba the landslides are small comparable with other regions in the world. A remarkable area for landslide in Cuba is the San Antonio del Sur area and its surrounding specially the Caujery Valley around which many scarps are actually landslide areas.

This paper presents a geomorphological study of San Antonio del Sur area focusing in its consequence for landslides. The study covers a general overview of the main landforms and its origin as well as the different hypothesis about how the current landforms were created.

The study area, San Antonio del Sur municipality and its surrounding contain such contrasting characteristics. The area is located at 60 kilometers of the capital's province Guantánamo with an extension of 600 square kilometers. The figure no.1 show the location of the study area.

The geomorphology of the study area, as well as of the whole island, is conditioned by: The Caribbean-North American inter-Plate zone, Climatic conditions and the paleoclimatic oscillations during the Quaternary period.

In general, the landforms were created by the combination of horizontal and vertical movements. In the Meso-Cenozoic Era, before The Middle Eocene, the movements were predominant horizontal and compressional acting, with folding and thrusting of several types of rocks into parallel belts along the island. After the Middle Eocene the movements were predominant verticals and characterized by strike-slip fault and extensional movements, sedimentation and blocks structures. The thrust-belts made large orographic units, but, even when they are important, the morphostructures are controlled by the strong neotectonic development, especially in the study area.

Due to climatic, tectonic and lithological factors, the study area has different landforms from the coast to the north. The coastline presents the more intensive semiarid region in Cuba (annual average temperature of 26 degrees Celsius and annual precipitation less than 600 mm) while inland, around Puriales de Caujeri town, tropical rain forests are predominant (annual average temperature of 23 degrees Celsius and annual precipitation more than 2000 mm). Tectonically, the area is the convergence of three principal systems, which seem to be still active. The lithology differences are also extraordinary, since the area presents several alternating layers of sedimentary rocks and the eastern part is almost totally covered by metamorphic rocks, which belong to a volcanic arc with many rock types.

Previous Research

There are not many papers on the geomorphology of the study area at detailed scale. One important publication was the last edition of the Nuevo Atlas Nacional del Cuba (Gutierrez, 1989), where the relief of the island was described according to many genetic characteristics. The atlas presents several maps regarding the relief and its genesis, with many general characteristics.

Another important publication (Magaz et al., 1991) describes the southern (coastal) parts of the study area and gives an inventory of the different landslides from Baitiquirí to Maisi (the easternmost corner of Cuba).

Materials and Methods

The applied geomorphological survey in the study area was done with the photointerpretation and later, the field checks. In the interpretation the area was subdivided in 603 Terrain Mapping Units (TMU). A terrain-mapping unit groups the following aspects (Meijerink, 1988): geomorphologic origin and physiography, lithology, morphometry and soil geography. According with the specific interests of this research each unit was differentiated in the stereo image on the basis of one or more of the following criteria: geomorphology origin, specify origin, morphometry and lithology. Additionally two more aspect was recorded: the geomorphological process and the complex. All these data was stored in a database using a Microsoft Access Application. The first three criteria were store as origin, main unit and subunit in the database. With them, a geomorphological map was created at 1:50 000 scale. In the map the boundaries of the original terrain mapping units remain, although some of them have the same geomorphological origin and therefore the same color. Another complementary and linked database was designed specially for the units, which are landslides or part of it. In the landslides database an extra 8 data was recorded for 296 units.

There was recorded also in the data base many statistics for each unit such as average, maximum, minimum, standard deviation, etc. of the morphometry variables slope angle, slope shape, internal relief and drainage density. All the data and the maps are part of a geographic information system application able to update, edit, analysis and manager the information with emphasis in disaster management applicability.

Description of the geomorphological complexes

The complexes are a geomorphological regionalisation considering the genesis, lithology and geography of the different landforms in the study area. Taking into accounts these factors and after photointerpretation and image analysis, the area was subdivided in the following Complexes: Coastal hills, Accumualtional slopes, Limestone hills, Metamorphic hills, Terrigenous hills and Caujeri depression. The distribution of the complexes is shown in Figure 2.

Coastal Hills

The coastal hills in the study area are isolated hills parallel to the coastline. The length is variable, depending of the mouths of the rivers, as the coastal hills are cut by the drainage system. The width is also variable and is between one or two kilometers. In the study area there are three coastal hills: between El Naranjo and Baitiquirí bay, between the Baitiqurí bay and Sabanalamar bay (Loma Los Aposentos) and between Sabanalamar bay and Macambo town. These three hills are located parallel to the coastline and separated by three different lineaments. Consequently, Loma los Aposentos in the northernmost, El Naranjo-Baitiguiri bay is in the middle and Sabanalamar Bay-Macambo is the Southeast.

One distinguished feature of the coastal hills is their top, which is almost horizontal and covered by a more resistant layer, probable Santa Cruz formation. It is possible to see local karst forms due to dissolution in the top layer of the coastal hills. The hills have different altitude and profile .The top of El Naranjo-Baitiquirí hill is around 190 meters; of Loma los Aposentos between 220 to 280 and of Sabanalamar bay-Macambo hill is between 100 to 130 meters. Also the isolated hill Pan de Azucar has similar altitude, of 220 meters. Figure 3 shows different Coastal Hills profiles for the three main coastal hills in the area.

Geologically, the Coastal hills are composed of four main geological formations, which play an important role in the current form of the hills and in the process going on. The lithology is different in the southern (coastal) side and in the northern side. The north side is totally covered by the Maquey formation, which are mainly terrigenous rocks and are susceptible to landslides. The coastal slope, characterised by marine terraces is composed of the Maya formation, except for the lowest terraces, which are composed of recent (Holocene) marine deposits. These recent marine deposits act as “rings” of the coastal hills and are uplifted between 5 and 10 meters from the current sea level. They are useful to recognize if coastal landslides were pre-Holocene or Holocene, depending of the conservation of these deposits. The vegetation is rare, although there are some endemic species typical from semiarid zones. The soil is also scarce due the high erosion, slope steepness and lack of humidity. The drainage system is limited to few channels because the proximity to the sea and the relative small area of the coastal hills.

Accumulational Slopes

The Accumulational Slopes are located between the Coastal Hills and the Limestone, geographically between San Antonio del Sur - Baitiquirí and Sierra de Mariana. In addition, there is another area to the east of the Sabanalamar River and south of Sierra del Covento. In fact, it is an intra-mountainous fluvio-marine plain with deltaic origin. This complex is lightly sloping to the south (sea) side with angles between 5 and 15 degrees as average. The area is elongated and curved with a width of around 2 kilometres.

The Accumulational Slopes are composed of recent (Quaternary) deposits transitioning from colluvial, in area close to the mountains, to Alluvial in the southern part of this complex. The materials are gravels, yellow and reddish sandy clays, which are generally compacted. The lithology also varies in the Southwest part and in the east part of this complex where the main rocks are from formations Cilindro, Maquey and San Luis.

This complex seem to belongs to an old planation surface, which collected all the sediments coming from the upward area, what is now Sierra de Mariana, during the Pleistocene. The extension and volume of the quaternary sediments reveals that the rainfall at that time was larger than currently. This might be true considering the fact that in the northern border of Sierra de Mariana the drainage seems to be cut-off due to large mass movements. In both the western and eastern sides of the area, the Pleistocene sediments are not present. In the western side the drainage system was sufficiently strong to erode the sediments to the Baitiquirí bay, besides this part appears to be slightly more uplifted. In the eastern part the pre-Quaternary formation overly the Ophiolites and the area has an irregular relief.

The planation surface is raised 10 to 30 meters above the current erosion levels, creating around ten new channels, which eroded the old plain and generated erosional scarps with the same high differences. These channels control the poor drainage in the area. Due the proportion of the terrigenous material, the water is infiltrated and the channels are being lost in the lower parts.

The vegetation is sparse with isolated shrubs being more common in the Southwest part. The land is mainly fallow, although in the Southwest there are some cattle farms.

Limesone Hills

The Limestone Hills include Sierra de Caujeri and Sierra de Mariana. This complex is located in the entire western side of the study area, although Sierra de Mariana also covers until the central part. The Limestone Hills is a monoclinal plateau with an average altitude of 500 meters. It is composed mainly of limestone of Yateras formation. Karst dissolution is present and generally in relation with tectonic processes. Then, there are karst depressions and isolated karstic hills. Wherever the upper limestone layers were eroded, coinciding with the drainage system, the underlain layers belonging to the Maquey formation are outcropping. Therefore, the erosional process is increasing due to the low competence of Maquey formation rocks.

The tectonic structure plays an important role in this complex since large fault scarps limit the area in the south and east. The south scarp has around 100 meters high difference and gives the impression of a normal fault as a consequence of extensional stress. The east scarp is the boundary of Sierra de Caujeri and also seems to be a normal fault. Both scarps are where most of the landslides are located in the study area. It is remarkable also the subsidence of a large rectangular block in the area of La Tinaja, at the west of El Mije. This block was subsiding and tilted to the south by two main faults, which even can be traced into the Caujeri valley. The interruption of Sierra de Caujeri scarp by these two faults is an indication of the dependence of one fault system to the other one.

Due to the karstic and tectonic processes in the limestone hills, the fluvial system has a combined pattern where rivers follow fault lines and karst-dissolved zones. Moreover, there is a significant the number of rivers and streams, which start close to the Sierra de Caujeri scarp to the west at such altitude as 700 meters. The Limestone hills are mainly covered by forest, although some parts are burned. The area is almost unpopulated and, therefore the terrain is underexploited.

Terrigenous Hills

The Terrigenous Hills are located in the central and north-central part of the area. They are composed of terrigenous and volcanogenic rocks belonging to the Cilindro, Charco Redondo, San Ignacio, San Luis and El Cobre formations. Due to the large number of rock types, the landforms are also diverse, but in general they differ from moderate to severely dissected hills. They can be classified as folded and dissected mountains (500-600 m) and hills (300-500). The area shows diverse altitudes between 200 and 500 meters with extreme exceptions.

Structurally, the Terrigenous hills are the limit between the Foldbelt and the Neoautochthon in the study area in an approximately north-south direction. The drainage system is well developed and also follows this north-south direction, collecting the water and sediments from the metamorphic rocks in the east, and from the terrigenous hills itself in the west. The water is collected to the main drainage, which is the Sabanalamar River and is stored in the Plamarito Dam. After the dam, the river also receives all the water coming from the west belongs to Caujeri valley. The vegetation is abundant and varied. Mainly coffee plantation and secondary individual farmers use the area. The rill and gully erosion is present and there are isolated landslides.

Metamorphic Hills

The Metamorphic hills are present in the east and north-east part of the. They are composed of the Sierra del Purial formation and the Ophiolites. Although the lithology is different in both geological units, from a geomorphological point of view, there are not many differences between these two units in the study area. This is because, the competence of the rocks and the tectonic processes going on are more or less the same. The volcanogenic and metasedimentary rocks of Sierra del Purial formation and the Ophiolites rocks are both included in the Metamorphic hills complex. This complex also presents an isolated rounded outcrop in the north part of the Caujeri valley, east of Mameyal and Letreros. This outcrop, belonging to the Sierra del Purial formation, seem to be a "window" of the metamorphic rocks where the young material were complete eroded.

The Metamorphic hills are the most dissected, from moderate to severely dissected, rocks in the study area. The area also has the highest parts reaching up to 1,060 meters high. They constitute folded blocks in relation with intensive neotectonic uplift. The new displacements are clearly in the design of the fluvial network, which are shaped in the combination of the neotectonic and metamorphic rock type. The area is mainly forest with abundant vegetation and there are some parts, which are used for coffee plantations.

Alluvial Valleys

The Alluvial valley complex is related to the recent sediments accumulated close to the principal river systems. Sabanalamar river floodplain, Macambo river floodplain and the most recent fluvial channels in the Caujeri valley are part of this complex. They are composed of alluvial and swampy deposits. The alluvial deposits are mainly gray and grayish mud, sandy mud and sandy clay. The swampy deposits are accumulations of mangrove rest, silting up fluvial lacustrine accumulation rich in carbonates, clays and peat. This complex is essentially a fluvial plain with a combination of erosive and accumulation processes. Accumulation is prevailing in the Sabanalamar and Macambo floodplains and erosion in the Caujeri valley. Three floodplain levels are recognizable: active, occasionally submerged and exceptionally submerged floodplains. The area is regularly inundated during intensive rain. It is not totally recognized the fluvial terraces levels.

Close to Sabanalamar bay and in the surrounding of San Antonio del Sur town, there are brackish water swamp lagoon and swamp deposits. The mangrove vegetation is abundant only in Sabanalamar river mouth where the brackish water is accumulated. The channels in Caujeri valley are the widest in the study area, between 2-5 meters; and in some places even 10 meters. They are dry most of the time and are used for local transportation. The bottom of the channels is totally covered by pebbles with a regular diameter of 10 centimeters and smaller. The channels in Sabanalamar river are more narrow and permanently cover by water. The pebbles are around the same size being smaller in the mouth of the river.

Caujeri Depression

Caujeri depression complex was called to Caujeri valley and the colluvial deposits of Sierra de Caujeri scarp including the main scarp. The area is a sequence of Scarp-colluvial-alluvial deposits, where in some parts it is difficult to distinguish the boundary between one type of deposits and the other. In the geological maps, San Luis formation has been mapped between the colluvial deposits of the scarp and the alluvial deposits of the valley. However, during the fieldwork this formation was not recognisable and all de material in this area seems to be terrigenous material originated by the combination of landslides and the weathering process.

The valley can be considered as erosive fluvial plain, relatively high (between 200 and 300 meters above sea level), presenting frequent small hills. The origin of the valley seems to be tectonic-structural and the main process going on is fluvial erosion. The scarp and colluvial deposits are a consequence of several multiple and successive landslides. The slope's shape is very variable due to overlapping of the mass movement processes. Therefore, many steps, including concave and convex forms, can be found in the slope profile, but three main steps can be recognised.

The lower or front part of the slope was delimited by mapping the end of the landslide transport zone. But, in many landslides, this boundary is not exactly recognisable, especially in the mud flow or debris flows where the material slides down until it is mixed with the alluvial deposits. The drainage is actually starting in the main scarp from where many springs originate. There are many small streams in the main scarp or in the colluvial deposits down hill, which are not in the topographic map and they are used for minor agricultural use. As soon as the drainage enter into the valley, only the main streams remains since the small ones infiltrate into the soil. This means the existence of high infiltration capacity in the valley. In some areas, the erosion creates large gullies in the valley and it is possible to see a lower layer with large unsorted materials belongs to previous mass wasting processes.

Towards the landform evolution modeling in the study area

The landform evolution in the study area can be explained using in two main models. One to explain the Caujeri valley and one to explain the Coastal hills and the pouch-shape bays. The reason of these two models is because in certain time both areas were developing independent landform due to different causes.

The Caujeri valley is an inland depression of the graben-type with high elevation differences up to 500 meters. The valley is limited in the west by a large scarp of Sierra de Caujeri, with constantly active west-retrogressive movements due to landslides. On the other hand, the valley is also surrounding by major fault scarps, which argued the depression form. Therefore, the origin of Caujeri valley can be interpreted as a combination of tectonic and mass wasting processes. The main fault systems (Mariana and Caujeri) started to generate a graben depression after the Second Transgression-Depression (Lower Miocene to Late Miocene). Later, a chain of landslides was moving back the Sierra de Caujeri scarp with an average of two kilometers, some times even three kilometers.

Regarding the Coastal hills, more literature is available. Talking about the marine terraces as early as 1945 the Dutch geologist F. G. Keijzer interpreted them "as a sign of intermittent uplift of the land". Thereafter, the last paper published about the marine terraces (Peñalver et al., 1998) characterized the lithology and other characteristics of the different terraces levels. One of the issues is the pouch-shape bays. They are distributed not only in the study area (Baitiquirí bay) but also in the entire coast along the eastern corner of Cuba. The better interpretation for this phenomenon is the eustatic change of sea level. Another possibility is the tectonic downward movement, which is not very possible since marine terraces show exactly the opposite: upward tectonic movement.

However, another aspect to find an answer for the isolation and linear shape of the Coastal hills. It may be possible (Keijzer, 1945) by the tectonic movement either slightly folding or faulting, by unconformable cover of "protective" rocks and by both. In the study area there are no signs of anticline of syncline forms, but there are tectonic lineaments (see Figure 4), which limited the coastal hills in the north side. Unfortunately these lineaments are not so clear in the field due the competence of the Maquey formations rocks.

Finally, three aspects are important to explain and they seem to be genetically close related: the pouch-shape bays, the marine terraces and the isolated and linear shape of the coastal hills. The recent evolution relief can be explained as an intermittent uplift, together with erosional process in the north side of the coastal hills, during the Pleistocene

The tectonic setting and the upper layer of the coastal hills generated its the isolation and linear shape. Later, in the last glaciation the erosive levels were much lower than the actual sea level and the mouth of the river were more dissected than as are now (Figure 4-B). When the sea level goes up, these areas were occupied (Figure 4-C) and finally differential movements now lifted the land out of the sea again generating the pouch-shape bays and the marine terraces (Figure 4-D). Wherever the recent sediments were enough, they filling up the bays as probable happened in Sabanalamar bay with the large amount of sediments coming from the Caujerí valley.

Conclusions

The relief of the study area was created by the combination of horizontal and vertical movements. The horizontal ones predominated up to Middle Eocene and later mainly vertical movements took place. The landforms in the area are a result of climatic, tectonic and lithological factors, which, due to their variability, present different geomorphological regionalization.

The area can be subdivided into six complexes: coastal hills, accumulational slopes, limestone hills, metamorphic hills, terrigenous hills, and mass movements complex.

The coastal hills are isolated, monoclinal, karstic, tectonic-structural hills with marine terraces parallel to the coastline. The limestone hills are a monoclinal plateau controlled by the tectonic and the lithology with karst dissolution. Terrigenous hills are folded, dissected small mountainous and pre-mountainous. The Metamorphic hills are folded blocks of metamorphic rocks with intensive neotectonic uplift. The alluvial valleys are erosive and accumulative fluvial plains with alluvial and swampy deposits. The Mass movement complex are the colluvial deposits of Caujeri scarp and the erosive fluvial plain of Caujeri valley with tectonic-structural origin.

The Caujeri valley was originated by a combination of tectonic and mass wasting processes. The coastal zone was affected by intermittent uplift with intensive erosion controlled by the tectonic lineaments. Later, eustatic movements during the last glaciation moved down the erosive levels and when the sea level rose again, the pouch-shape bays were created.

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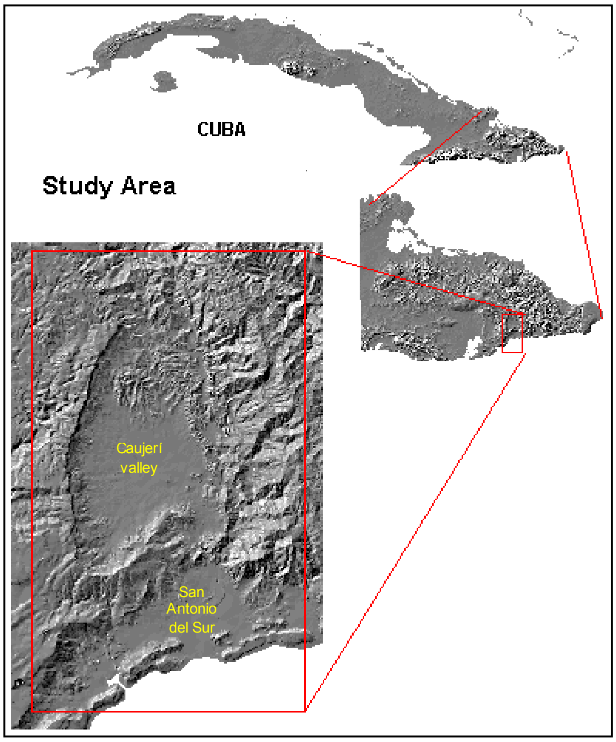


Figure No. 1 Study area. San Antonio del Sur and its surrounding.

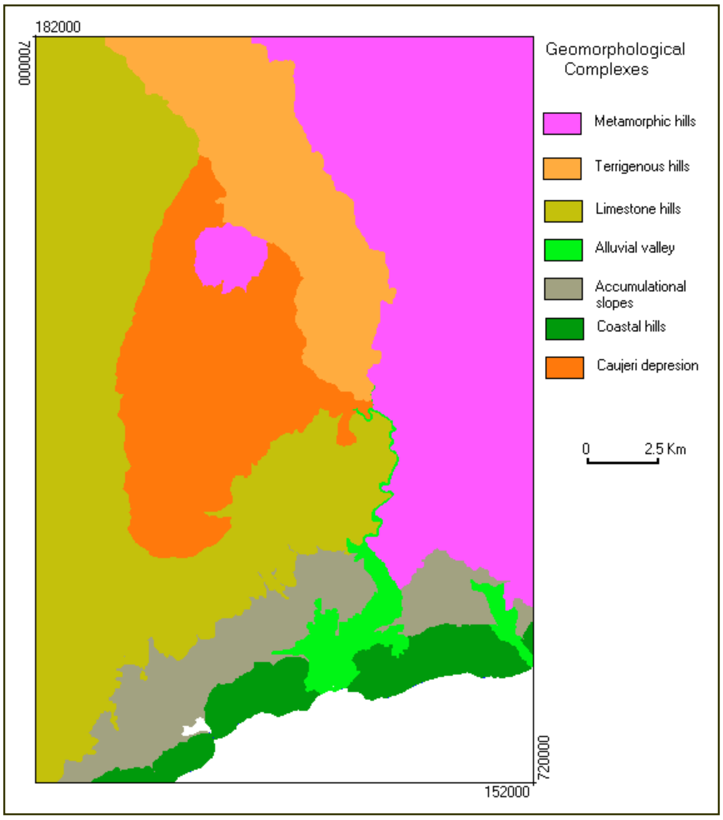
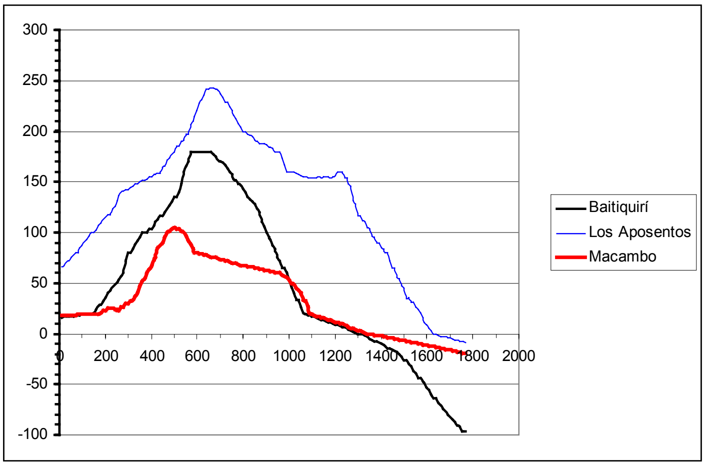


Figure 2. Geomorphological complexes in the study area



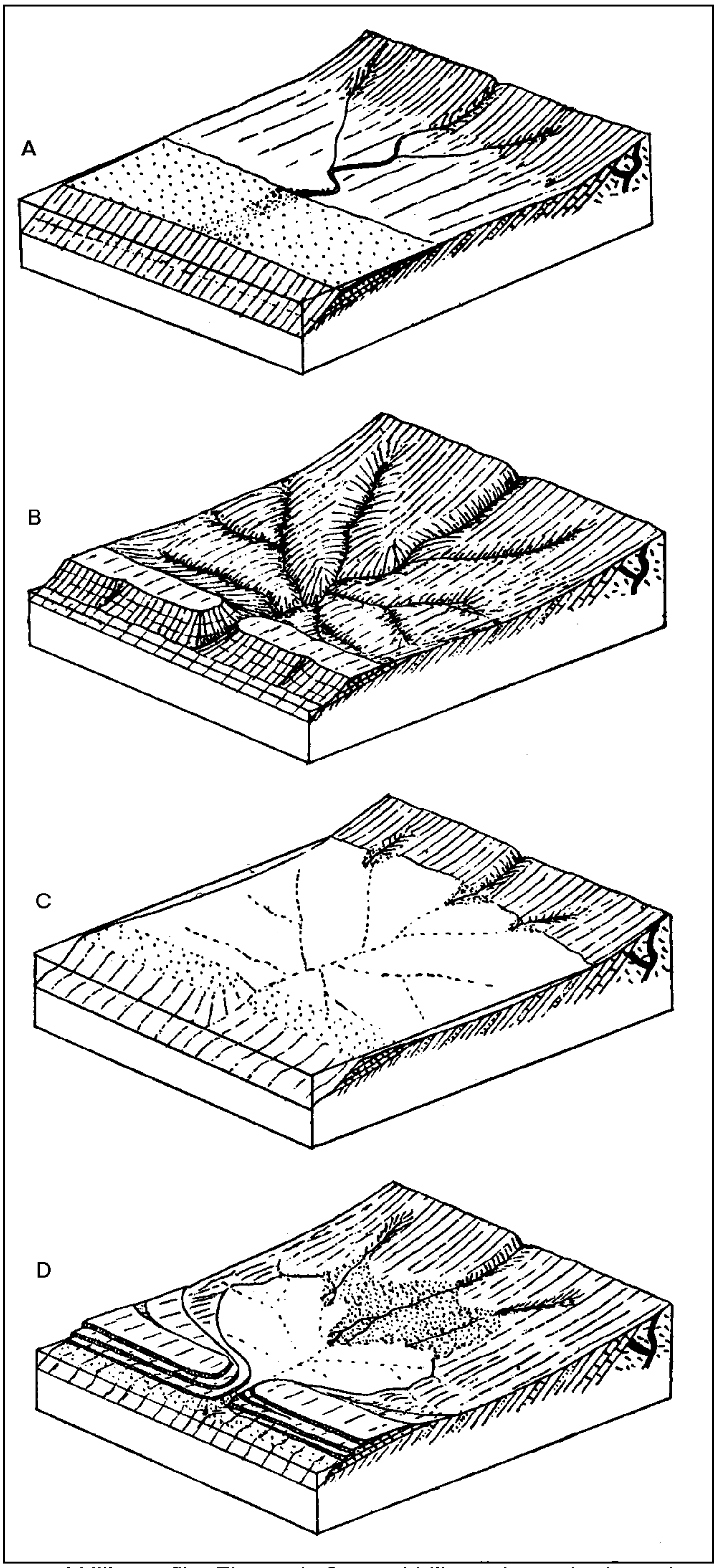


Figure 3. Different Coastal Hills profilesFigure 4. Coastal hills and pouch-shape bay evolution hypothesis (Taken from Keijzer, 1945)