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RIVER TERRACE FORMATION IN THE GUADALHORCE VALLEY, SPAIN

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PREFACE

With this report we have tried to give a general overview of the Guadalhorce valley, whereby our goal was to identify the terraces in our study area. Later we have tried to fit the results obtained from field data and sand bulk geochemistry into a 3-D computer simulation by using statistical progams.

We wish to thank a lot of people who have given us information or advice to establish this piece of work.

We would like to thank Salle Kroonenberg for giving us the opportunity to do this investigation and giving us free way to do this investigation in the way that we would like to do it. Learning from your own errors is a good experience for the future and it is also a good way to achieve your goal.

Rob van de Berg van Saparoea is thanked for his advice, although not always relevant, but always very amusing. That is not quite the truth. He has helped us with al our problems and we owe him a lot.

Jan van Doesburg is thanked for his advice on several matters on behaviour of minerals in the soil.

Bram Kuijper is thanked for his analytical work. We guess that by now he does not like us anymore, because we kept on asking him to do our samples in such a short time span, that it was impossible.

Ab Jonker is thanked for helping us with any problem of any kind.

Alfred Stein is thanked for helping us with the statistical programs. He loves to juggle with figures and the way he works is contagious.

Tom Veldkamp is thanked for helping us with the 3-D computer simulation on terrace formation. Without his advice we never would have been able to run his model and could never have drawn the conclusions the way we did.

Peter Buurman and Willem Wielemaker are thanked for giving us advice and spending some time with us in the field, while they had their hands full with the practical fieldwork in Spain.

We like to thank the students of the 1992 practical fieldwork in Spain for sharing our jokes in the evenings in Spain, and cheering and weeping by every football game during the European football championships in Sweden. It is a pity that the Netherlands did not become European champion.

Last but not least we would like to thank Lena Asseyeva, who is also working in the Guadalhorce basin but on more recent sediments of the Guadalhorce.

Specially I would like to thank Jos Hegmans. The cooperation and work were always in a relaxed sphere. His calmness and realism were of big importance to me. When I was curious about some matters, he was always in a condition to let me see things from his point of view. I could always rely on his capacity to drive the car even in the very narrow streets in Spain. He is very skilful with computers, so without his experience of these machines this report would not have its present form. Besides these points he is also a nice guy to get through the Spanish nights with the use of "cerveza".

Specially I would like to thank Joep Crompvoets. When something draws his attention he gets possessed to solve this case at any rate. He does not always take the easiest way, but with such a perseverance and enthusiasm that I always felt a bit guilty. I am sure that if I had to do this investigation with someone else, the results would not be able to stand in the shadows of this report. He always gave the best of himself and tried to accomplish the same of me. I hope that he liked to work with me, because I sure liked to work with him. Thanks, mate.

During our work we came to the conclusion that whatever happens, happens always for the best.

SUMMARY

The research presented in this paper is focussed on fluvial and marine (delta deposits) and turbidites in the Guadalhorce basin in the Betic Cordillera, Andalucia, Spain. The research was carried out in several stages.

At first field work was carried out to determine the terrace stratigraphy and chronology in more detail. Determination of terrace stratigraphy and chronology was done by describing terrace exposures and drawing a length profile of the Rio Guadalhorce. Important for this work was also to understand the geological structure and history of the study area. It seems very probable that there are six fluvial terrace levels of the Rio Guadalhorce. Besides fluvial terraces also marine/delta deposits and turbidites occurred in the valley of the Guadalhorce. These were also sampled and recorded. Further a fluvial terrace map of the study area was made.

Next, sand of various terrace units, marine/delta deposits and turbidites were collected. Afterwards the bulk sand geochemistry was measured with the XRFS-method. This bulk geochemical research allowed a statistically significant discrimination of different terrace levels and deposits. The discrimination is done with the use of factor analysis. The provenance of the sediments in the valley influenced the geochemistry of these deposits. The sediments from the tributing rivers the Arroyo de las Cañas and the Arroyo de Casarabonela differ from the Rio Guadalhorce. Also the weathering has a an impact on the sediment composition, but the terraces can be separated more easily with the content of calcium carbonate in the different terrace levels. There is a strong accumulation of calcium carbonate in time, so the older the richer in calcium carbonate is the trend.

Further a large scale and long term model of terrace formation was constructed using finite state modelling. This methodology allows the construction of a general 3-D terrace formation model, containing as well quantitative as qualitative knowledge on fluvial systems. Finally, an adapted version for the Guadalhorce is made incorporating all present knowledge on this system. Simulation results suggest that terrace stratigraphy in the study area is mainly the result of tectonism and climatic changes.

CONTENTS

1. INTRODUCTION

The main subject of this paper is Quaternary river terrace formation in the Lower Guadalhorce basin, Spain. The reconstruction of this formation is based on sand bulk geochemistry and 3-dimensional modelling.

The river terraces provide long, but fragmentary continental records of changing geo-environments. Each terrace unit is made up of several stacked incomplete sedimentary cycles representing alternating depositional and erosional stages. The resulting terrace stratigraphy provides relative chronology to which other geological, geomorphological or paleo-hydrological events can be related (Veldkamp, 1991).

Paleo-hydrological studies are at the moment actual. These studies use terrace sedimentology, stratigraphy, morphology, radiometric datings and sand bulk geochemistry as research methodologies. Bulk geochemical sand composition can serve as an excellent indicator of sedimentary processes and long term changes in sediment composition as a result of climatic changes and uplift history.

Fluvial systems are very complex and develop on such long time spans, that laboratory experiments and real system measurements can only partly part of their functioning. Computer simulation is increasingly recognized as a way to understand the way geomorphic system works. A. Veldkamp and S.E.J.W. Vermeulen have made a 3-dimensional graphical simulation model, which was focussed on river terrace formation.

The study area lies in the Lower Guadalhorce valley, province of Málaga, Andalucia, Spain. In this area only little research was done. Only the thesis of Lhénaff is dealt in detail about the geological aspects of the study area and its surroundings. Further some people of the I.T.C. Enschede (Elbersen, Zuidam) have worked for many years in the area around Álora. The I.T.C. was interested in the geology and soil science of this area.

Since 1991 the Agricultural University of Wageningen has a fieldwork program for students in the Lower Guadalhorce valley named "Sustainable land use". The department of Soil Science and Geology is participating in this fieldwork program and some geological and geomorphological items are reflected in some student reports.

At first the study area seemed to be suitable to find relations between the marine and fluvial terraces in the area, because the study area is situated near the Mediterranean coast and the area has a steady tectonical rise. In the study area a lot of fluvial terraces are present, but no marine terraces were found. Therefore the relationship between marine and fluvial terraces was not found.

The geological history and the geological structure of the Lower Guadalhorce basin are both very complicated. This has hampered

Figure 1. The area around Álora, NW of Málaga.

the interpretation of the geomorphological and geochemical data. Though there are a lot of fluvial terraces, fluvial sediments are not the only sediments deposited in the last 2-3 million years in the Guadalhorce valley. There are also marine/delta deposits and turbidites in the area which form important landforms in the study area. So it was necessary to do also some research in these deposits.

The research was carried out in three stages. The first stage was fieldwork in the study area in Spain to determine and sample the terrace statigraphy and chronology in more detail. A second phase with analyzing sand bulk geochemical data, and a third stage dedicated to modelling the Guadalhorce terrace formation.

This paper contains six chapters. The first one, chapter 1, is this introduction. In chapter 2, the study area is introduced, followed by the geological structure, history and lithology of the study area and its surroundings. Chapter 3 is dealt about the delta deposits and turbidites. Further are described the litho-stratigraphy of these deposits in detail. In chapter 4 a description is given of the terrace sequence of the river Rio Guadalhorce and its tributaries by litho-stratigraphy and a fluvial terrace map of the study area is showed. Chapter 5 deals with the sand bulk geochemistry of sediments in the valley Rio Guadalhorce. Sand bulk geochemistry is a good tool in terrace research. Not only the fluvial sands are geochemical analyzed, but also the delta deposits and turbidites. Analytic data of all sands has been done by statistical methods, for example "factor analysis". The complete integration of the current knowledge on long term dynamics of fluvial systems in general and the Guadalhorce system in particular is made in chapter 6. In this chapter a presentation and evaluation of an adapted and extended model for the Guadalhorce system is given. Finally in chapter 7 the conclusions of this research are drawn.

2. STUDY AREA

2.1. INTRODUCTION

The study area is situated in the southern part of Spain (Andalucia) in the province of Málaga. Our study area is a part of the Guadalhorce basin and its boundaries are the bridges over the Guadalhorce of Álora (in the north) and Cártama (in the south). The Guadalhorce drains the Betic Cordillera to the Mediterranean Sea.

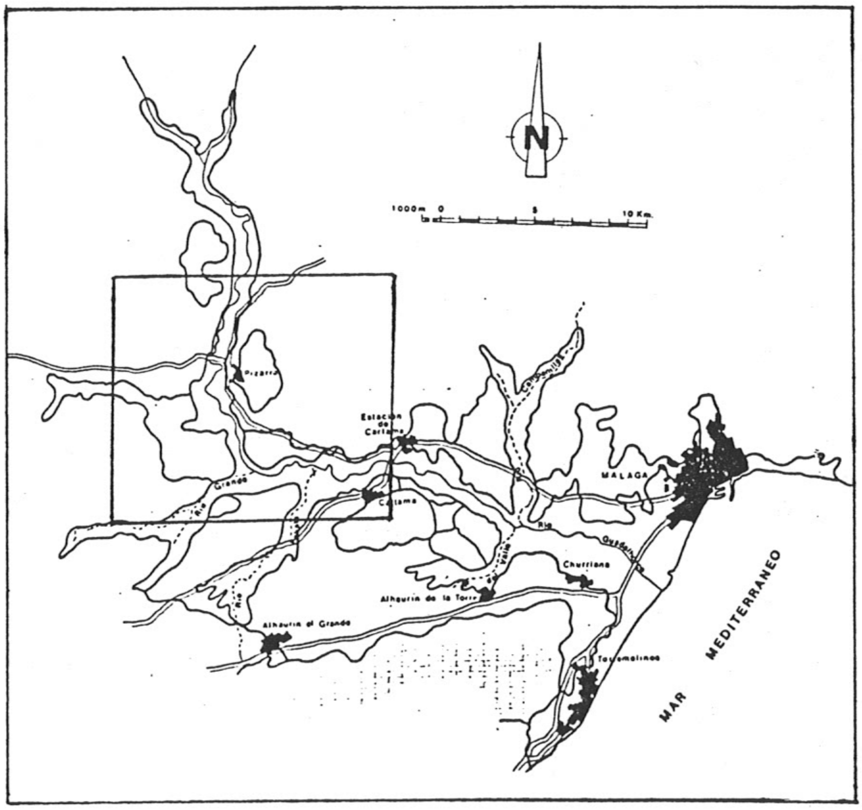


Figure 2.1. Situation of the study area.

The climate is strongly relief dependent but the larger part of the study area is characterized by a typical Mediterranean climate (Cw, according Köppen) with a warm, dry summer and a cool, humid winter. At Málaga the wet season lasts from November to March, in which time 75% of the average rainfall (474 mm) occurs. North of our study area near El Chorro the average annual pecipitation can increase to ± 820 mm (Zuidam, 1984).
Most information in this chapter is derived from review books. More details on the general geological settings of the study area can be found in Lhénaff (1981), and in an information book which belongs to the geological map of Álora (IGME, 1978). The geology

of the study area is mapped at a scale 1:50.000 by the IGME, 1978 (Instituto Geologico y Minero de España). The following maps served as a basis of the field investigations are Álora 16-44, 1052 (Mapa Militar de España, Servicio Geographica del Ejército, 1985) with scale 1:50.000 and Álora 1052; 2-1, 2-2, 2-3, 3-2, 3-3 and 3-4 (Mapa Topografico de Andalucia, Junta de Andalucia, Consejeria de obras y transportes, 1991) with scale 1:10.000. For field investigations were also necessary the next aerial photographs: runs 4614-4622 and 4732-4740 CEFTA, Junta de Andalucia, June 1990, scale 1:25.000, Sevilla.

2.2. GEOLOGICAL STRUCTURE OF THE BETIC CORDILLERA

Our study area is located in the region of the Betic Cordillera. The Betic Cordillera constitutes the main structural unit of the south of the Iberian Peninsula, extending for 600 kilometers from the Strait of Gibraltar to Alicante. In its north-eastern part it merges with the Iberian Cordillera, while the northern and north-western part are separated from the Hercynian block by a triangular depression drained by the Guadalquivir. The Balearic Islands mark its prolongation and it is connected to the internal zones of the Rif-Atlas in the north of Africa (Sala,1984).
The Iberian Peninsula can be subdivided into four morphological-tectonic regions:

1) Tertiary basins
2) Alpine fold belts
3) Mesozoic border of the Iberian Massif
4) Variscan zones of the Iberian Massif

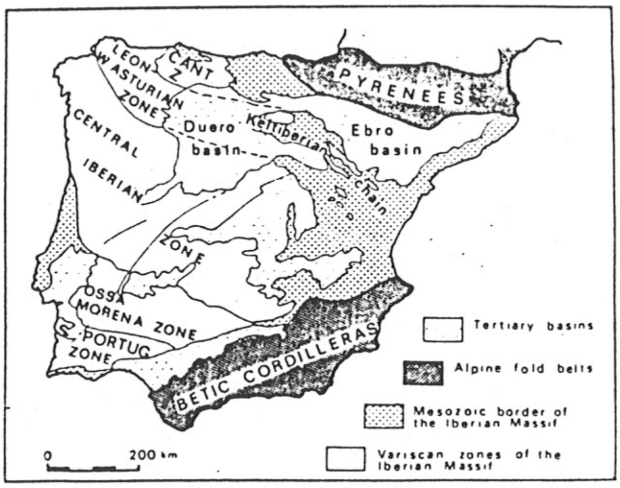


Figure 2.2. Tectonic map of Iberean peninsula (Source Weijermars 1991).

The morphological tectonic region: "The Alpine fold belts" includes the Pyrenees and the Betic Cordillera. The Iberian continent occupies a key position in reconstructions of the relative motion of the African and European tectonic plates. The Betic Cordillera (southern part of Iberia) is a Neogene fold belt which continues uplifting at the present time. It can be interpreted as a straightforward product of the collision between Africa and Spain (Weijermars, 1991).

The Betic Cordillera are traditionally divided into an External Zone in the north and an Internal (or Betic) Zone in the south.

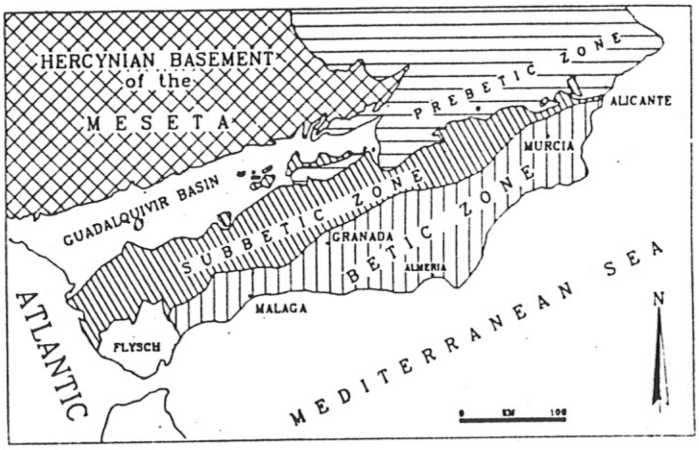


Figure 2.3. Structural sketchmap of the major tectonic provinces of the Betic Cordilleras (Source Weijermars, 1991)

The External Zone is subdivided into a Prebetic and Subbetic district only comprising non-metamorphic sedimentary rocks of essentially Mesozoic and Tertiary age. The Internal (or Betic) Zone comprises mainly Triassic and older meta-sedimentary rocks, exposed in nappes, thrust sheets of several kilometers in thickness. The Prebetic Zone is generally regarded as the autochtonous to para-autochtonous cover of the Spanish Meseta (Fallot, 1948). More specifically, it comprises a Mesozoic to Tertiary platform and shelf sequence which has been deformed by thin-skinned compression. The Subbetic Zone separates the Prebetic foreland fold-belt in the north from metamorphic Betic Zone in the south (Weijermars, 1991). Subbetic sedimentary rocks include Cretaceous to Early Tertairy deep-water sequences, associated with basaltic volcanic rocks and may have been deposited in a mid-Jurassic rifting basin (Weijermars, 1991).

The Internal Zone of the Betic Cordillera is situated in the southern part of the Betic Cordillera and runs along the coast of the Mediterranean Sea. In this zone are Paleozoic strata well represented, mainly by metamorphic rocks and plutonic masses (Serrania de Ronda) (Sala, 1984). This zone shows the highest deformation and the highest metamorphism of all the zones (Kroonenberg, 1992). The tectonic structure of the zone is very complicated, characterized fundamentally by the superposition of thrust nappes. As a whole, three great sets of superimposed masses can be distinguished, which are from the lowest to the highest (1) the Nevada-Filabre (2) the Alpujarride Complex and (3) the Malaguide Complex (Sala, 1984).

The Sierra Nevada is the highest part of the Internal (Betic) Zone, which contains heights above 3000 meters (Mulhacén 3470 meters and Veleta 3392 meters above present sea level).

In addition to these structural zones which are the fundamental elements of the chain there are some other independent structural elements:

1) The zones of Campo the Gibraltar (flysch), consisting of a group of thrust sheets

2) The interior depressions (Granada, Antequera). These depressions are located in the transition of the Betic to the Subbetic and within the Subbetic. Their character is that of intramontane depressions and their tectonic separation happened relatively late (Upper Miocene), when the Post-Orogenic phase in the Betic Cordillera was already initiated and continued during the Quaternary. They behaved as sedimentary basins, in which continental and marine episodes occurred. The results are a considerable amount of Neogene and Quaternary sediments in these basins (Sala, 1984).

2.3. THE GEOLOGICAL HISTORY OF THE BETIC CORDILLERA

During the Pre-cambrium and Paleozoic marine deposits have accumulated in this area. By Hercynian orogenysis these deposits were tectonized and metamorphosed. During the alpine orogeny, fluid mantle material intruded upwards into the deposits, forming a peridotite massif (Sierra de Ronda) (Buurman, 1992).

After the Hercynian orogenesis, in the Triassic, fluviatile, lagoonal and lacustrine sediments were deposited in a (semi-)arid environment (Keuper marls) (Buurman, 1992).

During the Jurassic a shallow sea was formed between Europe and Africa (Tethys). In this sea much marine deposits were accumulated in the form of limestone. In the Late-Jurassic and in the Cretaceous the Tethys became a real ocean basin. In this ocean also limestones and marls were deposited by suboceanic mudflows (Kroonenberg, 1992).

In the Paleogene the collision between the continents Africa and Europe started and as a result many rocks were deformed and huge nappes were formed. Metamorphism was intense in the Internal Zone. On the other side of the Tethys (Alboran Sea) the formation of the Atlas Mountains started. At the end of the Oligocene a period of mountain building of the Betic Cordillera started, so there is a tectonic uplift of the whole area (Betic-Rif orogen). Figure 2.4 shows the schematical equidimensional block diagrams which illustrate the Neogene geodynamics of the Alboran Basin and the Betic-Rif orogene.

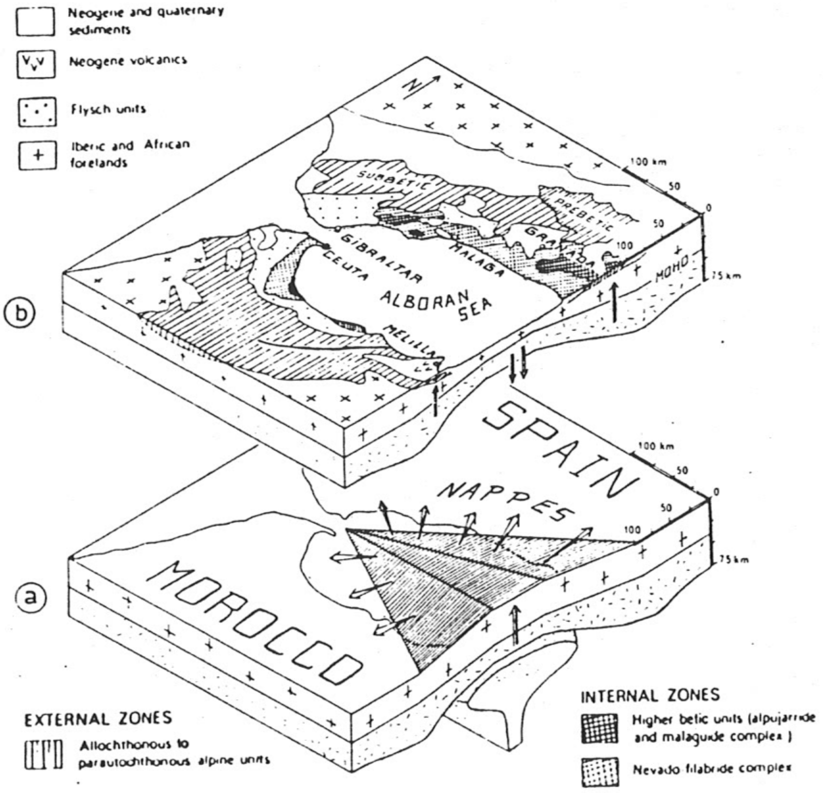


Figure 2.4. Schematic equidimensional block diagrams (Source Weijermars, 1991).

A consequence of this uplift is the formation of Molasse (typical post-orogenic rock). During the Miocene the Betic Cordillera partly rose above sea level (Weijermars, 1992).

At late Miocene the Mediterranean dried up. This happened during the Messinian Salinity Crisis. This crisis was a catastrophic event which led to the deposition of 10^6 km^3 of evaporite in the Mediterranean between 7 and 5 Ma before present. Before this event the main seaway was between the Mediterranean and the Atlantic, the so-called "Betic Straits" (Basin of the Guadalquivir). The Guadalquivir seaway was narrowed and finally closed by folding and thrusting of the Subbetic over the Pre-Betic. During the Early Messinian the Atlantic and the Mediterranean were only connected by shallow sills in the Arc of Gibraltar (Weijermars, 1992). A possibility is that also the present valley of the Guadalquivir belonged to one of these sills and was connected with the Guadalhorce on the Mediterranean side of this sill, and formed a connecting branch from the Atlantic to the Mediteranean. This could be explained by the remnants of the Molasse which lay in our study area near Alora and Pizarra. These Molasse deposits contain shells. A combination of the eustatic lowering of the sea level due to glaciation and (steady) progressive uplift of the tectonic Arc of Gibraltar may finally have disconnected the mediterranean from the Atlantic during the Late Messinian. This led to desiccation of the entire Mediterranean and periodic influx of marine water leading to cyclic evaporite sequence of laminated gypsum, anhydrite, dolomite and halite (Weijermars, 1992).

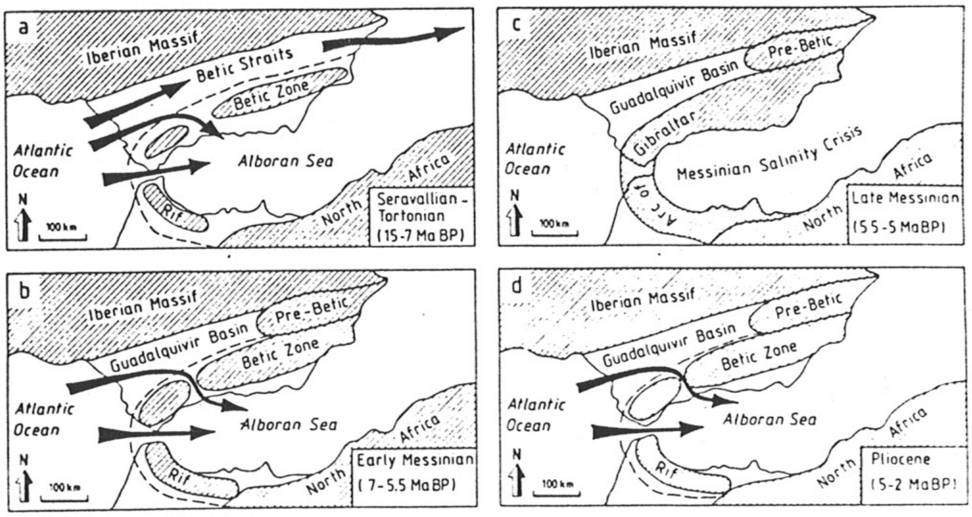


Figure 2.5. Palaeographic maps illustrating four major stages in the evolution of th Messinian Salinity Crisis (Weijermars, 1991).

The floor of the mediterranean sea was at its deepest point about 1500 meter below present sea level, so the erosion basis was lowered considerably, and rivers dug deep into the landscape (forming of deep canyons). The older river sediments were partly eroded. During this stage of erosion the recent Guadalhorce valley was formed (Buurman, 1992). Local graben tectonics and erosion, possibly in combination with a world-wide sea level rise, (re-)opened the Strait of Gibraltar and terminated the

Messinian Salinity Crisis (Weijermars, 1991).
When the sea level rose again during the Pliocene, the sea covered an extensive area of the present coastal zone and intruded into the Guadalhorce valley. It deposited a huge packet of marls and clays and also some thinny sand layers in the deep canyons in our study area. The top of these Pliocene marine deposits in the valley of the river the Guadalhorce lie at this moment at about 155 meters above the present sea level, due to steady tectonic uplift.
The deposition of gravel fan deltas (Gilbert-type) by slumping and mass flow of unstable slope due to faulting is typical for the marine Pliocene sedimentation. In our study area this occurred near the village of Álora. It started somewhat north and ended some 10 kilometers south of Álora, near a small village called Zalea. Also small thiny clay-layers of marine origin can be found in this huge packet of material, thus a conclusion can be drawn that both events of upfilling of the canyon with delta deposits and gravel fan deltas occurred at the same time.
Also in the Guadalhore basin mass flows have occurred in the time when the sea had intruded in the area. These under water sediments are called turbidites, and we have found very thick remnants of these turbidite currents somewhat south of Alora.
During the Quaternary a lot of river terraces formed in the Pliocene marine deposits by changes in sea level tectonic uplift and climate change. At the same time alluvial fans, or so-called "glacis" in the French and Spanish literature, were formed in this area and very recent sediments are the depositions of Holocene fluvial sediments in the valleys.

Table 2.1. Geologic time scale outlining the geological history of SE Spain (Weijermars, 1991)

Ma B.P.	Epoch/Period/Stage	Geological event
Present		Modern earthquakes and hydrothermal springs
Quaternary		Establishment of modern shorelines
Neogene(20-2 Ma B.P.)		
2.6	Late Pliocene	Alluvial fans after regression
5-3	Early Pliocene	Marine fan deltas; intensified strike-slip movements
5	Messinian/Pliocene	Opening of Straits of Gibraltar

5.5-5	Late Messinian	Salinity Crisis (2nd stage): desiccation of Mediterranean
6.5-5.5	Messinian	Salinity Crisis (1st stage): cyclic evaporization
6.5	Early Messinian	Reef complexes mark transgressional shoreline
8-7	Late Tortonian	Crustal shortening within Iberian microplate moving west along converging strike-slip faults, causing: A Thrusting of Subbetic onto Prebetic B Narrowing of the Betic Straits C Formation of Basin and Range structure in Betic Mountains
15	Serravalian	Sierras Nevada and Filabres rise above sea level: first occurence of Nevado-Filabride detritus
20-15	Burdigalian	Onset subsidence Alboran Basin, uplift Betic-Rif orogen
22±4	Middle Aquitanian	Emplacement of Ronda periodotite in hot thrust slides
25-20	Aquitanian	Alboran Diapir creates crustal high, northward emplacement of Higher Betic nappes

Palaeogene (65-20 Ma B.P.)

35-25	Oligocene	Deposition of youngest Malaguide sedimentary rocks
36	Late Eocene	A Final closure of Tethys in western Mediterranean B Formation of Atlas Mountains

Cretaceous (140-65 Ma B.P.)

85-80	Late Cretaceous	Emplacement of Nevado-filabre nappes by subduction and obduction
140-85	Early Cretaceous	Spreading in Tethys with passive margins

Jurassic (200-140 Ma B.P.)

146±3	Late Jurassic	Tethys opened

Triassic (250-200 Ma B.P.)

230-225	Carnian	Deposition of Almagride sedimentary rocks
235-230	Ladinian	Deposition of Alpujarride carbonates

Palaeozoic (600-250 Ma B.P.)

269±6	Early Permian	Intrusion of Bedar granite in connection with Hercynian orogeny
600-270	Paleozoic	Deposition of Nevado-Filabre sedimentary rocks

Precambrium (?-600 Ma B.P.)

800-600	Late Proterozoic	Gneissic basement formed

2.4. LITHOLOGY OF THE STUDY AREA

Our study area is influenced by the Internal and External Zone. North of the study area is situated the External Zone and the southern part of the study area lies the Internal Zone.

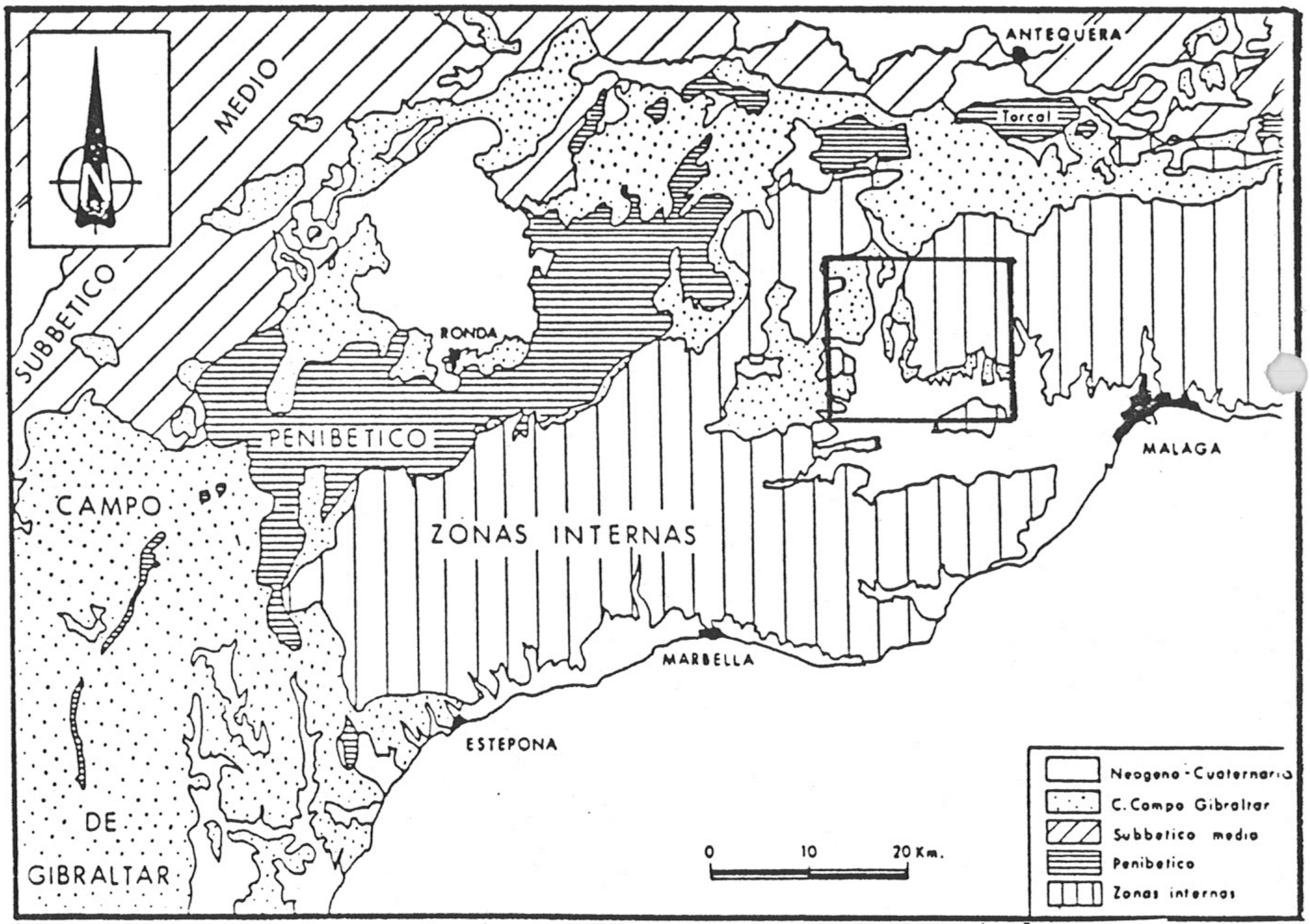


Figure 2.6. The geological structure around the study area (Source Duran, 1989).

Important rock types which represent the Internal Zone are schists, marbles, ultramafic rocks, conglomerates and gneisses. The Alpujarride fold nappes (in the study area east of Alora) comprise low-grade metamorphic Triassic carbonate rocks, marbles, slates, quartzites and a massif of peridotite (Serrania de Ronda, west of study area), which is world its largest exposure of upper mantle rocks, that only minimally is altered by serpentinisation (Weijermars, 1991). Peridotite is an unmetamorphosed ultramafic rock and consists mainly of olivine, serpentinite on the contrary is an ultramafic rock that is metamorphosed to the green mica-like mineral serpentine, which can be found in the Sierra de Aguas (consists predominantly of the serpentine mineral chrysotile) (Kroonenberg, 1992). The Triassic marbles form prominent mountains such as the Sierra de Mijas and the Sierra Blanca (which both lay in the southern part of the study area).

The Alpujarride nappes also comprise schists (black greenschist facies schists) (Weijermars, 1991). Schists are strongly schistose metamorphic rocks with macroscopic mica crystals (Buurman, 1992). The schists of the study area are interpreted as Paleozoic sediments which are metamorphosed by different phases of mountain building. Typical high-grade metamorphic schists with abundant garnet and sillimanite occur in resticted areas (Kroonenberg, 1992)

The Malaguide nappes consist of non-metamorphic to very low-grade metamorphic carbonate-rocks, sandstones, shales and conglomerates, ranging from Silurian to Oligocene in age.

The most important rock types of the External Zone are sandstones, marbles, evaporites, limestones, dolomites and flysch deposits. The Sub-Betic Zone does not have any Paleozoic outcrops. The Mesozoic comprises a marine sequence from the beginning of the Lias, while the Triassic is similar to that of the other units of the Iberian Peninsula, but with a higher relative abundance of marls and clays (Sala, 1984). Keuper gypsiferous marls are in the Guadalhorce valley near Alora found on pockets on the slates and schists. The gypsum occurs as large nodules, veins and crystals (Buurman, 1992). In the Jurassic and Cretaceous, marls and limestones are predominant. Some of these limestones developed later into dolomites (rocks consisting predominantly of $(Ca, Mg)CO_3$). These Jurassic massive limestones and dolomites form prominent mountains near the study area, such as Sierra de Valle de Abdalajis and the El Torcal de Antequera (Kroonenberg, 1992). The Eocene and Oligocene are represented by flysch deposits (submarine clays, marls and sand deposits). The flysch deposits were compacted and deformed during the onset of mountain building (particular at the end of the Oligocene) (Buurman, 1992). Large areas of flysch deposits occur north and west of Alora.

The most important rock types of the study area, that are not related to the Internal or External Zone of the Betic Cordillera are molasse (Miocene conglomerates and sandstones) and conglomerates. Both are typical post-orogenic rocks. They form impressive mountain massifs with vertical escarpments west of Alora and east of Pizarra.

All these kind of rocks influence the contents of the load of the river terraces.

There is also a strong diversity in different minerals in the study area. The Alpujarride nappes consist of biotite, andalusite, sillimanite, K-feldspars, spinel and cordierite and on some spots garnet and staurolite. The Malaguide nappes consist of quartz, plagioclase, muscovite, biotite and andalusite. The peridotites consist of olivine, spinel, orthopyroxene and plagioclase. The serpentines consist of orthopyroxene and magnetite. The Sierra Blanca near Cártama contributes to the variety in minerals with amphiboles and cordierite. In this report the term ultramafic material is used to indicate the group of plutonic rocks, with more than 90% of dark minerals. The main minerals are olivine, pyroxenes and hornblende. The color varies from dark grey to black and even to dark green (IGME, 1978).

In the valley Guadalhorce are recent and old alluvial deposits. And along this valley also Pliocene marine deposits occurs (particular south of Alora).

2.5. THE GUADALHORCE BASIN

This study mainly focusses on the terraces of the "Rio Guadalhorce" between the bridges of Álora and Cártama. The river Guadalhorce streams from the Sierra Corda to the Mediterranean Sea and has a total length of 154 kilometers. The river runs through the big alluvial plain of Antequera and arrives halfway at the artificial lakes between Campillos and El Chorro. At El Chorro, the river passes through a gorge (El Garganta del Chorro) and continues her way by flowing south through the "Valle del Sol". In this valley the river passes the following villages which lie in our study area, such as Álora, Pizarra and Cártama and flows into the sea near the city of Málaga.

In the study area quite extensive glacis have developed around the hills and mountains. The highest have raña characteristics, i.e. they are polygenetic accumulation glacis developed by fluvial and colluvial action in a savanna/steppe type of climate. These glacis and younger ones are frequently covered by detritical materials cemented by calcium carbonate to form calcrete crusts. Near the main rivers a series of terraces have developed, which near the hills and the mountains interfinger with the glacis mentioned before and the fans deposited by the torrential tributaries. Field evidence indicates that the present courses of many rivers are related to faults and that many glacis, fans and terraces are deformed as a result of neo-tectonism (Zuidam, 1984).

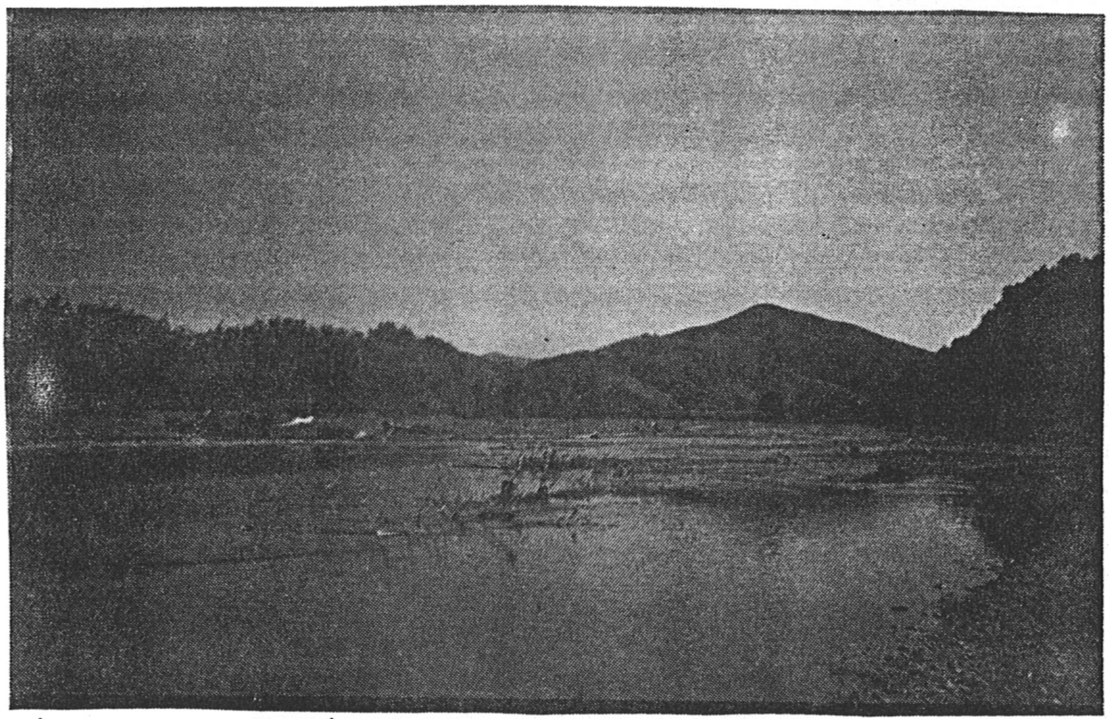


Figure 2.7. Picture of the Rio Guadalhorce shortly after the confluence with the Rio Grande.

The major tributaries in our study area are:
Arroyo de las Cañas, draining the Sierra de Aguas.
Rio Grande, with a total length of 30.9 kilometers and draining the Serrania de Ronda.
Arroyo de Casarabonela, also draining the Serrania de Ronda
Rio Fahala, with a total length of 16 kilometers and draining the Sierra de Mijas.
Arroyo del Buho, draining the hills nord-east of Pizarra.
The total Rio Guadalhorce basin covers a surface of 3157 km^2 and has a mean annual discharge of 13.5 m^3/s. The Rio Grande and the Rio Fahala basins cover respectively a surface of 338.1 km^2 and 64.4 km^2. The mean discharge of the Rio Grande is 3.5 m^3/s and of the Rio Fahala 0.8 m^3/s (Atlas Hidrologica de la Provincia de Malaga, 1988).

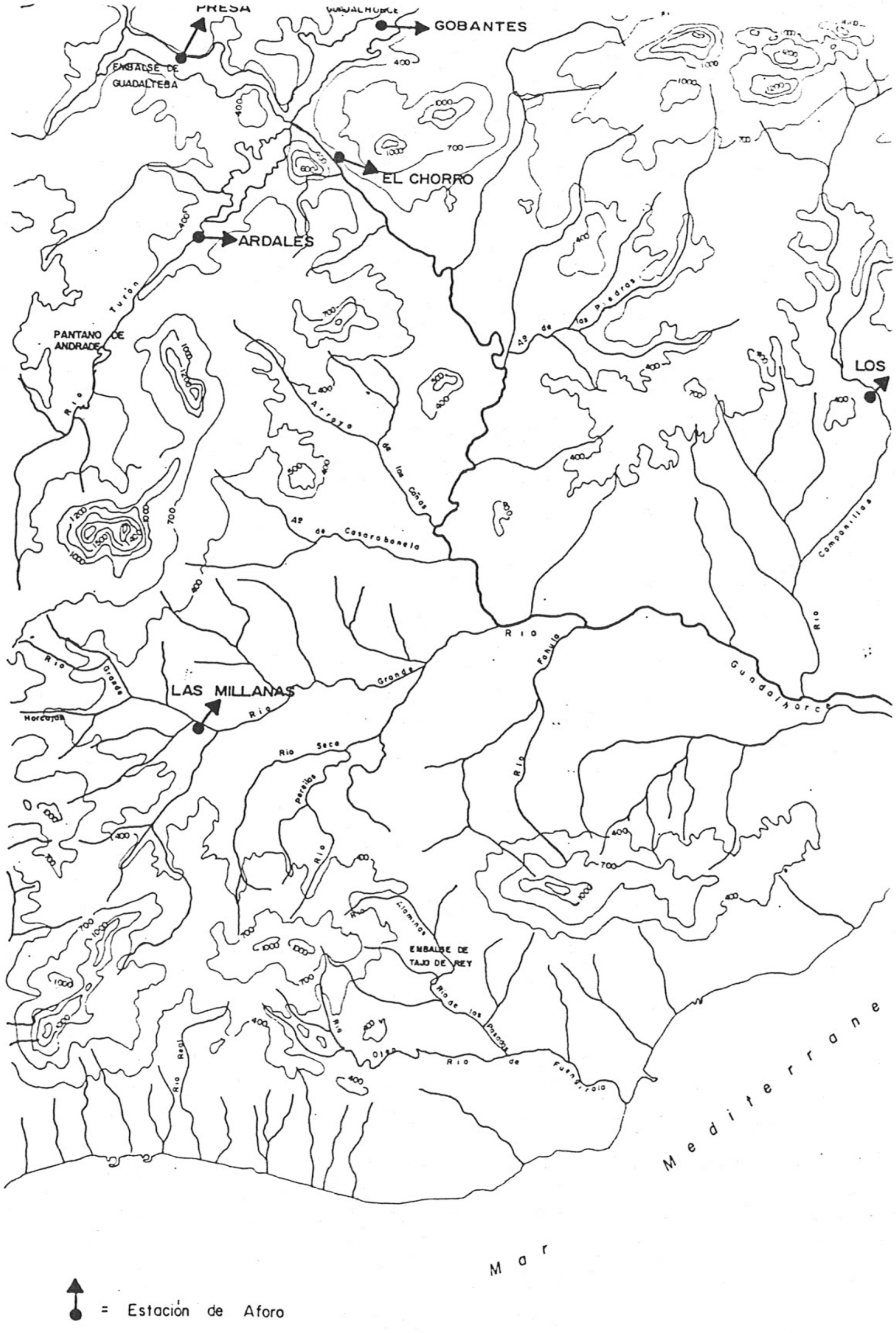


Figure 2.8. Map of the Lower Guadalhorce basin, with the river Guadalhorce and its tributaries (Source Ocaña, 1984).

3. DELTA DEPOSITS IN THE GUADALHORCE VALLEY

3.1. INTRODUCTION

During the Pliocene the sea level rose and the sea covered an extensive area of the present coastal zone and intruded also into the Guadalhorce valley. In the valley deltas were formed by different rivers. These deltas deposited marls, sands, clays and gravel layers.
The old Plio-Pleistocene coastline here is situated at an elevation of 100 meters near the present coast at Torremolinos and it extends into the Guadalhorce basin at a higher level as a result of tectonism (Zuidam, 1984).
The maximum transgression in the study area was at Late Pliocene (Villafranchian) and the highest part of the thick delta deposition is situated at about 155 meter above present sea level. At this height are also situated the oldest and highest terrace levels of the Guadalhorce basin. During the Quaternary, changes in sea level caused incision of rivers into the Late Pliocene deposits, resulting in a new serie of river terraces of the Guadalhorce.
Zuidam (1984) also found a marine terrace at an elevation of ± 40 meters, but there is no evidence of other marine terraces in the study area, probably because the lowest point in the study area is still some 45 meter.
This chapter concerns the formation and building of the remnant delta in the study area and its litho-stratigraphy.

3.2. FORMATION AND BUILDING OF THE DELTA IN THE GUADALHORCE VALLEY

3.2.1. INTRODUCTION

The Late Pliocene materials of the study area are deposited in a delta form, probably a Gilbert type delta. A Gilbert type delta is formed when there is no difference in the apparent densities of river water and receiving water bodies, and the influence of waves and tides are negligible, or if there is strong effidence that the river contains a lot of material, which is the case in the study area. In this type of delta, the coarsest material is deposited in the delta plain close to the mouth; finer sediments accumulated in the submerged delta slope and the finest (clay) particles travel the farthest (prodelta). Thus, a grain size gradation evolves across the delta. When the delta progrades

under continuing sediment supply, progressively coarser sediments cover finer sediments: a so-called coarsening upwards sedimentary sequence. Such sequences can be hundreds of meters thick. The fine prodelta sediments are the "bottom-set beds", the sloping delta front sediments the "fore-set beds", and the top most delta plain sediments the "top-set beds" (Driessen, 1989).
The top of the Pliocene delta sediments lies about 150 meter above present sea level. These Late Pliocene deposits do not necessarily indicate high Pliocene sea levels, as they have been uplifted to their present position after their deposition (Buurman, 1992).

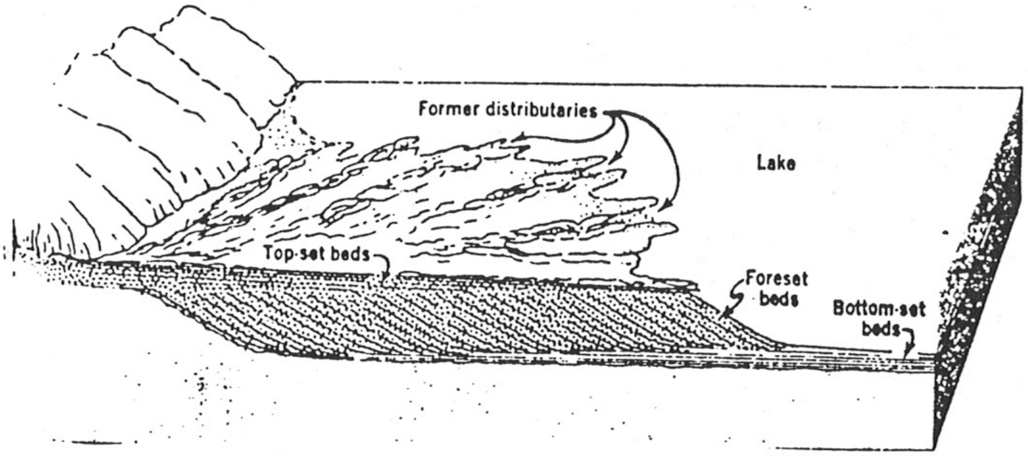


Figure 3.1. Structure of simple delta shown in vertical section (after G.K. Gilbert) (Kroonenberg et al.).

The study area has been subjected to tectonic uplift since the Pliocene. Tectonic movements accelerate sedimentary processes, so during Late Pliocene the sediment supply was much bigger than sediment discharge. Not only sands and clays deposited, but also gravel.
During the Villafranchian, a lot of deltas have been made by the rivers in our study area such as the deltas of the rivers Guadalhorce, Cañas and Arroyo del Buho.
Typical fine prodelta sediments are situated in the southern parts of the study area (Villafranco de Guadalhorce and Cerralba). The sediments are predominantly clayey (smectite). Typical delta plain material is situated near Alora and in the valley of Arroyo del Buho. The sediments consist of sands, clays and gravel. We also detected that the sand we found here was typical, angular beach sand (with the real surf far away). These shell bearing sediments were sedimented under relatively quiet environments and did not travel over a long distance. At the maximum extension of the sea in the Guadalhorce valley (Villafranchian) the tide difference was low, only half a meter. In this time the Sierra de Mijas was a peninsula and Sierra de los Espartales

(directly south of Cártama) was an island. The coastline was to be found near Alhaurin el Grande and Coin in the south and in the north near El Chorro. Figure 3.2 shows a map of the maximum extension of the sea in the Guadalhorce valley in the Villafranchian (±2 Ma B.P.).

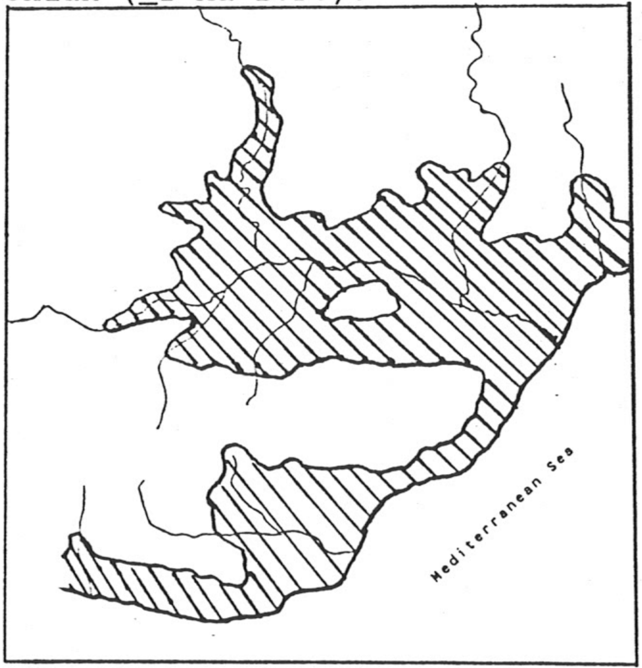


Figure 3.2. Maximum extension of the sea in the Guadalhorce valley in the Villafranchian

The conclusion can be drawn that a big area (valley of the Guadalhorce and its tributaries) was below sea level. We figured out with the aid of exposures, that the coastline (and thus the maximum transgression phase) at that time was situated about 160 meter above present sea level. The fluvial terraces of that height are the highest and oldest fluvial terraces of the whole Lower Guadalhorce basin and protect the Pliocene "delta" sediments against erosion. On other spots in our study area the marine material has been partly eroded by (water) erosion.

The Pliocene deposits are extremely sensitive to landslide, so many of this material has been eroded during the Quaternary. Thick deposits of the "delta" sediments occur in the southern part of the study area.

In the whole of our study area there are no more marine deposits, only those of the Villafranchian (Late Pliocene). Near to the sea (near the village Churriana) we suspect that there are more different former marine levels, but we did not investigate this area. Other researchers have found more marine levels on other spots in the Mediterranean. Ovejero and Zazo, for instance, have distinguished five marine levels: 80 m (Sicilian), 20-25 m (Tyrrhenean I), 5-6 m (Tyrrhenean II), 2-3 m (Tyrrhenean III0 and below 2 m (Flandrian) above present sea level. The differentiation of the levels is based on fossiles of tropical fauna (in particular Strombus bubonius) (Ovejero, 1971).

3.2.2. EXPOSURE "ARROYO DEL BUHO"

The most important characteristic of this exposure (exposure 34) is the variation in deposition of fluvial and marine material. The top of the sediments lies about the 155 meter above present sea level and lies relatively far into the valley of the Arroyo del Buho (more than a distance of four kilometers distance from the confluence with the Guadalhorce).

During Villafranchian the Arroyo del Buho formed a small delta and supplied at the same moment a lot of gravel. This gravel was deposited in the delta. In the Villafranchian there were also periods of relative sea level rise. So there was an interaction between the sea and the river. At quiet moments in this interaction and on quiet spots it deposited clays and on lesser quiet occasions it deposited sands or even gravel layers. These different stages are very clearly visible in the exposure which is built of layers of sand, gravel and clay.

The composition of the gravel layer consists of schists, gneisses and a lot of slates and are derived from the surrounding mountain range which mainly consists of slates. The sand layers contain a lot of shells and the clay layers show oxidation/reduction properties and have a lot of cracks (description in appendix I).

3.2.3. EXPOSURE "ÁLORA, DELTA DEPOSIT"

This exposure (exposure 19) lies on the opposite side of Álora, near Álora Estación. The exposure is characterized by clay and sand sediments, which are deposited in a delta environment. The clay was deposited under very quiet circumstances and the sand in less quiet occasions. In the delta was, at the time of the maximum transgression in the Villafranchien, a kind of meandering system. This delta consisted of levees and floodplains. In the levees sand was deposited and in the plains clay. The deposition occurred below water. The influence of the tide was neglectible (half a meter), thus it can not be called a tidal flat. Another reason that it was not a tidal flat is because of the fact that the valley was too narrow to become one. In the exposure are characteristics of soil formation, such as secondary calcium carbonate accumulation of dissolved shells. In the clay some properties of oxydation occurred on spots in thin bands (brown colour) but most of the clay is under reduced circumstances. The sand is angular and is probably a kind of beach sand. Further we found small gravel layers in this exposure which mainly consisted of schists and slates. This is not very strange because the dominant rock type in the mountains nearby consist mainly of slates and schists (Alpujaride nappe).

3.2.4. LITHO-STRATIGRAPHY OF PLIOCENE MARINE DEPOSITS (BOTTOM-SET BEDS)

We have described one beautiful exposure (exposure A, for description see appendix I) along the road near the confluence of the Rio Grande and the Guadalhorce. In our case the exposure consists of clay, which is mainly sedimented under reduced circumstances, but also it contains some layers of medium to coarse sand. The exposure lies at a height of about 80 meters above present sea level. Further characteristics are that it is calcareous and shell-bearing. These kind of sediments are found in the southern part of the study area and have very little soil formation. These deposits were sedimented in the "prodelta". The exposure lies far away from the delta plain and therefore consists mainly of clay (Gilbert-type delta).

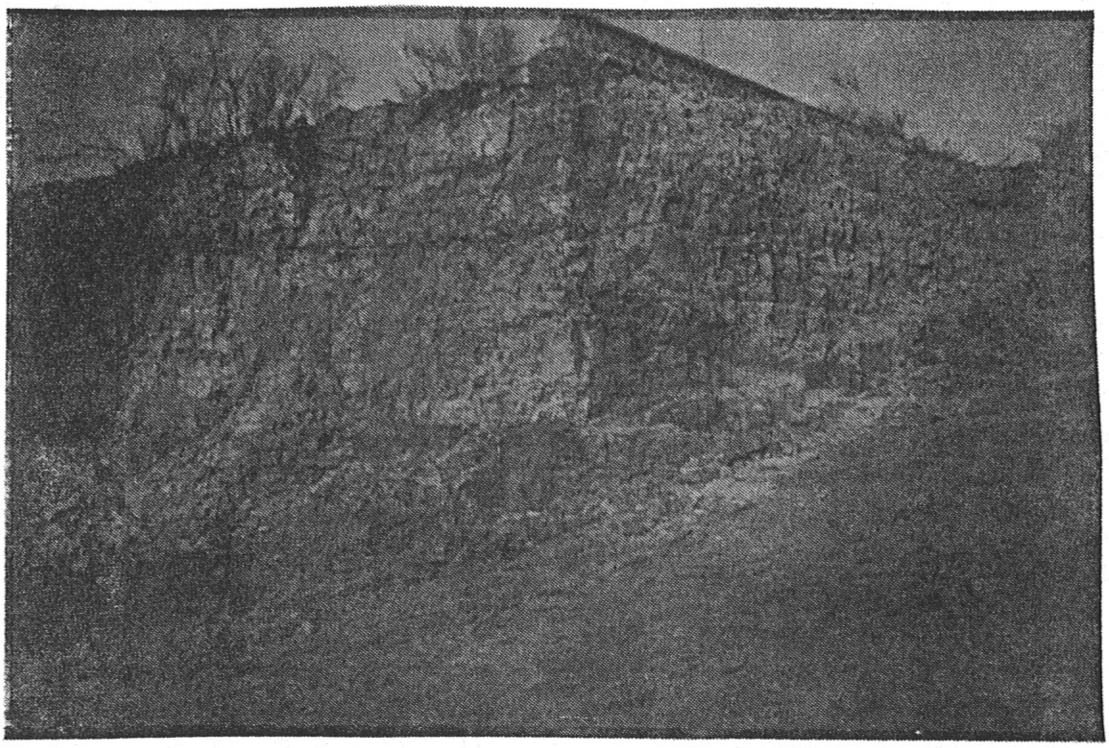


Figure 3.3. Exposure A.

The sediments are greyish, layered and contain pyrite and gypsum. Gypsum is formed by aeration of pyrite. The clay has a high content of smectite, which accounts for strong swelling and

shrinking upon wetting and drying. The sediments were deposited in a (shallow) marine environment, so they contain small amounts of soluble salts, which may locally give rise to brackish groundwater (Buurman, 1992). Locally these sediments are overlain by sandy deposits. These sandy deposits are remnants of beaches when the sea receded during the Villafranchian.
At the moment a big part of the marine Pliocene sediments are cultivated by the local population for agricultural purposes. To retain maximum use of these areas artificial terraces have been made in the past (especially around the villages Cerralba and Villafranco de Guadalhorce).

3.3. TURBIDITE DEPOSITS

3.3.1. INTRODUCTION

We located in the study area big exposures of turbidite deposits. Turbidites are submarine mudflow sediments and the turbidity currents occur mainly on the continental slope of the sea. A cause of turbidity currents is the dilution of landslide masses that slump down the slope. These currents are observed frequently to flow down submarine canyons, causing deeper entrenchment of the latter. Detrital fans from turbidity currents accumulate at the mouths of these canyons. The merging of these fans gives rise to the tilted depositional plain of the continental rise. Turbidites can be stretched over more than hundreds of kilometers (Embleton, 1989).

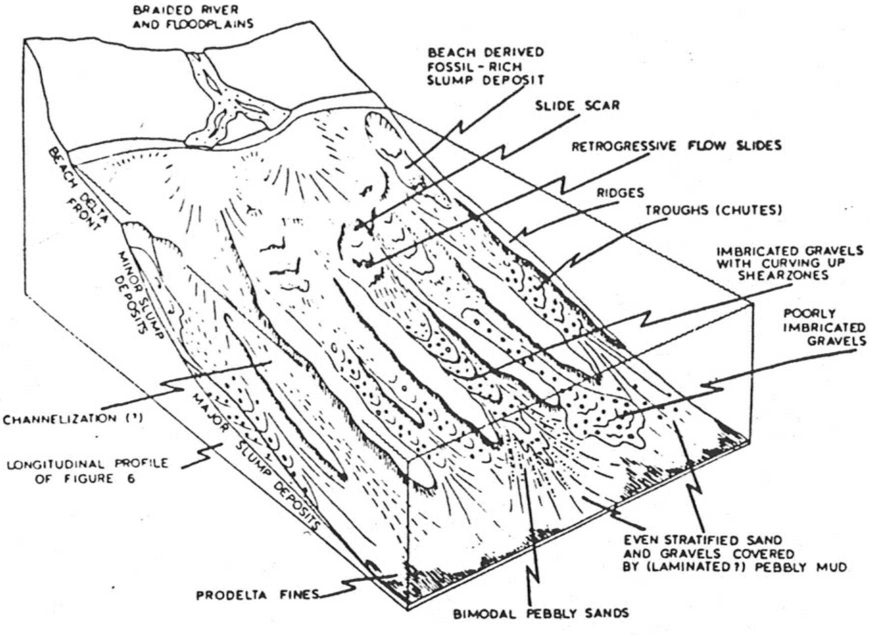
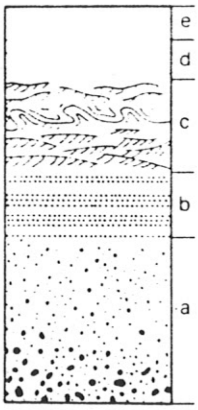


Figure 3.4. Sedimentation model for slumping and gravity collapse of meta stabel deposits (Source Weijermars, 1991).

The most important characteristic of turbidites is the graded layering of the sediments. During the distribution in suspension the coarser elements are relatively concentrated near to the floor and the finer elements are relatively suspended higher from the floor, so every layer of the turbidite deposits shows a fining upwards sequence. Bouma (1962) divided one turbidite layer into five intervals. From under to above this figure 3.5 is divided in:



a) graded interval (coarse sand and gravel). At supply of much coarse material this interval can contain half or more of the total turbidite packet.
b) first interval with parallel lamination (coarse sand)
c) false layering interval (fine sand and silt)
d) second interval with parallel lamination (mainly silt)
e) pelite interval (clay)

Big turbidity currents are very rare and catastrophic. One turbidity current deposites its own sediment, thus thick exposures of turbidite sediments were involved by different currents (Pannekoek, 1982).
Near Álora we found thick exposures of turbidite sediments, one exposure is more than 45 m thick. The exposures are graded very obviously and consist of gravel, sand and clay layers (bands). The deposits of the turbidity currents have been deposited during the Pliocene, when the Guadalhorce valley was a kind of submarine canyon. Directly after the Messinian Crisis the deep valley of the Guadalhorce was intruded by sea water and from that moment it was possible to form turbidite currents. It is not totally clear of these deposits are really turbidites. Some questions still remained. It is also possible that it are alluvial fans, but these turbidites differ a lot from the common piedmont rañas in the area. The pebbles are rounded. An other evidence that it is not an alluvial fan in the normal way is that these deposits have clear visible clay layers of marine/delta origin.

3.3.2. TURBIDITE DEPOSITS IN THE STUDY AREA

In the study area are some obvious exposures of turbidites. The most beautiful exposures of these deposits are situated around the village Álora. Two of them are situated directly south of Álora and one north. The last one is not described because it lies outside our study area. The most southward exposures of turbidites are situated around Pizarra and Zalea.

The turbidites were deposited, when the Guadalhorce valley was a deep valley (canyon). This was during the Pliocene, after the Messinian Salinity Crisis. During this event the Mediterranean Sea dried up, so the erosion basis was lowered consideraly, so rivers dug deep into the landscape. During this stage of erosion the Guadalhorce valley was formed. Detrital fans from turbidity currents accumulate at the mouths of these canyons. The merging of these fans gives rise to the tilted depositional plain of the continental rise.

Our conclusion is that probably a detrital fan from turbidity currents accumulated between Álora and Pizarra and is stretched out over the total distance.

3.3.3. LITHO-STRATIGRAPHY OF TURBIDITES (SUB MARINE MUDFLOW DEPOSITS)

The five exposures of turbidite deposits will be described in this chapter. The first one (exposure 17) lies some two kilometers south of Álora, and it is more than 45 meters thick and its basis is situated along the river the Guadalhorce. The top of this turbidite exposure lies around 130 m above present sea level. Most of the sediments are classified in the "graded interval", according Bouma. The exposure consists mainly of coarse sand and gravel and the lower 15 meters are characterized by accumulations of stones. Sandstones and limestones are dominant in the exposure, but other rock types are conglomerates, slates, gneisses, schists, quartzites and ultramafic rocks.

Some sands are situated in layers with a small gradient in the layers. The sorting of the sediments is in general good and the weathering degree is low. The upper 10 meter of the exposure are characterized by clay bands and by sand and gravel layers. Some of the layers are false layered, according Bouma. In general the material of the highest 10 meters is finer than the lowest 15 meters. The clay bands and some sand layers are of marine origin. In the upper 10 meters we found no ultramafic rocks. In this part the sandstones dominate. The sorting of this part is good and the weathering degree is low (for description see appendix I).

The second turbidite exposure (exposure 5) is situated one kilometer south of Álora and the top lies about 125 m above present sea level and the thickness of the exposure is 6 m. The exposure shows some remnants of gully deposits. In the whole profile there is slight gradient, parallel to the recent valley. The exposure consist only of coarse sand and gravel. The gravel consists of sandstones, limestones, gneisses and slates (no occurrence of ultramafic rocks). In the exposure we found occurrence of paleosols. The sorting is not very good and the weathering degree is low.

Figure 3.6. Exposure 17. In front J. Crompvoets, halfway S. Kroonenberg and on top of the hill R. van den Berg van Saparoea.

The three other exposures (12, 24 and 37), are situated between Zalea and Pizarra within a distance of 200 m of each other. These are the most southwards turbidite exposures we have found. The gravel consists of limestones, gneisses, sandstones (dominant rock type), quartzites and ultramafic rocks. That we have found a lot of ultramafic rocks is not very strange, because the exposures lie south of the confluence Cañas/ Guadalhorce. In the exposure we found coarse sand layers, but the overall sorting of the exposure is bad and the weathering degree is low.

3.3.4. COMMENDS AND CONCLUSIONS REGARDING THE TUBIDITES IN THE STUDY AREA

Later the idea was raised that the turbidites are no turbidites after all. First more investigation on this matter is advisable. Other suggestion is that it is an alluvial fan. The alluvial fan could be deposited in the time when the sea was at its lowest level. The river dug deep in the valley and formed a canyon. A lot of material was formed and could slump easily downwarts in alluvial fan or piedmont rañas. Later when the sea was on its highest level, it is possible that these fans have slumped again, with some intervals. In these intervals it is possible that thin clay layers have formed. That the idea of a turbidite was transformed is also caused by the fact that it is sorted. A turbidite is a catastrophic event in which sortation is only small. Overall conclusion is there is no real evidence whether it is a turbidite or an alluvial fan (or even more turbidites or alluvial fans) and that further investigation is neccessary to solve this question.

4. THE FLUVIAL TERRACE SEQUENCE OF THE RIVER GUADALHORCE

4.1. INTRODUCTION

This chapter concerns the terraces of the river the Guadalhorce. It has about six main fluvial terrace levels, numbered from A1 (present river bed) to A6 (oldest and highest terrace level).
The tributaries of the main river, called Rio Grande, Arroyo de Casarabonela, Arroyo de Cañas and the Rio Fahala, show also some obvious fluvial terraces.
The composition of the gravel reflects the different lithologies within the Guadalhorce basin. This composition is not linear correlated with basin lithology. Sandstones, limestones and slates predominate, while the Paleogenic rocks (flysch) are usually rare.
The river terraces are in general situated on the right side of the river and the most complete terrace sequence in the Guadalhorce basin, and in our study area, is found between Zalea and Pizarra.

4.2. FLUVIAL TERRACE FORMATION IN GENERAL

Changes in channel gradient, discharge or sediment load can lead to a river channel incising into its floodplain. The original floodplain is thereby abandoned and is left behind as a relatively flat bench, known as a river terrace (Pannekoek, 1982).
A distinction is usually made between terraces cut on bedrock, which are called "strath terraces", and those comprising former floors of alluvial valleys (Leopold, 1964).

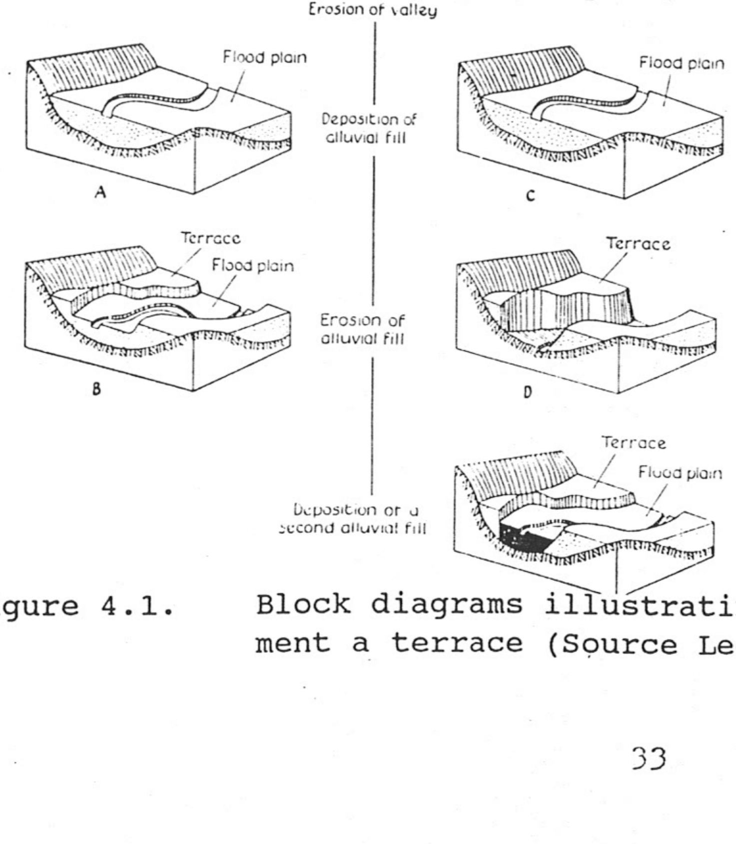


Figure 4.1. Block diagrams illustrating the stages in development a terrace (Source Leopold, 1964).

River terraces are inclined downstreams but not always at the same inclination as the active floodplain. A valley side may contain a vertical sequence of terraces. The lowest will be the youngest and may retain traces of floodplain morphology, while the highest will be the oldest and will usually be partly degraded. Paired terraces are formed when vertical incision is rapid in comparison with the lateral migration of the river channel. Unpaired terraces are formed where lateral shifting of the channel is relatively rapid; this results in the river cutting terraces alternately on each side of the valley floor (Summerfield, 1991).

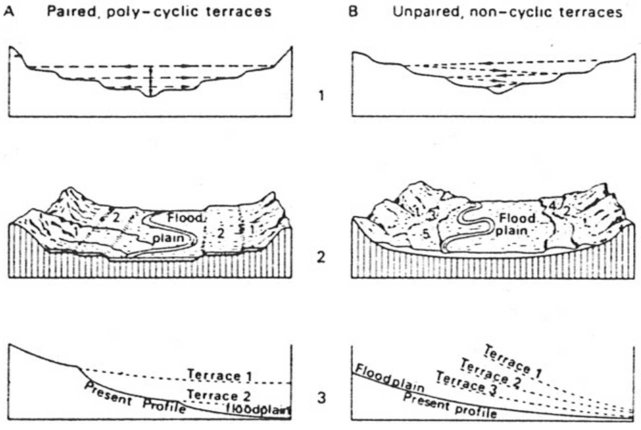


Figure 4.2. Paired and unpaired terraces. Note how the vertical spacing of terraces is more or less retained in paired terraces but converges downstreams in unpaired terraces. (Source Summerfield, 1991).

The mechanism of terrace formation is usually sought in three major external factors; climate, tectonism and base level (Veldkamp, 1991).

The contribution of tectonism to terrace formation is valley deepening throughout the time. A fall in base level can lead to a terrace if it generates a downstream increase in channel gradient (Summerfield, 1991). The tendency of fluvial systems to aggradade or incise is particularly sensitive to climatic fluctuations in semi-arid regions (southern part of Spain belongs to semi-arid regions). This is due to the fact that in such areas modest changes in annual precipitation can produce significant changes in vegetation cover which are reflected in large changes in the rate of sediment supply to stream channels (Leopold, 1964).

It is very difficult to identify a terrace in the field and to interpret a terrace form. Positions of a flood plain near the valley sides are subject to local deposition resulting from erosion of the valley sides by local wash, tributary rills and mass movements (slumps). These alluvial fans (in Spain called piedmont rañas) can have a thickness of several meters. A significant property of fluvial terraces to other landforms is that it consists of rounded pebbles which indicate a longer distance which these pebbles have traveled and on which these pebbles have rounded. Pebbles from other landforms such as an alluvial fan consist of mainly angular pebbles.

To identify the amount of terrace levels for a river is done in this case by drawing a longitudinal section. This gives an idea of the amount of terraces and terrace levels. The plot of the position of terrace remnants along the present river is given in appendix II. The variation in height of these remnants on a supposed single or correlative surface, can also be seen in this figure. There are two graphs; one with all the exposures found in the area and the other one only with the Guadalhorce terraces. In the last one the terrace levels A3, A4 and A5 are clearly visible.

Other methods, besides the method of the longitudinal profile and their relative elevation, to identify the different terrace levels are: stratigraphic discontinuities between terrace fills, differences in particle size and sorting, sand bulk geochemistry, differences in primary sedimentary structure, buried soils or paleosols and fossil fauna and flora.

Terrace description are only given of exposures and this is done according a checklist. This checklist contains:

- location
- height (above sealevel and present level of river)
- thickness and the character of the exposure

and in the profile itself (if they can be estimated):

- occurrence of gullies
- paleo-streams
- lamination
- bioturbation
- dominant grain size
- gravel and stone composition
- roundness of the sediment
- post-sedimentary properties

The terraces are presented in appendix I.

4.3. FLUVIAL TERRACE FORMATION IN THE GUADALHORCE BASIN

Our study area shows six different Guadalhorce terrace levels, numbered from A1 (present riverlevel), A2 (level in the alluvial floodplain), A3, A4, A5 and A6 (oldest terrace level). Besides these six levels we have determined one sublevel A7. The distinguished terrace levels were based on their relative altitude and general sediment composition. As in most other fluvial systems the stratigraphy of the Guadalhorce terraces is far from uniform. In our study area we have determined 16 different Rio Guadalhorce exposures. At first we thought that we had found more exposures of river terraces of the Guadalhorce, but later on we came to the conclusion that they belonged to the tributaries of the Guadalhorce such as the Rio Grande, Rio Fahala and the brooks (Arroyo's in Spanish) Cañas and Casarabonela.

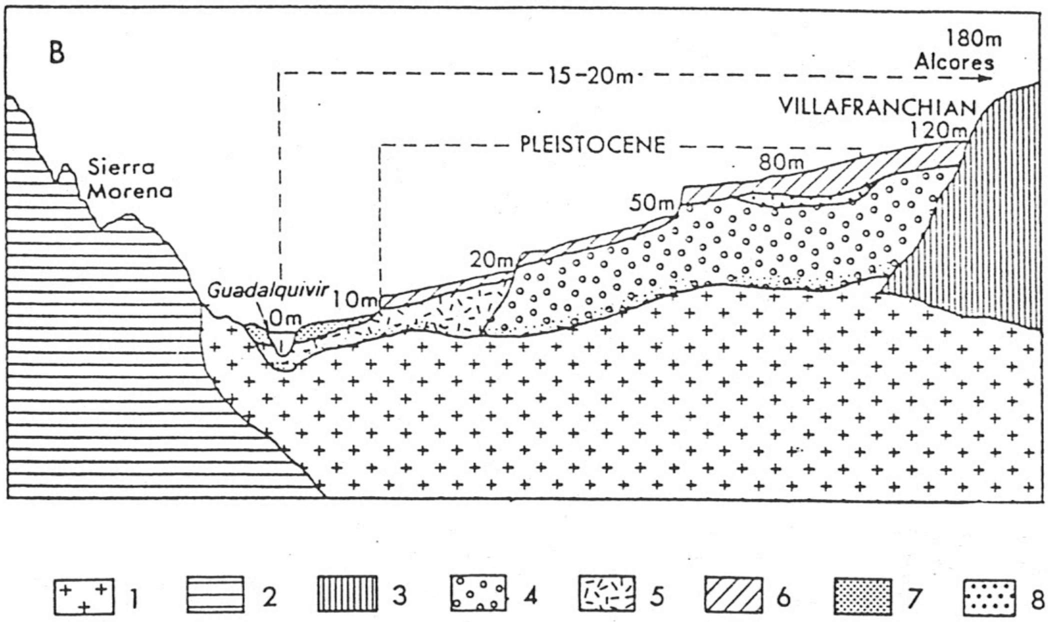
We were able to determine in the Casarabonela three different fluvial terraces, or remnants of them and of the Cañas two terraces. From the other two tributaries we could only determine one fluvial terrace.

In general the terraces of the Guadalhorce are found at the right side of the river Guadalhorce in the outside bend. This is due to the fact that at the inner side of the river (the left side) the underlaying material consists of flysch and molasse deposits. Flysch and molasse deposits are very sensitive to erosion, so terrace formation is very difficult, because they are disturbed by mass movement. Most fluvial terraces are situated on the Late Pliocene marine deposits, especially at the boundaries with the alluvial floodplain.

The external factors, which determine fluvial terrace formation are (as written before) climate, tectonism and base level. It is very probably that the external factor climate plays a big role on the fluvial terrace formation in the Guadalhorce basin. Some of the terrace levels in this basin are probably related to glacials, because Spanish geologists have been able to correlated the terraces of the Guadalquivir to different glacials.

They have estimated that the highest and oldest fluvial terraces of the Guadalquivir have been formed during the Plio-Villafranchian.

The 80 m terrace level is related to the Saletian (Gunz-Villafranchian). The level between 50-80 m belongs to the Amizian (Mindel). The 20-50 m terrace level is correlated with the North African Tensiftian (Riss). The 7-20 m terrace level, which lies in a well defined step above the Holocene plain, is related to the Soltanian (Würm) episode (Clemente, 1974).



General cross-section (north-south) of the lower Guadalquivir valley [Clemente *et al.* (1981)]. (1) Tertiary marls, (2) Palaeozoic and Mesozoic, (3) calcarenites (Mio-Pliocene), (4) early Quaternary microlitic calcareous sediments, (5) middle Quaternary conglomerates with sands and gravels, (6) middle Quaternary clays, sandy silts, sands and gravels, (7) recent alluvium and (8) early Quaternary calcrete.

Figure 4.3. General crosssection of the Lower Guadalquivir (Source Clemente 1981).

The contribution of tectonism to terrace formation in the Guadalhorce basin is obvious from the tendency towards valley deepening throughout the Quaternary. During the Pliocene and the Quaternary the area is influenced by a gradual tectonic uplift.
A direct or indirect influence of sea level variations on the erosion and sedimentation in the Guadalhorce basin appears possible, because the study area is situated very near to the sea. For example shortly after the Messinian Salinity Crisis the area was deeply incised by the river Guadalhorce (canyon).
The tectonic uplift in the Sierra Mijas by sedimentation of travertine is measured (Conesa, 1988). The speed has been estimated at 0.2 mm/y.

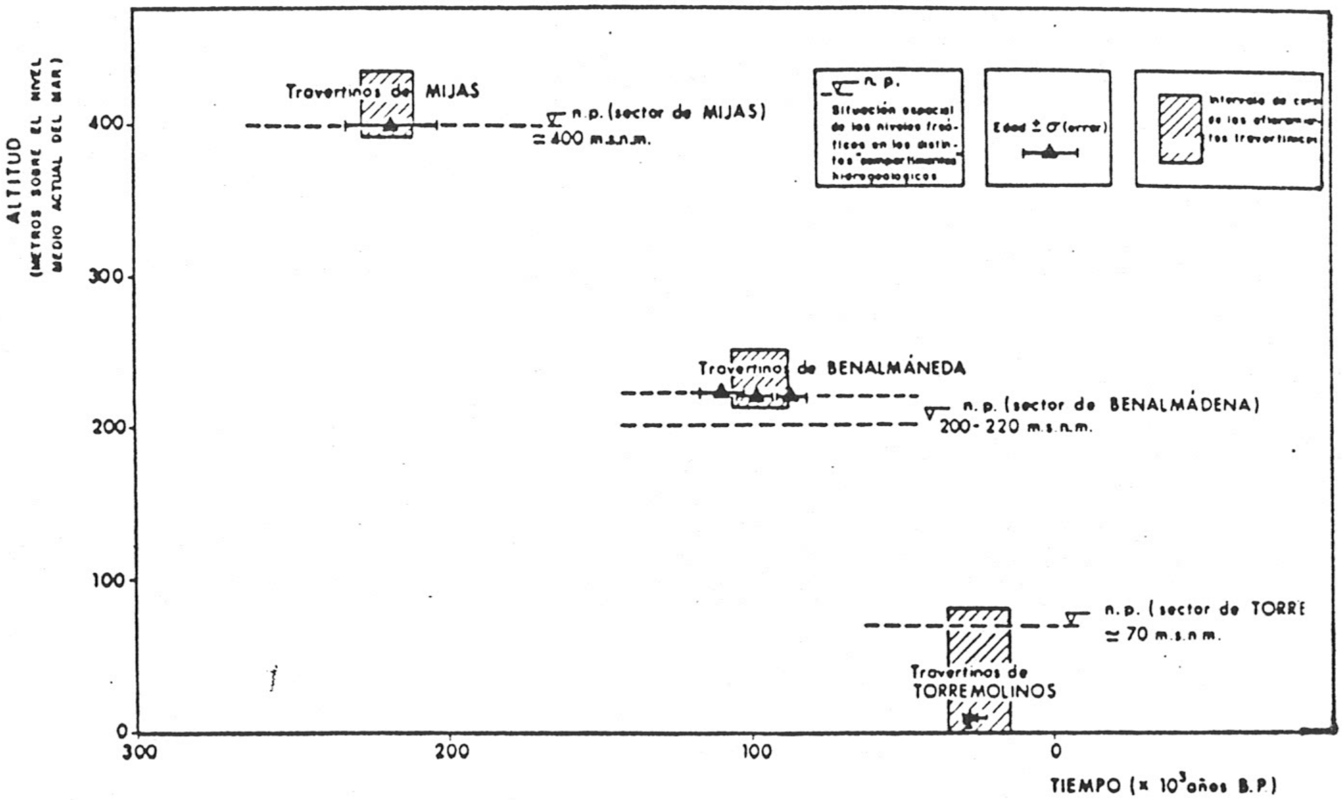


Figure 4.4. The travertine deposition at Sierra de Mijas; relation between altitude and age (Source, Duran 1989)

Another method is finding an old coast and determine its age. We have found the coast of the marine Pliocene deposits and have estimated its age. At the moment its height is 157 meter above present sea level and geologists from Sevilla have estimated that its age is some 2.000.000 years. Thus the uplift has been some 157/2.000.000 m/y which is equal to 0.08 mm/y. Two different estimations give a total different answer, but our guess is that the Sierra the Mijas is stronger uplifted than other parts and especially the Guadalhorce basin. For our measurements we thought it would be more reasonable to take the second estimation of the uplift rate of the area.
The heights of the terraces above the actual river level are: 4-6 m (fluvial Guadalhorce terrace A2), 12-17 m (A3), 20-28 m (A4), ± 60 m (A5) and ± 90 m (A6). Figure 4.5 shows the distribution of the terrace remnants and their height relative to the present level of the Rio Guadalhorce.

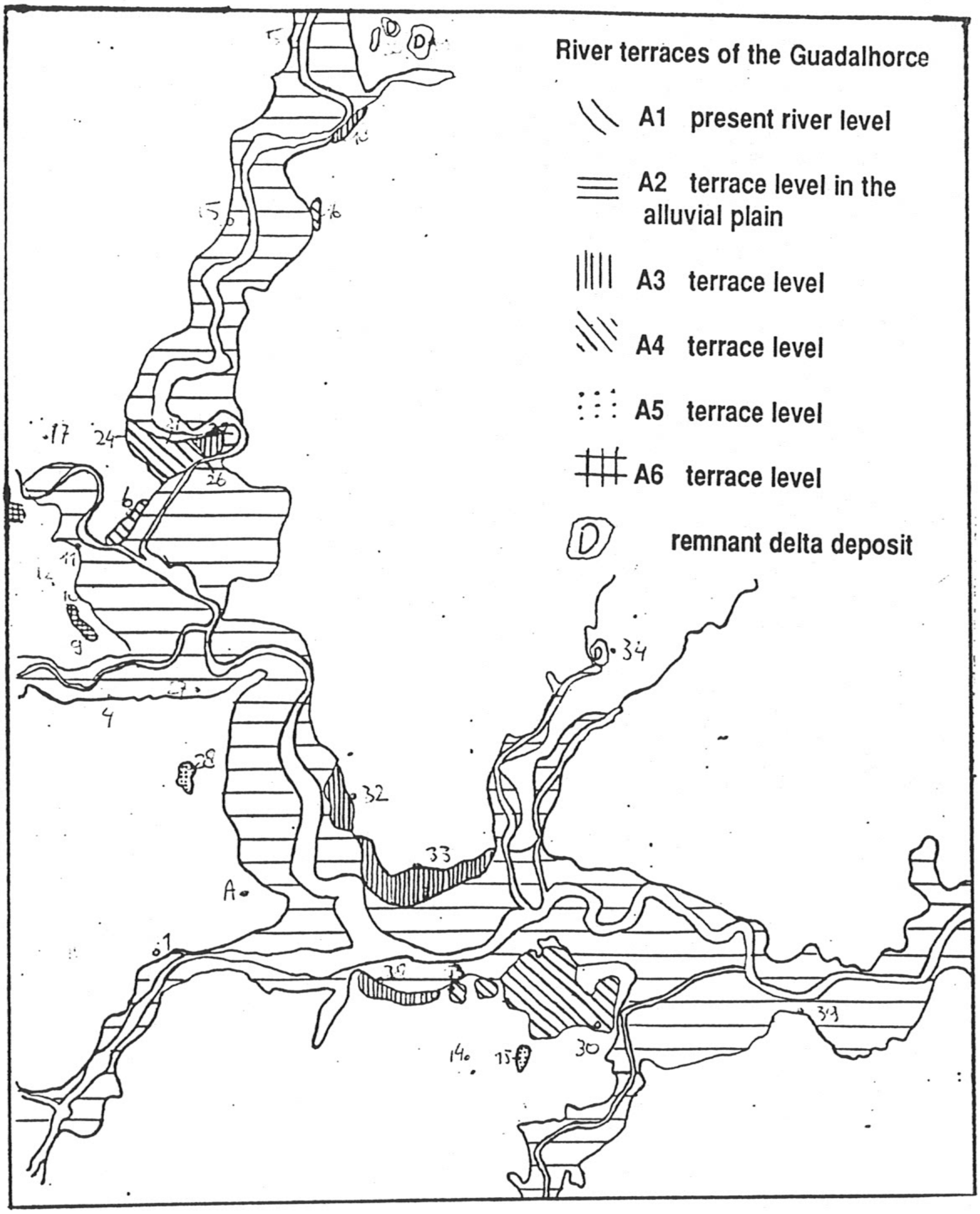


Figure 4.5. Location of the different river terrace levels of the Guadalhorce.

The most complete terrace sequence in the Guadalhorce basin is found near Pizarra. Figure 4.6 shows the schematical cross section of terraces at Pizarra. The levels of the terraces in the study area are somewhat of the same height as in the Guadalquivir basin and at first it seemed reasonable to take the same ages for the terrace levels in the study area. But as will be declared later in this report in chapter 6, the ages are different from the Guadalquivir basin. Maybe its just pure coincidence that the levels seem to be the same.

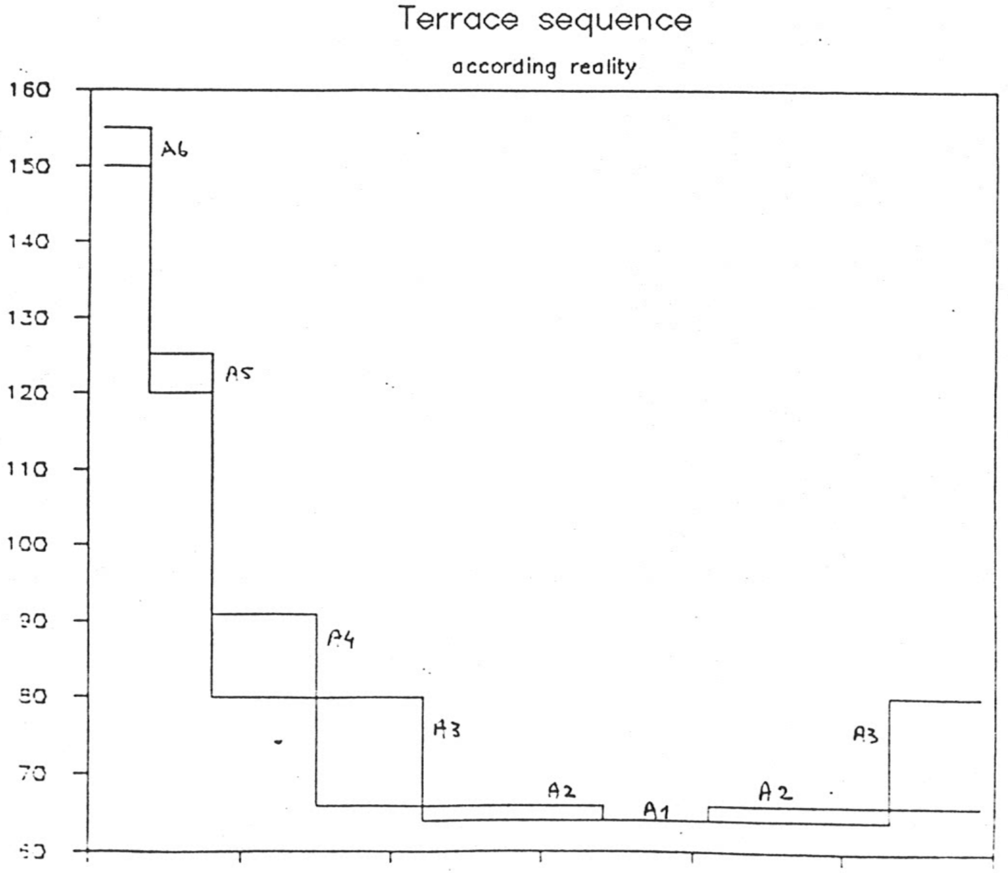


Figure 4.6. Cross-section near Pizarra.

The heights of the terrace levels of the Casarabonela above present river level are 20-25 m, 40 m and 50 m. The Cañas has two remnant river terraces at 20 m and one on 70 m. The Rio Grande has one river terrace at 40 m above present river level.

4.4. LITHO-STRATIGRAPHY OF THE FLUVIAL TERRACES OF THE GUADALHORCE AND ITS TRIBUTARIES

4.4.1. RIO GUADALHORCE

The ages of all the Guadalhorce terrace levels are still uncertain, because we have not dated the sediments of the exposures with experienced methodes such as for example the Th/U - method, because we did not have the time to wait for the results. The only way the age is estimated is done with the use of the computer simulation of A. Veldkamp 1991, that has proven its value in other cases.
The various terrace levels have been thoroughly investigated by studying all available exposures along terrace scarps. Based on

these sedimentological field observations and measured bulk geochemical sand composition a litho-stratigraphy was made.
Recent investigation in the correlation of age (relied on height difference in the field, at the highest levels the oldest material, and topography) and the kind and stadium of soil forming processes in the soil of the different fluvial terraces called A2 and A3, was done in 1992 by students during their fieldwork in 1992.

A1-terrace: The actual Guadalhorce
The Guadalhorce is at the moment a braided river, with occasional heavy discharges, when it may transport large amounts of gravel, sand and clay. The streambed is very typical of such a river: it has short distance transitions from extremely coarse to fine material, and a shallow bed.
The most common rocks in the actual streambed of the Guadalhorce are: serpentinites, limestones, (garnet)gneises, (garnet)schists, slates, sandstones and cherts.

A2-terrace: Terrace in the alluvial plane (3-6 m above present level)
The soils on the A2-terraces are relatively young and have a greyish-brown colour and contain a lot carbonates in the matrix (Mulder, 1992). The upper layer of these terraces show a fining upwards sequence and are not very much involved in any kind of erosion. Illite-clays dominate in the A2-terraces. The soils do not show very much soil development. Beneath the upper 1.5-2 meter the soil meets the stones and the gravel. The composition of the rocks is nearly the same as the actual Guadalhorce streambed and consists of: sandstones, limestones, quartzites, schists, slates and ultramafic rocks. The weathering degree of these stones is low.

A3-terrace: Guadalhorce terrace remnants (12-17 m above present level)
We have described 6 exposures (exposures 18, 21, 26, 30, 32 and 33) belonging to this terrace level. Two of them are located at a curve of the Guadalhorce near to Pizarra. Two other we found about 4 km south of Pizarra at the left side of the river.
Very typical for this terrace level is the brown colour of the surface. The A2-terraces are greyish brown and the A4-terraces are reddish brown. The A3-terraces are real brown. Some soil forming processes in these terraces are clay-illuviation and decalcification, and the soil is involved in erosion processes. Typical rocks and gravels are the dominant sandstones, slates and limestones, other are gneisses, ultramafic rocks and (garnet)schists. The sorting of the material is bad. Normally the

sandstones have the biggest size and the slates are small. The weathering degree is low to medium, only the ultramafic rocks show properties of rotten rock.

A4-terrace: Terrace sediments (situated 20-28 m above present level)
We have described 4 exposures (13, 16, 21 and 30) of this terrace level. The most beautiful exposure is situated near Casapalma. Typical for this terrace level is that it has a reddish brown clayey (illite) soil. The colour of the matrix is reddish, which means strong dehydradation of the iron compound. The mineral, that gives soils its red colour, is hematite. Hematite forms out of ferri-hydrite under favourable circumstances which are a high iron concentration, a low organic content of the soil, high temperatures and a pH higher than 4.0 (Driessen, 1989). An other important mineral in this terrace level is magnetite. It is found in highly weathered soils in the tropics and subtropics. Because magnetite occurs preferently on ultramafic rocks, the terraces of the Guadalhorce are influenced by it, It colours the soil matrix dark (magnetite is black) (Mulder, 1992).
The soil has secundary calcium carbonate accumulations, which are very clear on pebblebottoms. Typical rocks and gravel of this terrace level are limestones, slates, sandstones, ultramafic rocks and quartzite. Typical for this level is the presence of quartzite. The biggest in size are sandstones and the smallest are slates. The sorting is bad and the weathering degree of this terrace level is medium.

A5-terrace: Terrace sediments (situated 60 meter above present level)
We described only two exposures (15 and 18) of this terrace level. One of these two is situated near Cerralba and the other one between Villafranco de Guadalhorce and Cártama.
The surface of the soil is dark-greyish with secondary calcium carbonate accumulation. The dominant rocks of this terrace level are limestones and slates. Less dominant are sandstones, gneisses and ultramafic rocks. The weathering degree is high and the cementation of calcium carbonate is strong. The sorting of this terrace level is bad. The particle size of the terrace level is small, mainly gravel (big rocks have fallen apart by weathering to smaller fragments). Under this terrace we found Pliocene marine deposits. The marine deposits are clayey and calcareous.

A6-terrace: Terrace sediments (80-90 meter above present level).
This terrace level is only described by one exposure. The exposure has a thickness of 3 meter and lies at 2 kilometers distance from Pizarra on the opposite side of the river at a height of

about 157 meter above present sea level (exposure 23).

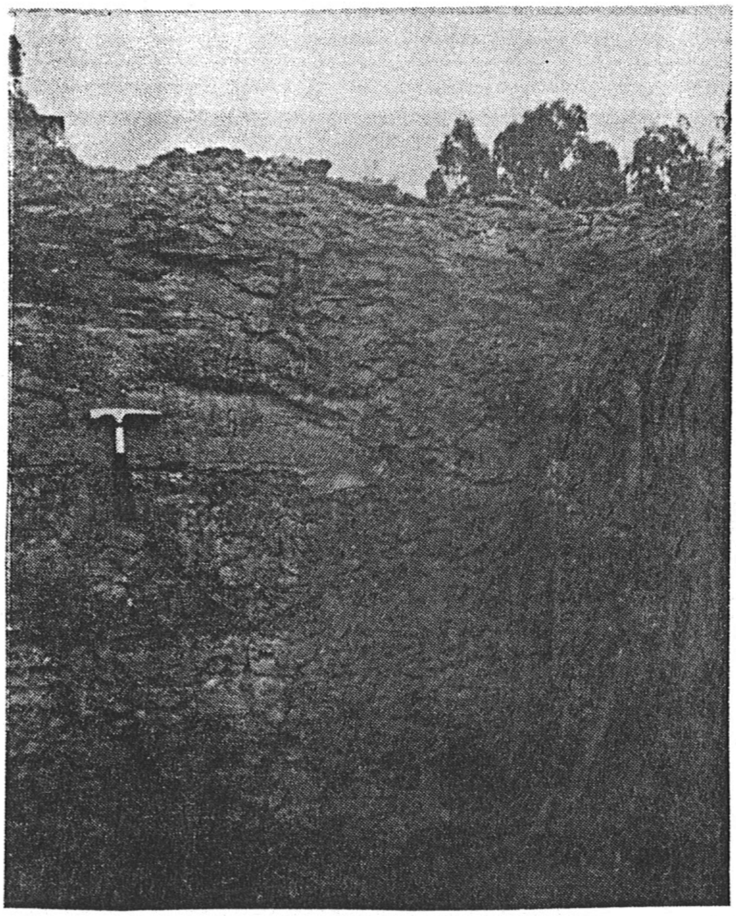


Figure 4.7. Picture of exposure 23. Visible is the sharp boundary of the fluvial terrace with the underlaying Pliocene marine deposits

The colour of the surface is greyish. The rock types of this stony, gravelly material consist of sandstones, limestones, gneisses, slates and ultramafic rocks. As is also to be seen in the terraces of other levels, the sandstones form the bigger stones, due to the fact that they are the most resistant rocktype to weathering. The weathering degree and the cementation of calcium carbonate of this terrace is high.
The terrace remnants of this level are the oldest ones in the area and can be found on the higher spots in the study area. Probably this terrace is formed shortly after or during the maximal transgression phase of the sea in the Villafranchian. This terrace has protected the underlaying material against erosion.

Beside these six major river terrace levels we have also found one other level. This level is only represented by just one exposure and because we don't know its age, we have not separated it to a lonestanding terrace. Other reason that we didn't specify it as a terrace is because we don't know for sure that it belongs to the Guadalhorce.

A7-sublevel terrace: Terrace sediments (45 meter above present level)
We described only one exposure and this one is situated on the opposite side of Álora, near Álora Estacion. The exposure consists of fluvial material with a particle size of gravel. There are only a few little stones in this material. The gravel lies on marine sands and consists of (garnet)schists, limestones, quartzites and slates. Schists are predominant (about half of the total amount of material) and ultramafic rocks are rare. They are rare because we are in the northern part of our study area and there are no ultramafic mountains in this part. The weathering degree is high.
The marine sands are typical beach sands, which are very angular (sharp). This is due to the fact that the pebbles have only travelled over a short distance and didn't have the time to get rounded.
We have also found some remnants of these terrace level on the Alora side of the river, near the castle of Álora.

4.4.2. RIO GRANDE

We have described only one terrace level of the Rio Grande. It is situated about 40 meter above the present level of the river. The Rio Grande starts its way to the Guadalhorce in a massif of periodotite (Serrania de Ronda). Some tributaries of the Rio Grande come down from the mountain chain the Sierra de las Nieves, which consist of mainly limestones. Further downstreams the Rio Grande crosses an area that consists of flysch deposits. Although we find some gneisses and schists it is very understandable that the main rock types are ultramafic rocks, limestones and sandstones. The weathering degree is medium and the cementation of calcium carbonate is strong. This is relied on the fact that the soil on this terrace level shows secondary accumulation of calcium carbonate in the soil matrix.

4.4.3. ARROYO DE LAS CAÑAS

The Arroyo de las Cañas flows from a mountain chain near Carratraca. Its upper watershed lies in the serpentinite (Sierra de Aguas) and flysch deposits and thus the river supplies a large amount of serpentinite. Near the exposure the river has cut its way in the marine deposits and shortly after the exposure the river streams into the Guadalhorce. The influence of the Cañas on the total amount of material in the Guadalhorce is clearly visible in the terraces. After the confluence of the Cañas and the Guadalhorce, the material contains much more ultramafic rocks than the Guadalhorce had before this confluence.

The Arroyo de las Cañas has two terrace levels. The highest one has its main exposures between Zalea and Pizarra. The level of these terraces lie 70 meter above present river level and have both a thickness of about 2 meters. One is situated 155 meter (exposure 7) above present sea level, while the other one lies 143 meter (exposure 9) above present sea level.

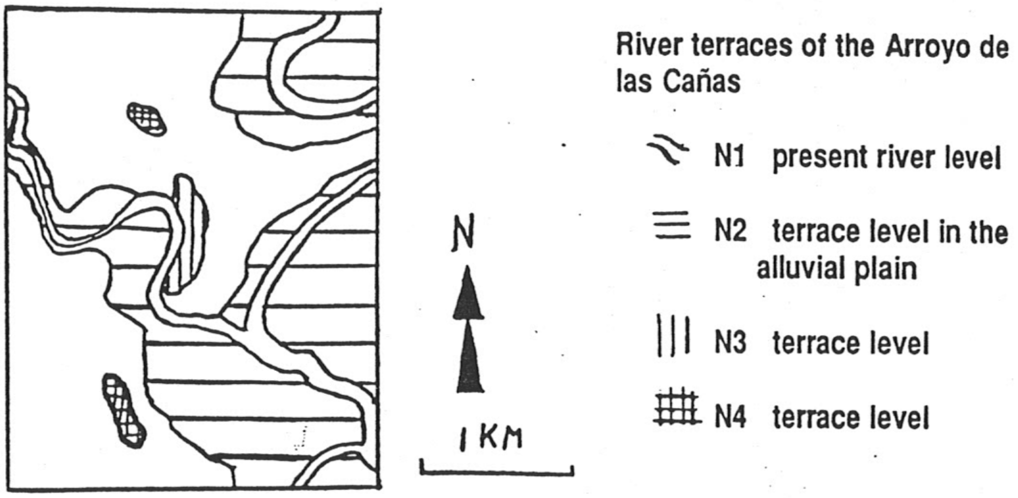


Figure 4.8. Location of the terrace levels of the Arroyo de las Cañas.

This terrace level is formed in the same period, we suspect, as the A6-terrace of the Guadalhorce. Thus it is formed in the maximum transgression period, (which happened to be) in the Villafranchian. The fluvial terraces are situated above the delta deposits.

The second terrace level has one beautiful exposure. The exposure has a length of about 200 meters and a height of 12 meters. The location of this magnificent exposure is between Zalea and Pizarra. The composition of rock types is the same as in the higher terrace. Also the degree of weathering is comparable (high) mainly due to the enormous amount of ultramafic rocks. Below the exposure are a lot of slumps. The gravel layer is about 4 meter thick, and a clay-rich layer has formed in this layer.

In this clay layer (which itself don't include gravel material), bands of reduction and oxydation are visible. The gravel layer is strongly cemented by calcium carbonate.
Below the gravel layer there are two big other layers, one of clay (immediately below the gravel layer) and the other of sand. The clay layer shows also as the other clay layer in the gravel layer bands of oxydation and reduction. In the sand layer there are also small clay layers. These two layers are Pliocene marine deposits.
Both river terraces are very well preserved and have a thick, strongly weathered, reddish brown soil with calcareous nodules. The soil is rich in smectites. The reason is simple because smectites are the weathering product of serpentine. The smectite formation happens not in situ in the soil. About half of all the stones and gravel consist of serpentines, 30% consist of limestones and about 10% are gneisses. The remaining 10% consist of quartzites, (garnet-)schists and sandstones. The serpentines form in general the smaller particle size part while the bigger stones are mainly the sandstones, limestones and gneisses. The weathering degree varies from rocktype; the gneisses, serpentines and (garnet-)schists are rather weathered, while the limestones and the sandstones seem untouched by weathering processes.

4.4.4. ARROYO DE CASARABONELA

We have described four exposures of the Casarabonela and have found three different remnant terrace level. All the exposures are found at the right side of the river, so the river has probably been shifted northwards through time. The terrace levels are estimated on 20-25 m, 40 m and 50 m above the actual river level of the Casarabonela. The river rises from the Sierra Prieta (1521 m, a part of the Sierra de las Nieves). A big part of the Casarabonela streambed lies in flysch deposits and smaller parts in serpentinite rocks (part of the Sierra de Aguas) and schists and slates (Sierra Gibralgalia). All the terraces that we have determined are located near Cerralba. The river Casarabonela supplies a large amount of slates, which is in contrast with the Rio Grande and the Cañas.
The 20-25 meter terrace level.
We have described two exposures of this terrace level. One is situated along the road near Cerralba and the other one is situated at a eucalyptus plantation and lies one kilometer west of Cerralba. Both exposures show obvious a fining upwards sequence. The soil of this terrace level is thin and red-coloured. The gravel layers consist of slates (the most abundant rock type, about 40%), ultramafic rocks, sandstones and limestones. The

weathering degree of the rocks is medium and the cementation of calcium carbonate is strong. The stones are not very rounded which means that the stones are deposited near their original formation place.

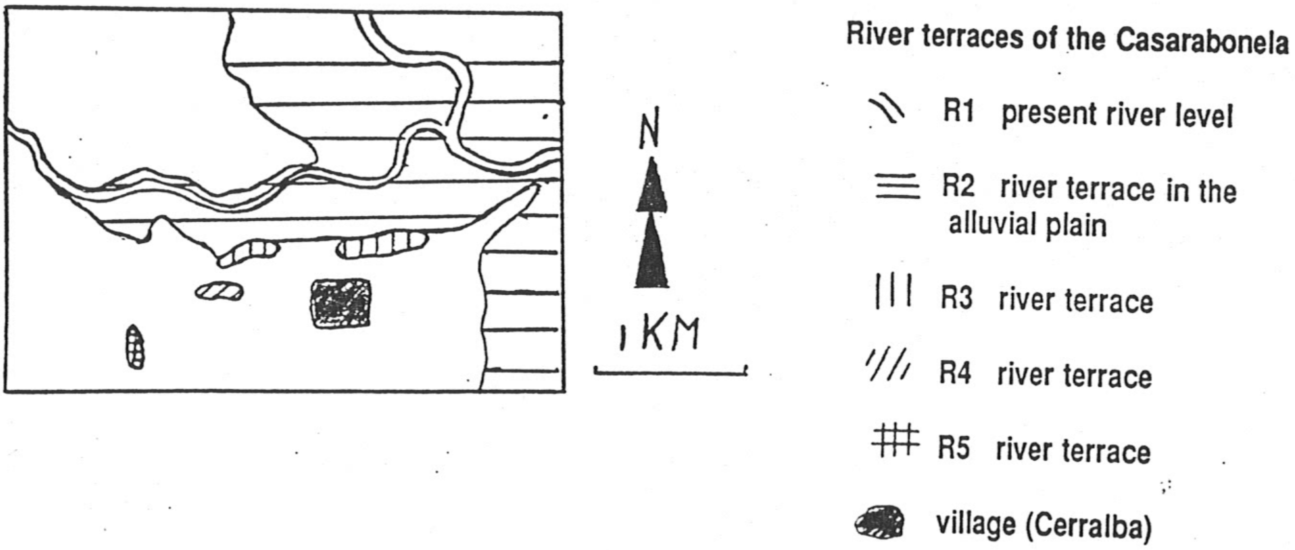


Figure 4.9. Location of the terrace levels of the Arroyo de Casarabonela

The 40 meter terrace level.
This terrace can be found near the road, but the material has slumped, maybe during the road construction. It has somewhat the same features as the 20-25 meter terrace but the stones are more rounded. The sorting is bad and the cementation is strong. Dominant rock type are slates while other types are sandstones, limestones, ultramafic rocks, gneisses and quartzites. The weathering degree is high. In the exposure also clay pebbles occur and on top of the exposure lies a red soil which contains a lot of small, rounded pebbles.
The 50 meter terrace level.
We are not sure of this exposure represents the top of this terrace level. In a way it seems to be truncated by erosion, though it lies in situ. The height above present sea level is 123 meter and the height of the exposure is less than a meter. Rock types are ultramafic rocks, slates and also sandstones and limestones. There is almost no cementation of calcium carbonate and the weathering degree of this terrace level is very high.

4.5. OTHER FLUVIAL SEDIMENTS IN THE VALLEY GUADALHORCE

The valley of the Guadalhorce was during and after the Villafranchian transgression influenced by alluvial fan formation. An alluvial fan consists of coarse sediments of shifting channel of braided rivers. It develops where the gradient of a stream decreases and that is at most cases where a river enters a floodplain. There the sediment load of a river can no longer be carried and most of it is dropped right at the entrance to the plain. This rapidly blocks the channel which then sweeps left and right to obviate the obstacle. An alluvial fan has often a grain sized gradient, coarse near the entrance to the plain and fine far into the plain (Driessen, 1989).

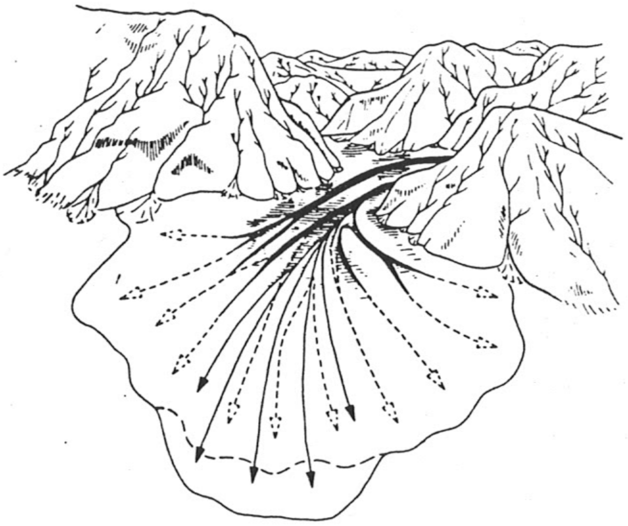


Figure 4.10 Building of an alluvial fan (Source Summerfield 1991).

The soils on the alluvial fans in the study area grade from a well defined reddish clayey soil at the top (deep dissection, 45-60% clay, 20% stones), to a very young, hardly to developed to loamy soil at the bottom (no dissection, 10-15% clay, 0% gravel) (Wielemaker,1992).In contrast to the fluvial deposits, alluvial fans consist exclusively of local material, deposited from nearby mountains. The rock fragments in the fans are typically angular, also in contrast to the rounded river gravel (Kroonenberg, 1992). The tributaries and the Guadalhorce river itself supplied very much sediment load from the mountains, which were uplifted by the Alpine orogeny. The alluvial fan deposits are deposited in whole the Guadalhorce valley. Big areas of alluvial fans are deposited in the south-eastern part of the study area.

Acording to french authors, who were working in the mediterranean areas, the coarse grained alluvial fans and sheet-wash deposits on pediment like surfaces are called "glacis".

In the western part of the Cordillera and in the depressions, Lhénaff (1981) has found only small glacis, which are always related to terrace levels. This supports the hypothesis of Solé-Sabaris (1964) that a subhumid climatic tendency in an area produces a greater development of fluvial processes, and thus of alluvial terraces, to the detriment of glacis development which is optimal in a semi-arid environment.

Some Spanish authors (Lopez-Bermudez et al) have found that one glacis level belongs to the Villafranchian period (Embleton, 1984). Thus, some alluvial fans in our area were formed in combination with delta formation in the valley of the Guadalhorce.

5. SAND BULK GEOCHEMISTRY OF SEDIMENTS IN THE GUADALHORCE VALLEY

5.1. INTRODUCTION

As Quaternary research is more and more interested in the quantitative aspects of major environmental changes, it will be necessary to develop new quantitative methods. A way to determine quantitative paleohydrological changes is by studying the changes in bulk composition of fluvial sediments (Kroonenberg, 1990). As it is rather cumbersome to derive a bulk composition from the mineralogical composition of separate fractions and point-counting of thin sections is time consuming; so it was decided to measure bulk sand composition geochemically. In this study fluvial deposits of the Rio Guadalhorce and its tributaries (Arroyo de las Cañas and Rio Casarabonela) were sampled in various exposures of different fluvial terraces and delta deposits and turbidites.

Several regional and local factors have a significant contribution on the actual bulk sand composition in the Guadalhorce drainage basin. The most important local factors are sorting processes and post-depositional weathering. The factors provenance and changes of sediment compositon in time have a more regional character and are of interest for Quaternary research (Veldkamp, 1991).

5.2. MATERIALS AND METHODS

All the samples of the study area were taken from exposures in the valley of the Guadalhorce. From these exposures, samples were taken as deep as possible in the profile to avoid effects of soil formation. In total 29 locations were sampled which led to a total of 69 different samples. The fluvial deposits of the Guadalhorce terraces were sampled on 12 locations (total of 17 samples) along a section between the two bridges of Álora and Cártama (27 kilometer along the river). The sample locations are situated in the four highest terrace levels (A3, A4, A5 and A6). Besides the fluvial terraces of the Guadalhorce some terraces of the tributaries were sampled. The Arroyo de las Cañas was sampled on 3 locations (in total 3 samples) and the Rio Casarabonela on 3 locations (in total 3 samples).

Further more the delta deposits were sampled on 6 locations with a total of 34 samples. This high figure is due to the fact that from one big profile, which consisted of marine/delta Late Pliocene sediments (exposure A), 24 samples were taken. Besides these terraces and delta deposits also turbidites were sampled.

This was done on 5 locations with a total of 12 samples.
While sampling, care was taken to sample as much as possible sand from foreset laminae in small scale cross-bedded sets in order to avoid concentrations of heavy minerals in horizontally laminated lag deposits. Samples were taken as deep as possible to avoid effects of soil formation.
At first all sediments were dried and sieved by a two-millimeter sieve. The reason of sieving is to get a one size fraction. It is common practice in exploration geochemistry to sample only one size fraction from stream sediments in order to obtain measurable and comparable results, because the concentration of many elements is strongly grain-size dependent. Just a few, random taken, grams of the sieved material were used for further investigations. First the samples were ground in a tungsten-carbide mill. Next the samples were weighed in cups and put in an oven at 105 °C to get them air-dry. The samples were weighed again and put in the oven again at a temperature of 900 °C for at least 4 hours for determination of loss on ignition. This is done by weighing the cups again. The loss on ignition is calculated with the next formula:

$$\frac{W\ (\text{grams at } 105\ ^{o}\text{C}) - W\ (\text{grams at } 900\ ^{o}\text{C})}{W\ (\text{grams at } 105\ ^{o}\text{C})} \quad *100\%$$

Loss on ignition is the loss of organic matter and water of crystallization and absorption (Locher, 1990).
After this determination of the loss on ignition from each soil 0.6 gram of the samples were taken and mixed together with 2.4 gram lithium tetraborate to form a glass bead. The major and minor elements were measured with X-ray fluorescence spectroscopy on a Philips XRFS assembly. (Further details in Appendix III.) The system was calibrated using USGS Geochemical standard as listed by Abbey (1980).
Analytical results summing <98% or >102% were repeated until a sum within these limits was obtained. In Appendix IV the bulk geochemical measurements of the Guadalhorce and its tributaries are listed. Also in this appendix the measurements of the turbidity currents and the delta deposits of the Guadalhorce valley are given. For each sample the following data are listed:
sample number, terrace code, x-coordinate, y-coordinate, absolute and relative altitude (m), content in % of SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, BaO, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Zr, Nb, Ba, La and Pb.
The following two remarks are necessary to interprete the data of the XRFS-analysis:

- impurities are present in the samples because of use of apparatus made of Tungsten alloy (causes Co-, Ni-, and W-impurities (Tiemensma, 1992).

- the contents of BaO, NaO, Co, Ga, La and Nb are for some samples around the detection limit and therefore of limited value.

Statistical treatments were performed with SSPS and FACTOR software packages. The interpretation of the complex multivariable data set was carried out using factor analysis. Factor analysis examines the interrelationships among the variable (elements) in an effort to find a new set of variables (factors) fewer in number than the original set of variables, which express that what is common among the original variables (Veldkamp, 1991).

A factor analysis is presented as a matrix giving the factor loadings of each variable. A factor loading indicates the relative contribution of a variable to the factors made; the larger the loading, the more important the variable in the interpretation of the factor.

5.3. FACTOR ANALYSIS OF ALL THE SAMPLES IN THE STUDY AREA

The Guadalhorce sand data set is divided in two groups, one consists only of macro and the other one consists of micro elements.

The macro elements are described by three significant factors, together explaining 87.2% of the total bulk geochemical variance.

Factor 1, explaining 46.5% of the total variance, contains the variables TiO_2, Al_2O_3, Fe_2O_3, Na_2O, K_2O, P_2O_5 and -CaO. All the variables show a good positive correlation with each other, only CaO shows a negative correlation with the other elements.

Factor 2, explaining 24.5% of the total variance, contains the variables CaO, L.o.I. (loss on ignition) and $-SiO_2$. A high percentage in the soil of CaO gives a high loss on ignition. This is due to the fact that Ca is often in the soil in the mineral $CaCO_3$, and CO_2 is one of the products that gets lost while heating the sample. That also is SiO_2 is correlated (negative though) is also not strange.

Factor 3, explaining 16.2% of the total variance, contains only two variables MnO and MgO. Both show a good positive correlation. A high content of MnO indicates also a high content of MgO.

The eigenvalues of factor 1, 2 and 3 are respectively 5.11192, 2.69478 and 1.778482.

The sand data set of the micro-elements is also described by a set of three significant factors, together explaining 74.9% of the total bulk geochemical variance. First a list of minerals and some elements . The elements are known "pollutions" of these minerals.

Table 5.1. Minerals and their "strange" elements.

List of minerals and their strange elements (Parferova, 1962)	
Augite	Li, Ni, Co, Zr, Sc, Cr, V, Pb, Cu, Ga
Apatite	Sr, F Pb
Biotite	Rb, Ba, Ni, Co, Sc, Li, V, Zn, Cu, Ga, F, Sr, Cs, Cr
Diopside	Cr, V, Ni, Sr, Ba, Sc
Epidote	Sr, Cr
Garnet	Cr, Ga, Y, V, Zr, Be
Hornblende	Ni, Co, Se, Li, V, Zn, Cu, Ga, Cr, Sr
Magnetite	Zn, Co, Ni, Cr, V
Muscovite	F, Rb, Ba, Sr, Ga, V
Olivine	Ni, Co, Li, Zn, Cu, Mo, Pb
Orthoclase	Rb, Ba, Sr, Cu, Ga.
Staurolite	Zr
Titanite	V, Zn, Cr, Zr, F
Tourmaline	B, Li, F, Ga, Sr, Be, Cu, Cs, Ba, Cr,
Spinel	Cr, V, Se, Zr, Cu, Ni, Co, Sr
Zircon	Zr, Hf, Y, Ce, Nb, Ta, Th, U, Sr, Be

By using this tabel one has an indication of the minerals that can be found in the study area.

Factor 1 explains 48.0% of the total variance, which includes the variables Ba, Cu, Ga, Rb, Pb, V and Zn. The contributing elements are known to occur in many different minerals of the sand, notably olivine, biotite, K-feldspars, micas and staurolite. (see list of Parferova, 1962). Some of these elements can substitute K, especially in micas and Ga can substitute Al. Therefore these micro-elements are logical constituents for this factor (see combination of the two factor analysis).

Factor 2, explaining 18.3% of the total variance, includes the micro-elements Ni, Cr, Co and -Sr. So Sr shows a negative correlation with Ni, Cr and Co. The latter elements show a positive correlation on one another. These elements belong to the following minerals (according Parferova) magnetite, serpentines and spinel. Thus the contributing elements are known to occur in ultramafic rocks (olivines, pyroxenes and serpentines) which derive in the study area from the Sierra de Aguas. Ni and Cr are normally present in "polluted" serpentines.

Factor 3, explaining 8.6% of the total variance, includes the elements Zr and Nb. These elements are common in stable heavy minerals, like magnetite, rutile and zircon. A high Zr content indicates also a high Nb content.

The eigenvalues of factor 1, 2 and 3 are respectively 6.72020, 2.56105 and1.20481. The results can be found in appendix V.

In the second part of appendix V the factors are related to one another. In each individual graph two of the three factors are related to each other.

It is possible, by means of these graphs to find some obvious clusters (groups of exposures). For example, the clayey and sandy samples of exposure A are separated from each other in groups.

In most of the graphs the A-3 terraces and A-4 terraces form also obvious clusters especially when factor 2 of the major elements is involved. The reason that in these factor the differnecs are very clear is due to the fact that there is an accumulation of secundary calcium carbonate. The leaching of minerals is low in comparison to other studies on this matter. This is because our study area lies in an arid area. The rainfall is low and also the intensity of the casual rainfall is not very high. result is that elements do not get washed out of the soil. But soil formation on and weathering of minerals on the other hand is very common. Conclusion can be drawn that the different terrace levels can be determined with the secundairy enrichment of calcium carbonate.

A6 on the contrary is very low in calcium carbonate. This is very strang at first but when you look in detail to th exposure, the explanation could be that it is influenced by the tributaries. (A6 lies near the former confluence with the Arroyo de las Cañas). Another reason not to look to long at this terrace level is because it is only represented by one exposure and errors could be made easily. Turbidites are not grouped very easily, so it is possible to find samples of these deposits everywhere in the graphs.

Some samples of the delta deposits belong to the same group, for example exposure 14 has in a geochemical way the same characteristics as the sandy layers of exposure A and exposure 6B belongs to the same group of the clayey layers of exposure A. Other samples of these deposits can not be grouped.

An example of this are the samples of exposure 19, which is always situated on "isolated" places of the graphs in comparison to all the samples of the study (thus not only the samples of the delta).

The samples of all the terraces of Arroyo de las Cañas form also an obvious group in all the different graphs. In this case bulk sand geochemistry was a good method to analyse different terrace levels, because in a geochemical way exposure 7 and 9 are nearly the same, so it is reasonable that these exposures belong to the same terrace level of the Arroyo de las Cañas. By means of length profile it was not very obvious that these exposure belongs to

each other. Shortly after the maximum transgression the confluence of the Arroyo de las Cañas and the Guadalhorce was situated more southwards than at present.
Arroyo de las Cañas and the Arroyo de Casarabonela are both very different in their minor elements. This is caused by their high content of ultramafic material.
According the geochemistry the samples of exposure 20 (sublevel A7) show the same properties as terrace level A4, but according the length profile of the exposures it is not possible that sublevel A7 belongs to level A4. Therefore the division is made to separate them from one another, but A7 is not taken as a lone standing terrace level, but a sublevel.

5.4. SAND BULK GEOCHEMISTRY OF THE GUADALHORCE AND ITS TRIBUTARIES

5.4.1. INTRODUCTION

Fluvial terraces are mainly formed by a complex interplay of changes of the external factors climate, tectonism and base level. These factors are directly or indirectly reflected in the composition of the resultant sediments. Sediment composition is also controlled by local factors such as sorting processes and post-depositional weathering. Major changes within a fluvial system do not only change sediment granulometry and mineralogy, but also the quantity of sediment delivered to the river. The total sample composition quantitatively reflects such changes.
As Quaternary research is more directed towards the quantitative aspects of major environmental changes, it will be necessary to determine such changes by studying the bulk composition of fluvial sediments.
From the river the Guadalhorce were sampled all the different terrace levels were sampled and besides this river, also some fluvial deposits of the rivers Arroyo de Casarabonela and de las Cañas were sampled. The geochemistry of the deposits of the latter are characterized by an enormous high rate of ultramafic rocks.

5.4.2. RESULTS AND DISCUSSION

From the analytical data of the fluvial sediments of the Arroyo de las Cañas and the Arroyo de Casarabonela it is clear that all the sandy sediments are relatively high in TiO_2, Al_2O_3, Fe_2O_3, MgO, Cr, and Ni and low in CaO, in comparison to the Guadalhorce deposits. The main reason that these rivers are high in these elements is the occurence of ultramafic rocks in their watershed. These rocks consist predominantly of olivine (peridote). The chemical formula of olivine is $(Mg,Fe)_2[SiO_4]$, so it is easily to understand that the fluvial deposits of the Arroyo de las Cañas and the Arroyo de Casarabonela, which stream from the ultramafic rich Sierra de Aguas, are rich in MgO and Fe_2O_3. Ultramafic rocks are almost always polluted by Ni and Cr. Thus it os not very strange that the fluvial deposits of the Cañas and Casarabonela water basin are also rich in Ni and Cr.

Arroyo de las Cañas has a higher content of MgO and a lower content of CaO than the Casarabonela.

All the fluvial sediments of the Rio Guadalhorce which are situated downstreams of the confluence of the Guadalhorce with the Cañas show a higher content of Cr and Ni than the deposits upstreams of this confluence.

The A3-terrace levels are (normally) richer in MgO, Na_2O, P_2O_5, Cu, Ga, Pb, Rb and V, than the A4-terraces. A4-terraces on their turn have a higher content of MgO, P_2O_5, Pb, Na_2O and Rb than A5-terraces. There is a clearly visible trend through the age of the levels. A5 is older than A4 which is on his turn older than A3. The trend is a decrease of MgO, Na_2O, P_2O_5, Pb and Rb in time. The reason of this trend is probably post depositional weathering.

Terrace A5 is rich in CaO and is probably due to the fact that secundary accumulation of calcium carbonate has occured. Probably this could also be an indicator to find the relative age of the different terrace levels.

In the study area there is only one exposure of the A6-terrace level of the Guadalhorce. This exposure (23) is situated near to the former confluence of the Arroyo de las Cañas and the Rio Guadalhorce. The deposits of this exposure are therefore in a geochemical way influenced by the Arroyo de las Cañas. In comparison to the fluvial deposits of the Arroyo de las Cañas exposure 23 is low in MgO, Cr and Ni and high in Na_2O and P_2O_5. It is very difficult to compare this A6-terrace level with the other terrace levels of the Guadalhorce in geochemical way, because it is influenced by the Arroyo de las Cañas.

5.5. SAND BULK GEOCHEMISTRY OF DELTA DEPOSITS

5.5.1. INTRODUCTION

The delta deposits were sampled at 6 different locations and with a total of 34 samples. The locations are situated at different heights above present sea level. Three sample locations are situated about 150 meters above present sea level (exposures 19, 25 and 34 see Appendix I). These locations are typical examples of top-set beds of a Gilbert-delta.

Exposure 6 and exposure A are examples of fore-set beds. The delta deposits of exposure 6 are overlain by fluvial depposits of the river Arroyo de la Cañas. Exposure A is a big exposure in the Villafranchian marine/delta sediments. From this exposure 24 samples were taken, so this exposure is also a reference to other sediments in the area.

Exposure 14 is an example of a bottom-set bed, which can be seen in the amount of clay. This exposure 14 is rich in montmorrilonite clay.

All these deposits were sedimented during the Villafranchian.

5.5.2. RESULTS AND DISCUSSION

Exposure A is an excellent exposure to compare the sand bulk geochemistry of sediments with other remnant delta deposits and it is situated near the confluence of the Rio Grande and the Rio Guadalhorce. The remnant delta sediments are rich in MgO, CaO (but relativetely poor in comparison to other deposits in the area) and are relatively poor in NaO, Cr and Ni. In exposure A shows an obvious accumulation of SiO_2 in the sand layers. These sand layers are low in TiO_2, Al_2O_3, $_{Fe}2O_3$, MnO, MgO, Na_2O, K_2O, Cr, Cu, Ga, Pb, Sr and V and are high in Co, Ni. The reason that so many elements are low in percentage in the sand layers in comparison with the clay layers is due to the higher SiO_2 content in the sand layers.

In comparison to the other delta deposits in the study area, exposure A is relatively rich in CaO and poor in SiO_2.

In geochemical way exposure 6 has nearly the same composition as exposure A. Exposure 14 is relatively poor in Fe_2O_3, MgO, Cu, Sr and Zn.

Of the top-set beds exposure 19 is in comparison to exposure A very rich in TiO_2, Al_2O_3, Fe_2O_3, Na_2O, K_2O, P_2O_5, Ba, Cu, Ga, La, Rb, V, Zn, Zr and low in Sr. Exposures 25 and 34 form in general a geochemical transition between exposure 19, which is enormous rich in some minor elements, and exposure A.

Exposure 14 differs from the other exposures because it is low in K_2O. This is caused by the fact that the surrounding area is rich in montmorrilonite clay and not in illite as is in the areas around the other exposures.

Conclusion is that there is a geochemical gradation, which evolves across the "remnant" delta. The top-set beds are relatively rich and the bottom-beds are relatively poor in the elements Fe_2O_3, Cu and Zn. The delta deposits show the highest percentage of SiO_2 of all the deposits in the valley, but in comparison to the sands of the southeastern part of the Netherlands (Kroonenberg, 1990), the Allier basin (Veldkamp, 1991) and the Caucassus (Tiemensma, 1992), the samples of the Guadalhorce basin are low in SiO_2. The reason that all the samples of the study area are relatively low in SiO_2 in comparison to the three other regions is caused by the fact that there is a high percentage of CaO and MgO in the samples.

5.6. SAND BULK GEOCHEMISTRY OF TURBIDITES

5.6.1. INTRODUCTION

The turbidites are sampled on 5 different locations. These deposits are situated in the northern part of the study area, and are also found north of Álora. These deposits are probably older than the "remnant" delta deposits. The confluence of the Cañas and the Guadalhorce was at that moment situated more to the north than the present confluence, nearby point 17. This was probably some time before the maximum transgression phase in the Pliocene. In the Pliocene the valley was very deep, a kind of (submarine) canyon in which turbidites occur are normal.

5.6.2. RESULTS AND DISCUSSION

In some way it seems that there are two different turbidites. Exposure 5 is different from exposure 17, which had its provenance in an other area. One (5) came from de direction of El Torcal and the other one (17) from the direction of the Sierra de Aguas. The other exposures show a transition between these "extremes". In general the turbidites are high in MnO, CaO, MgO, Cr and poor in Na_2O, K_2O, Ga, Cu, and the Sr content of all the samples was the same some 140 ppm.

In comparison to exposure 17, exposure 5 is high in SiO_2, TiO_2, Al_2O_3, Fe_2O_3, K_2O, BaO, Rb, V and low in MgO, Na_2O, Co and Ni. Very characteristic for the big exposure 17 is its high content in Ni and Mg, which is almost the same as the fluvial deposits of the Arroyo de las Cañas and the Rio Casarabonela. Further exposures 12 and 24 are rich in Co in comparison to the other samples of the turbidites.

6. LONG TERM MODELLING OF RIVER TERRACE FORMATION

6.1. INTRODUCTION

Within geomorphology the use of long term models has increased strongly in recent. As geomorphological theories have mostly been validated for small spatial and temporal scales only, they are not necessarily appropriate for the larger range of scales. Constrains in the development of longterm geomorphological models are therefore mostly due to the relationships between conceptualization and scale. Especially longterm simulations are hampered by the lack of large scale quantified knowledge. There are two main reasons, for this poverty:

1) As only short-term processes are measured in experimental studies we can only guess at the quantitative effects of the long term processes.

2) Every scale has its sets of laws. Due to these scale effects, extrapolation of experimental results to large scales will certainly lead to considerable errors.

It is very difficult to fill the gaps in geomorphology, because some things are not known and never will be. There is not much that can be done about the scale problem, just beware of the fact that it excists (Veldkamp, 1991).

An important step in long term modelling is the determination of the scale dependent system variable hierarchy. The system and process variables are listed in hierarchy with increasing degrees of dependence. Depending on the time span involved, time may be either an extremely important independent variable or a relative little significance to a geomorphological study (Schumm, 1965).

Another scale modelling aspect is the source scale of the used numerical relationships in the model. This scale aspect can be determined by a systematic scale analysis. Such a scale analysis is based on the assumption that relationships can only be used in a model when they are applied on the same scale as on which the original measurements were done. The scale analysis can be done in a very similar way as the commonly applied unit analysis, except that not only the units should match but also their magnitude. Such a model scale analysis can be applied succesfully for relative short time spans. On such scales, a model scale analysis should be incorporated as a standard procedure in geomorphological modelling (Veldkamp, 1991).

When a scale analysis is strictly applied on longer time spans, thousands of years or even longer, it can be concluded that reliable quantitative modelling is actually impossible. Most knowledge on such timespans is descriptive and interpretative. But it is the large time scale which attracts many geomorphologists as most landforms are the result of long term processes. The scale problem is "solved" by a number of assumptions. In such cases it is assumed that a short time span relationship can be extrapolated to a longer timespan. A very creative solution is given by Tetzlaff & Harbaugh (1989) who used 'compute-and-drift' and 'compute-and-stop' schemes to overcome long time spans. These schemes use short term calculations for longterm simulations. In case a direct application of such a relationship does not work out properly, a scale (tuning) factor is included to obtain more realistic results. It is obvious that this approach obscures the lack of knowledge and suggests a simple straight forward solution of the scale problem which certainly does not exist.

Another approach of long term modelling is to abandon the goal to make a full numerical model, as there is to less quantitative knowledge for that purpose. Consequently it is decided to use also the knowledge which is sufficiently available, qualitative descriptive relations. Modelling with both quantitative and qualitative relations can be done with finite state modelling (Veldkamp, 1991).

A finite state model describes a system which can be in different states at different times. The basic principle of finite state modelling are to choose a finite sets of inputs, states and outputs, and to specify for each state combination one and only one transition to another state in case a change in state takes place.

A system behaviour can be represented as a finite state model in a scheme, flowchart or table, showing the system states and state transitions, including the conditions when changes of state take place. The state descriptions and transitions can be as well descriptive as quantitative.

The most uncertain and difficult part of finite state modelling is extracting the qualitative information from literature. A major problem is that descriptive knowledge contains many uncertainities, but if a computer language is used you have to make clear decissions, known as 'rules'. When you take the simple and limited syntax of PASCAL (which is used for this long term model) into account you have to deal with rules such as:

1) No uncertainities, a state exists or does not (true or false).
2) The reasoning and combining can only be done with the use of AND, OR, THEN, UNTIL, CASE, FOR ... DO, IF ... ELSE, REPEAT ... UNTIL, WHILE ... DO etc. (Findlay, 1981).

One can conclude that finite state modelling, allowing the application of qualitative descriptive relations in a model, is proposed as an alternative strategy for long term modelling in geomorphology. By this kind of modelling the computer is not only used as a calculator but also a reasoning machine. The computer makes the decissions.

The model is given in Appendix VI. Only one the part with the values obtained from field data is given. Of course this has a reason. The model is not published yet in its present form and because we did not make it, we can not and will not publish it in this report.

6.2. RIVER TERRACE FORMATION, MODELLING AND 3-D GRAPHICAL SIMULATION

A fluvial system in dynamic equilibrium is able to adjust itself to changes of external variabilities by changing its internal variables like channel depth and width, river roughness, mean velocity, channel form, and slope. River terrace formation is caused by changes of the equilibrium due to climate, base level and tectonic (Veldkamp, 1991). Formation of river terraces is thus a very complicated business. To create a model which includes all these changes is very hard because it involves a very long time span in which a lot of factors are not known. Though many scientists have tried to make a computermodel which tries to explain and reconstruct the formation of river terraces. The model used in this study is written by dr. A. Veldkamp and presents river terrace formation, written in PASCAL and run on a VAX 8600.

The model calculates the influence of a fluvial system on the relief of an area with macroscopical dimensions (10 km x 10 km X 0.5 km) over a period of 2 million years. The initial settings are set at zero. The model does not deal with mountain building that has happened before this time. Relief is also set at zero and this is of course a big assumption. The idea behind this is that relief that was formed before these 2 million years have already been diminished by erosion.

Model input relies on uplift and alternations in discharge and sediment load as a function of climatic changes. The output of the model are 3-dimensional grid drawings which visualize the impact of uplift, discharge and sediment load on a landscape. Model formulation is based on empirical information on fluvial systems, which was incorporated in the model by means of a slighty adapted way of finite state modelling in which decisions act as thresholds. The model produces plausible (x,y,z) and (x,y,t) plots in the light of existing geomorphological theories. At each time step (of 1 ky) a certain scenario is considered to compute model behaviour. Calculations of the volume to erode or to deposit were followed by state determinations and calculationsd which determine the boundaries of relief changes and the processes which change the landscape.

The described modelling procedure shows that it is possible to simulate river terrace formation three dimensionaly with the use of empirical information (Veldkamp, 1991).
One of the aims of the study was to prove this model for the river Guadalhorce in Spain. By lack of time it was impossible to get to know all of the programm or to use every possibility it has in it. Therefore the simulation was only done, with the best information obtained from the field data, to draw pictures of the area similar to the reality. The result can be seen in clearly drawn 3-dimensional grid drawings, and these drawings are achieved by fitting the parameters by trial and error.

6.3. A 3-D MODEL OF FLUVIAL TERRACE DEVELOPMENT IN THE GUADALHORCE BASIN

6.3.1. INTRODUCTION

River terraces are a fundamental part of fluvial landscapes. How they are formed has always been a "gordian knot" to many researchers. Could the formation of terraces be linked to geological, geomorphologicalm or paleohydrological events. A few events are of influence on the formation of terraces. For instance climatic and sea level oscilliations seem to be linked to terrace formation. The combined effects of climate and tectonism on general terrace stratigraphy during the last 2 million years in the Guadalhorce system are simulated by a 3-D conceptual model.
Climate is important for the simulation. The Quaternary has known many astronomically controlled mondial changes in climate, which can be very satisfactory described by Milankovics curve (Berger, 1978). A climatic change leads to an effect on the discharge and the sediment load. In this model the assumption is made that there is a linear relation between fluvial dynamics and climate effects.
During glacials much water is stored in glaciers and rivers have only little water. Due to these drier and colder glacial environments the vegetation cover decreases causing an increase in the erodibility of the landscapes and thus an increase in the sediment load of the rivers. Interglacials show the opposite effect. Glaciers can not be expected in the Guadalhorce basin, but that there is an influence of the glacials on the amount of water in the Guadalhorce that is for sure.
To fit these (inter)glacials in the model the figures of the Milankovics curve are set at figures that can be divided by 1000 (Veldkamp, 1991).

The other important factor for the model is tectonism. Tectonism is divided in two major components in this program. A component of gradual uplift of the whole simulated landscape and an uplift rate of the landscapes on both sides of the Guadalhorce. The latter component is not used in this study for the Guadalhorce river. This is due to the fact that there is no evidence of a different uplift rate on one side of the river. The calculations have estimated the uplift of the study area to be around the 0.08 meters/1000 years.

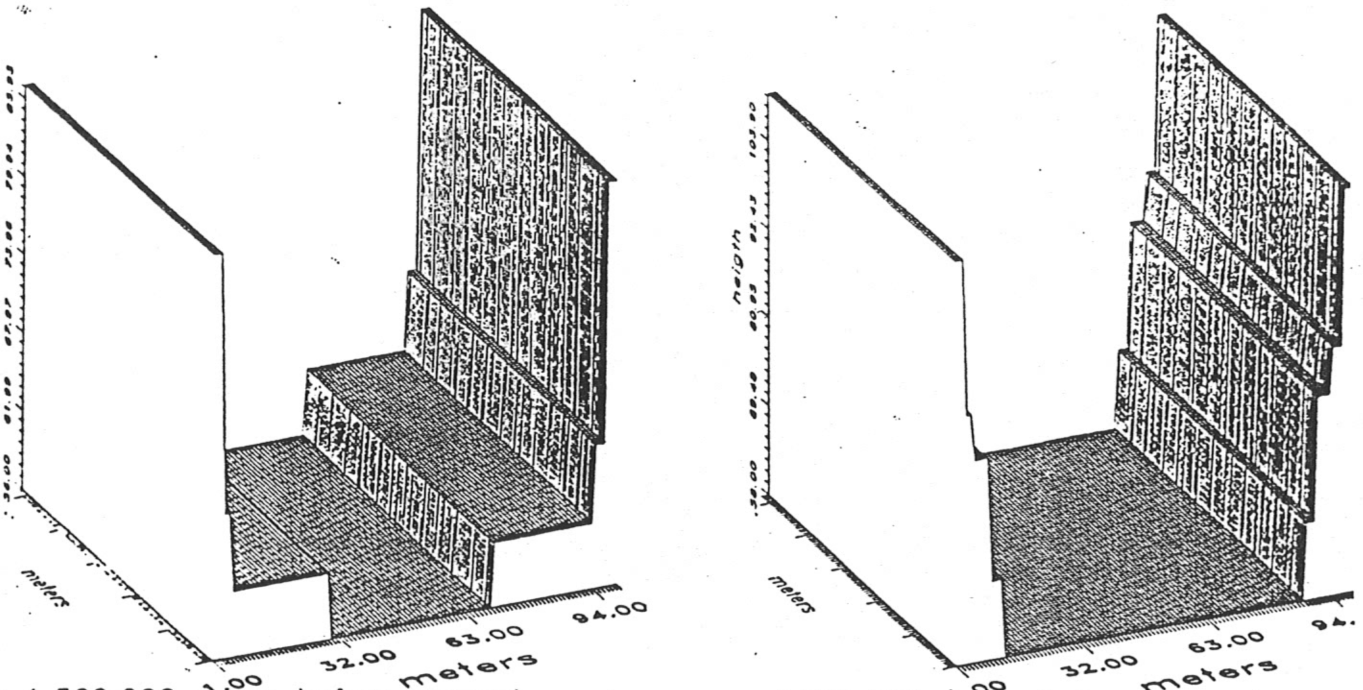
6.3.2. RESULTS

The parameters used to fit this model are achieved by trial and error. First they have been measured with field data and afterwards they have been "manipulated". The model itself can be seen in apendix V. For model purposes the simulation starts 2.000.000 years ago, and the relief starts at 65 meter (Zmid). This done because the lowest part in the cross section near Pizarra lies at 65 meter. For the model an area of 10.000 by 10.000 meters is taken. This is because the model needs a square and the information important for the simulation are spread over a distance of about 10 kilometers along side the river. Qtekgem is set at 0.09 because the heigth difference was 155-65=90 meter. 90 meter uplift in 2.000.000 years is the same as 0.09 meter in 2000 years. Conesa and Duran (1988) have estimated the present amount of water in the Guadalhorce river. They have measured that it is 13 m^3/sec. But the situation is today is very different from the past. Today there are artificial lakes where water will evaporate in the air and there are to big canals which also drain water from the Guadalhorce. Therefore the figure of 13 m^3/sec is not quite realistic. By trial and error 95 m^3/sec with an amplitude of 80 seemed to be the best. The same proces of trial and error was done by the amount of material in the water. The Inlgem was estimated at 0.12E-3 with an amplitude of 0.1E-3. An other important figure for drawing the 3-dimensional grid drawings is the flux. The flux says something about the (in)stability of the system. The expectations of the Guadalhorce terrace formation is that it is rather unstable, therefore this figure is set at 5. The input factors are shown in table 6.1. The total list of information is given in Appendix VI.

Table 6.1. The major factors used in the 3-D simulation

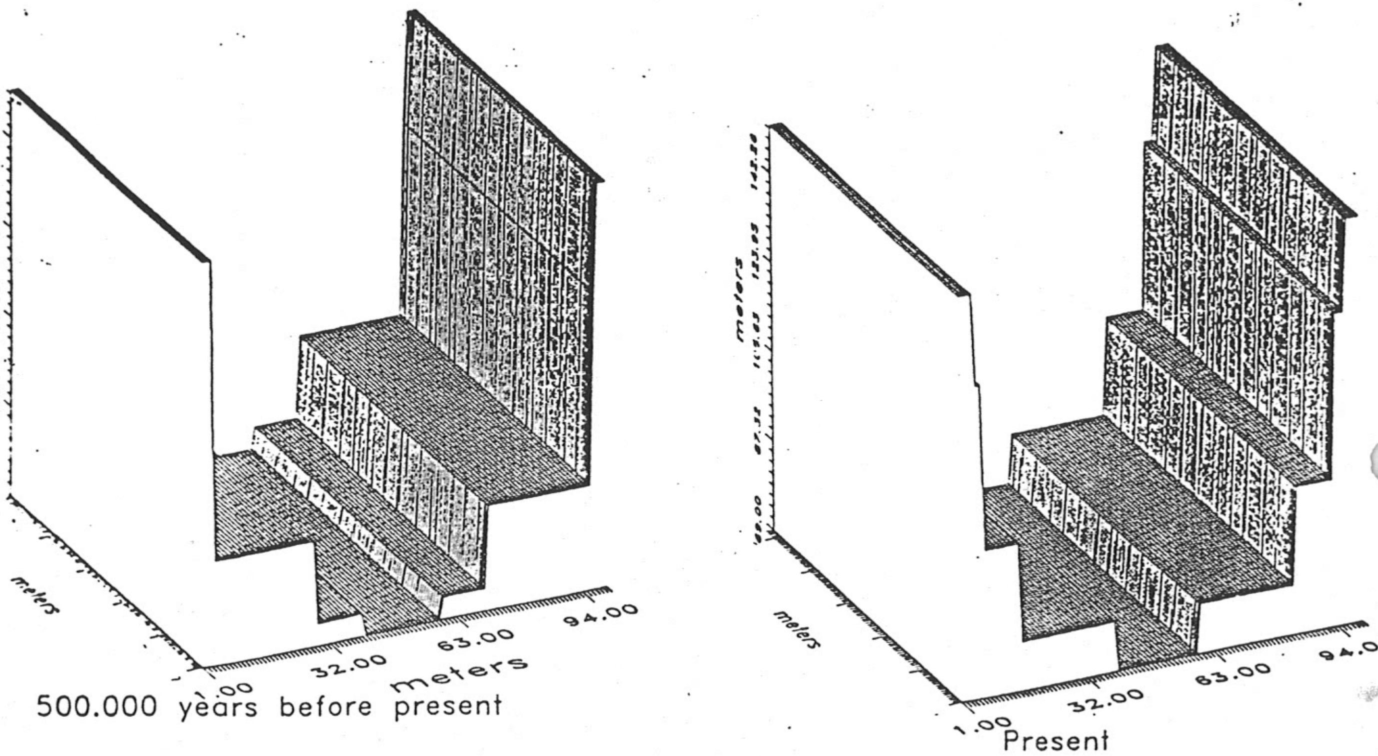
Tmax = 2.000; (ending time in thousand years)
Tmin = 2; (starting time in thousand years)
Zmid = 65; (height of the relief in the begin)
Xmeter = 10.000; (cross section in meters)
Ymeter = 10.000; (length profiel in meters)
Zmeter = 500; (height in meters)
Qtekgem = 0.09; (the average tectonism in meters/2000 years)
Qgem = 95; (average amount of water in m^3/sec)
Qamp = 80; (variation in m^3/sec)
Inlgem = 0.12E-3; (average amount of material in m^3/sec)
Inlamp = 0.1E-3; (variation in m^3/sec)
Flux = 5

The model can give at any time pictures of the terrace sequence. This set of input has lead to the following pictures.



1.500.000 years before present

1.000.000 years before present



500.000 years before present

Present

Figure 6.2. Different stages of the formation of the Guadalhorce terraces sequence, shown in x,y,z plots.

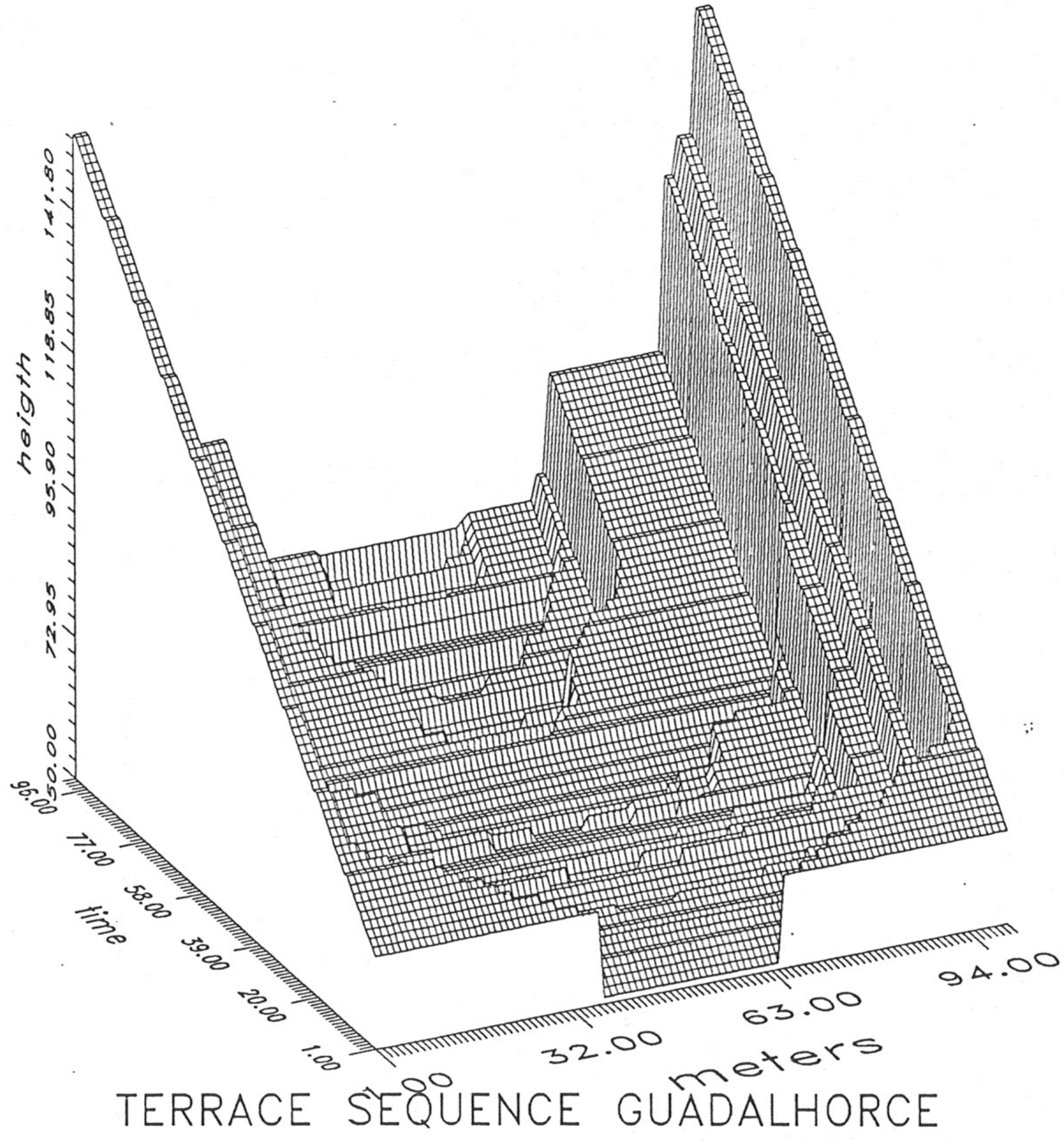


Figure 6.3. The formation of the guadalhorce through time shown in a y,z,t plot.

Goal for the modelling is to achieve the same picture by measuring and in some cases tuning the figures as given in this chapter, to achieve the same drawing. To become a good impression in the differences and the similarities of the model with the reality we have made pictures of a lesser advanced method than the simulation model.

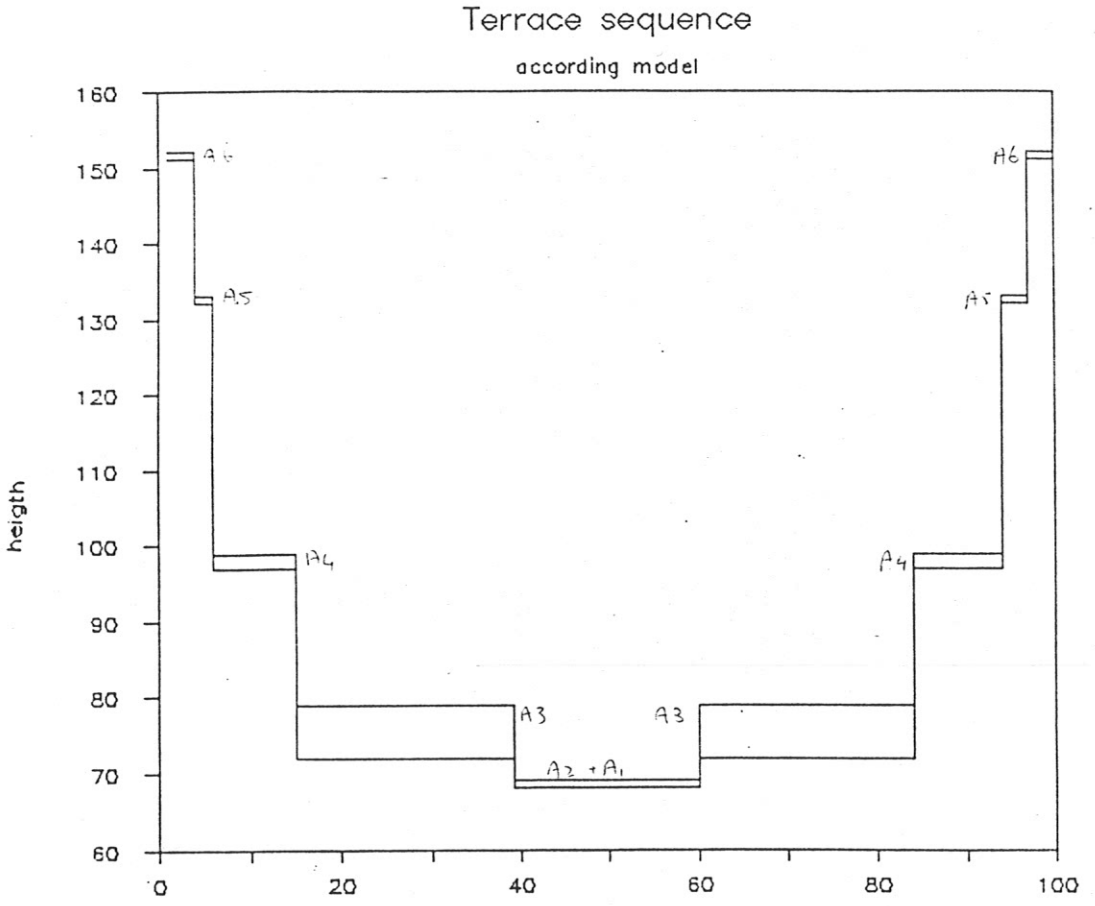
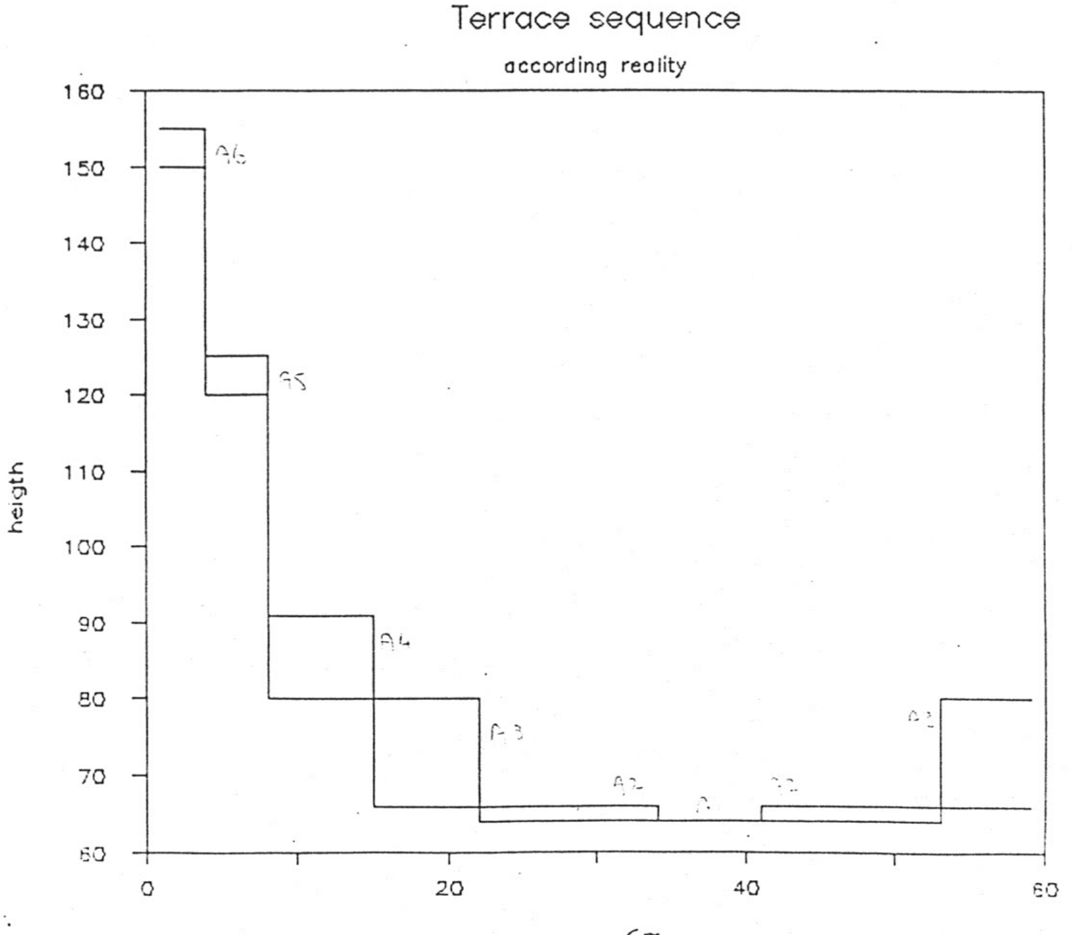


Figure 6.4. The terraces according model and in reality.



As can be seen the results shows big conformities. The computer simulation is very similar to the reality, which is the goal of modelling. It is a pity that there are no datings of this area and especially of the terraces done, otherwise a comparison of the age estimated with the computer and the reality could have been done. It is possible to compare the results obtained form the computer model with the results spanish geologists measured in the Guadalquivir basin (see chapter 4.3).
The results of the age of the terraces in the Guadalhorce basin are as follows.

A1: recent (present river)
A2: recent (alluvial plain)
A3: ± 250.000 years (Elsterien)
A4: ± 780.000 years (Bavelien of Cromerien)
A5: ± 1.480.000 years (Eburonien)
A6: 2.000.000 years (start of modelling)

Conclusions is that there is a strong difference with the spanish geologists who think the last five glacials have formed the river terraces in Andalusia, Spain and if there are no real datings of this area it is not quite sure who has chosen the right way of determining the age of the terraces of the Guadalhorce. One should take in account that the spanish geologists have worked in another river basin, but in general the two basins show a lot of similarities and the rivers have always had the same climatic conditions.
It is quite sure that for the formation of a terrace you need a cold period, because in a cold period a lot of water is stored in the glaciers. Result is also that the environment in general gets drier. By lacking water there will be a decrease of vegetation and thus an increase in erosion.
In time many glacials have occurred, so why are there no more terraces or remnants of terraces present is the next question one can ask. That there are no more terraces is due to the fact that the material sedimented during this colder period has been taken away by the river after the glacial.
Only a few terraces have survived until now.

7. CONCLUSIONS

The conclusions of different units of this report can be found in the thereby belonging chapters. This chapter briefly repeats those conclusions and gives general conclusions and recommendations.

The aim of our study was to find a relation between marine and fluviatile terraces in the lower Guadalhorce basin. Because there were no marine terraces in the study area, we were not able to find any relation of this kind at all.

There was only one huge marine/delta deposit in which the Guadalhorce terraces were formed, by incising of the river in this marine/delta material.

Further was the area a black spot on the map. In the surrounding area a lot of investigation was done by the universities of Sevilla and Granada, but inbetween these two cities nothing special was done. Therefore we do not have much geomorphological information of this area.

The Rio Guadalhorce has 6 terrace levels and one sublevel.

Fluvial sediments of the same terrace level of the Guadalhorce can have a very different composition in minerals (and thus in elements) if the tributary rivers are involved. The influence of a tributary river is very big. For example the Arroyos de las Cañas and the Casarabonela and the Rio Grande are very rich in ultramafic rocks. Before the confluence with these rivers the Guadalhorce carries only little ultramafic rocks thus the terraces formed by the Guadalhorce before the confluence are poor in ultramafic rocks; after the confluence with the two Arroyos and the rio Grande, the Guadalhorce is rich in ultramafic rocks and the terraces formed are also rich in ultramafic rocks. Conclusion is that there is an increase in ultramafic rocks in the different terrace levels further downstreams in the study area.

The terrace levels show a clearly visible geochemical trend, so the relative ages can be determined of the terraces. The trend is a decrease of MgO, Na_2O, P_2O_5, Pb and Rb in time and an increase of CaO (secundary enrichment of calcium carbonate). The weathering degree is high. That not many elements are washed out can be related to the fact that the climate in this area is very dry and therefore the leaching in this area is very low.

With the use of these factors one can distinguish different terrace levels. The older the terrace the more calcium carbonate it has.

The Late Pliocene marine materials deposited in the study area are probably delta deposits of a Gilbert type delta. The top of this delta lies at the moment some 155 meters above present sea level (at this heigth is also the highest river terrace of the Guadalhorce), and is formed around the maximum transgression phase during the Villafranchian.

In the marine/delta deposits there is a big difference of the geochemical composition between the sandy and the clayey layers. Also in these marine/delta deposite there is a difference between the top-set beds and the bottom-set beds. The top-set beds are rleatively richer in the elements Fe_2O_3, Cu and Zn.

The factors provenance and post depositional weathering have a significant contribution on the actual bulk sand composition in the Guadalhorce basin.

The presence of many landslides and alluvial fans and also human activity has given a lot of trouble of finding and determining terraces and terrace levels.

Determining ages of the terraces found during our practical fieldwork with for instance Th/U method would give answers to a lot questions. Important question solved would be which one is right: the prediction of the model or the Spanish geologists about the right ages of the terraces.

The model gives also answer about the question if terraces are formed in cold periods (glacials). The terraces in the study area are formed in glacials but not the same as the spanish geologists found.

What we have called a turbidite, can also be an alluvial fan (a very big one), but the clayey layers in the exposures give us the idea that it was formed beneath water. There are still questions unanswered and still more things to investigate in this area on the same matter as we did, but the most intriging question that annoyed us, is how old are the terraces in the area. We recommend dating of these terraces with for instance Th/U method.

REFERENCE LIST

Abbey, S. 1980, Studies in "standard samples" for use in the general analysis of silicate rocks and minerals, Part 6: 1979 edition of "usable" values, Geol. Surv. Canada Pap. 80-14:30 pp.

Berger, A.L., 1978, Long-term variations of calcoric insolation resulting from the Earth's Orbital elements. Quaternary research 9, 139-167.

Bouma, A.H., (1962). Sedimentology of some flysch deposits, Amsterdam, Elsevier Publ. 168 pp.

Buurman, P., Photo interpretation for the Alora area In: Introduction to the field trainingsproject "Sustainable land use" in Alora - Spain, 1992. Wageningen, Agricultural University, pp 69-81.

Buurman, P., and R.M. van de Berg van Saparoea, Introductory excursion to the Alora area, landscape morphological aspects, In: Introduction to the field trainingsproject "Sustainable land use" in Alora - Spain, 1992. Wageningen, Agricultural University, pp 115-123.

Clemente, L. and G. Paneque, Propriedades, génesis y clasificatión de suelos de terrazas del Guadalquivir. I. Factores ecolgicos y relaciones edafogeomorfológicas. An. Edafol. Agrolio, P. 215, 1974, Sevilla.

Conesa, J.A. and F. Durán, Atlas hidrologico de la provincia de Málaga, Diputación de Málaga, Málaga, 1988.

Driessen, P.M. and R. Dudal, Lecture notes on the major soils of the world, geography, formation, properties and use, Agricultural University Wageningen, Wageningen and Leuven, July 1989.

Duran, J.J., 1989, Segundo encuentro de campo sobre geomorfologia Cuarternario y neotectonica, pp.157, Sevilla.

Embleton, C., 1984, Geomorphology of Europe, the MacMillan Press Ltd., London & Basingstoke, pp. 465.

Fallot, P. 1948, Les Cordillères Betiques, Estudios Geol., 8. 83, Paris.

Findlay, W and D.A. Watt, 1981, PASCAL, an introduction to methodical programming. Pitman publishing limited, London, second section.

Instituto Geologico y Minero de España, E1:50.000, segunda serie-primera edición, servicio de publicacionnes, Ministeria de Industria, 1052, Madrid, 1978.

Kroonenberg, S.B., J. Bouma and N. van Breemen, Inleiding geologie en regionale bodemkunde, Wageningen, Landbouwuniversiteit Wageningen, pp. 152.

Kroonenberg, S.B., M.L. Moura, A.T.J. Jonker, 1988, Geochemistry of the sands of the Allier river terraces, France, Geologie en Mijnbouw 67: p. 75-89.

Kroonenberg, S.B., 1990 Geochemistry of Quaternary fluvial sands from different tectonic regimes. Chemical Geology, Volume 84, no. 1/9 p. 88-91.

Kroonenberg, S.B., M.C. Hoorn, M.L. Moura and A. Veldkamp, 1990, Variability in bulk geochemistry of fluvial terrace sands, consequence for the study of weathering chronosequences, Pedologie XL-1, p 19-31.

Kroonenberg, S.B., 1992, Geology of the Alora area, Betic Cordilleras, southern Spain In: Introduction to the field trainingsproject "Sustainable land use" in Alora - Spain, Wageningen, Agricultural University, pp 5-15.

Kuijper, A.J. and E.L. Meijer, 1987, Het meten van sporenelementen in boraatparels met de Philips PW 1404 röntgenspectrometer. Intern rapport, Vakgroep Bodemkunde en Geologie, Wageningen.

Leopold, L.B., M. Gordon Wolman, J.B.P. Miller, 1964, Fluvial processes in geomorphology, W.H. Freeman and company, San Francisco and London.

Lhénaff, R., 1982, Recherches Geomorphologiques sur les Cordilleres Betiques Centro Occidentales (Espagnes), thesis, University of Lille.

Locher, W.P. and H. de Bakker, 1990, Bodemkunde van Nederland, deel 1, Algemene bodemkunde, Tweede druk, Malmberg Den Bosch, 406 p.

López-Bermudez, F., 1973, La Vega Alto del Segura (clima, hidrologia y geomorfologia, Pullner Depto. Geogr. Univ. Murcia.

Moura, M.L. and S.B. Kroonenberg, 1990, Geochemistry of Quaternary fluvial sediments in the southeastern Netherlands, Geologie en Mijnbouw, 69. p 359-373.

Mulder, M., H. Otten, M. Sybesma, B.J. Wiersma, 1992, Soil formation on river terraces in the Guadalhorce area, Alora, July 1992, pp. 15.

Ocaña, C. Excursiones geograficas en la costa Mediterranea Andalusia, primeras jornados interuniversitarias, Málaga, 1984, Instituto de Ciencas de la educacion asociacion de geografas españoles, Universidad de Málaga, p. 229.

Ovejero, G and C. Zazo, 1971, Niveles marines pleistocenes en Almeria (SE España), Quaternaria, 15.

Pannekoek, A.J. and L.M.J.U. van Straaten, 1982, Algemene Geologie, Wolters-Noordhoff, Groningen, derde, herziene en uitgebreide druk.

Parfenova, E.I. and E.Y. Yarilova, 1962, Mineralogical investigations in SOIL Science, USSR Academy of science, Moscow, in Russian language, pp 206.

Sala. M, 1984, Betic Cordillera and Guadalquivirbasin in: Geomorphology of Europe, the Maximillan Press Ltd, London, p. 323-340.

Schumm, S.A. and R.W. Lichty, 1965, Time, space and casuality in geomorphology. American Journal of Science, vol 263, p 110-119.

Solé-Sabaris, L., 1964, Las rampas o glacis de erosión de la peninsula Ibérica, Aportación esp. XX, Congr. Geogr. Int. p. 13.

Summerfield, M.A., 1991, Global geomorphology, An introduction to the study of landforms, Longman scientific & technical, pp 537, London.

Tetzlaff, D.M. and J.W. Harbaugh, 1989, Simulating clastic sedimentation. Computer methods in the geosciences. Van Nostrand Reinhold.

Tiemensma, H. and T. van der Koppel, 1992, Modelling of the denudation rate in the caucasus by mean of ice cover, Agricultural University Wageningen, Department of Soil Science and Geology.

Veldkamp, A., 1991, Quaternary river terrace formation in the Allier, France, a reconstruction based on sand bulk geochemistry and 3-D modelling, thesis, pp. 172.

Veldkamp, A. and S.E.J.W. Vermeulen, 1989, River terrace formation, modelling, and 3-D graphical simulation, Earth Surface Processes and Landforms, vol 14, pp 641-654.

Weijermars, R., 1991, Geology and tectonics of the Betic Zone, SE Spain, Earth-Science Reviews, 31, Elsevier Science Publishers B.V., Amsterdam, pp 153-236.

Wielemaker, W.G., Soil survey methodology, In: Introduction to the field trainingsproject "Sustainable land use" in Álora - Spain, 1992. Wageningen, Agricultural University, pp 99-114.

Zuidam, R.A. Introduction to the geology and geomorphology of the Málaga-Álora-Ardales fieldwork area, March 1984, Enschede 9 p.

Appendix I

Descriptions of profiles

A	80 meter	Pliocene clay
1	94 meter	Rio Grande
2	107 meter	Probably a slump
3	95 meter	Exposure in eucalyptus plant
4	123 meter	Fluviatile against cement
5	120 meter	Álora, alluvial fan, thick sediment
6	95 meter	Beautiful exposure
7	155 meter	Heighest terrace, beneath slumps
8	125 meter	Exposure alongside the road
9	143 meter	Maaike and Marnix terrace
10	140 meter	Marine sand (clay)
11	91 meter	Zalea
12	115 meter	Zalea
13	65 meter	Point 17 of excursion
14	102 meter	Scorpion
15	95 meter	Fluviatile gravel count
16	102 meter	Fluvial exposure in flysch
17	100 meter	Alluvial fan
18	95 meter	Flu-flysch bridge Guadalhorce
19	150 meter	Bauke footballground
20	140 meter	Drawings in curve of the road
21	85 meter	Beautiful exposures between Pizarra and Zalea
22	75 meter	" "
23	157 meter	Cerrajon (marine cover)
24	95 meter	Vega Ribera (rain/farmer)
25	154 meter	Cerrajon (fluviatile cover)
26	75 meter	Near the bridge of Pizarra
27	85 meter	Cerralba near the road
28	111 meter	Killer bees
29	88 meter	Opposite excursion point 13
30	63 meter	Crossroad direction Cártama
32	56 meter	Pizarra-south
33	54 meter	Paco the orange cutter
34	151 meter	End of valley of Arroyo del Buho
35		Wielemaker terrace south
36		Near the road to Valle de Abdalajis
37		Wielemaker terrace north
38	54 meter	Casa Palma
39	40 meter	Casa la Colonial

Profile A Pliocene clay

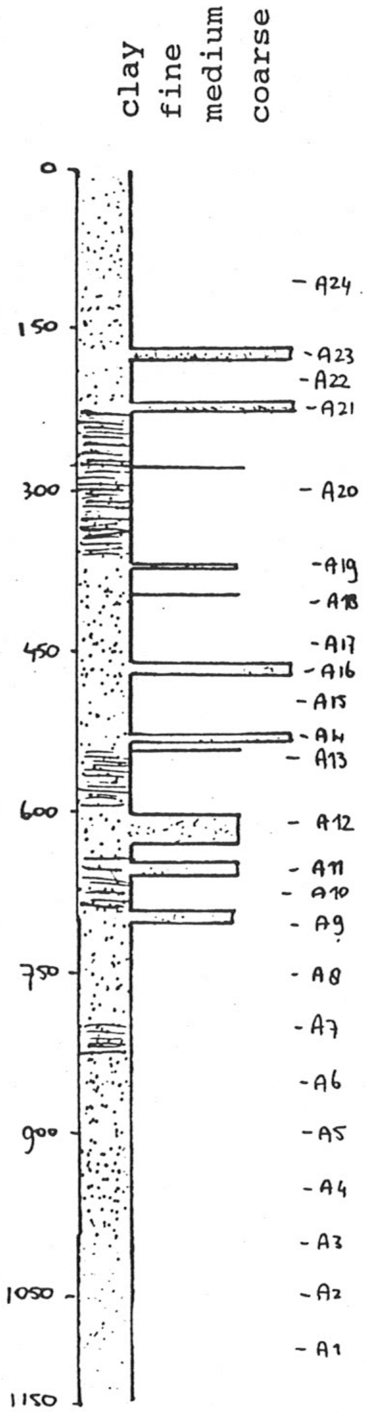
Height: 80 meter
Thickness of exposure: 11.5 meter
Kind of exposure: Exposure near the road

Exposure: grain size: clay except for some sand layers which can be seen in the drawing of this exposure

Slight soil formation, lightly disturbed At about 150 centimeter first sandlayer
Salt accumulation occurs
Clay reduced

At 400 centimeter, occurence of former animal channels, probably made by lobworms. These animals live near the coast there fore at this dept it was a coast or the coast was nearby. Sand has filled the holes in the clay and also clay filled the holes in the sand as a result of this bioturbation
The whole profile contains calcium carbonate though some layers less abundant than other layers

At 700 centimeter the clay shows clearly visible layering, but can also be seen at other depths in the profile



∴ homogenous

≡ layered

Profile 1 Rio Grande

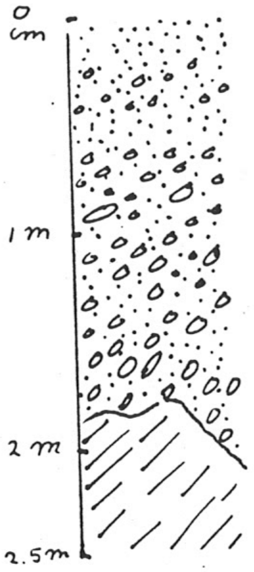
Height:	94 meter
Thickness of exposure:	70 centimeter
Kind of exposure:	Border of parcel
Exposure:	
0-50 cm: grain size:	Dominant size: 2-8 cm Maximum: 15 cm Existence of "kalkbaarden’, enrichments of secundary calcium carbonate
50-70 cm: grain size:	Dominant size: 2-16 cm Maximum: 25 cm
Rocktypes:	Quartzite, gneiss, schist, sandstone, ultramafic rocks and limestone.
Roundness:	Moderate
Degree of weathering:	Medium
Special properties:	Secundary enrichment of calcium carbonate, also some cementation occurs.

Profile 2 Probably a slump

Height: 107 m
Thickness of exposure: 220 cm
Kind of exposure: Exposure near the road

Exposure:
0-50 cm: grain size: Dominant size: <1 cm
Maximum: 5 cm
Badly sorted, angular
Special properties: No ultramafic material
50-100 cm: grain size: Dominant size: 1 cm
Maximum: 10 cm
Special properties: Calcium carbonate and clay accumulations in nodules
Rock types: Slates and sandstones are dominant
100-150 cm: grain size: Maximum: 20 cm
Special properties: At this depth the amount of ultramafic material increases
150-225 cm: grain size: Maximum: 60 cm
Special properties: A lot of calcium carbonate and an increase in amount of quartzites and gneisses.

Roundness: Rounded, except for slates
Degree of weathering: Strong
Special properties: Slight cementation



soil formation

calcium carbonate with clay

Profile 3 Exposure in eucalyptus plant

Height:	95 m
Thickness of exposure:	300 cm
Kind of exposure:	Exposure in a forest, lies at the moment 30 meter higher than the present river

Exposure:	
0-150 cm: grain size:	Dominant size: 0-4 cm Maximum: 20 cm (sandstones)
Rocktypes:	Slates 70 %, ultramafic rocks, sandstones and limestones.
150-250 cm: grain size:	Mean size: 12 cm Maximum: 30 cm
Rocktypes:	Less slates and more ultramafic rocks, other stones are limestones and sandstones
250-300 cm: grain size:	Maximum: 80 cm

Roundness:	Angular
Degree of weathering:	Strong
Special properties:	Fining upwards sequence Clearly visible are the former streambeds, the flow direction of the former river is from west to east, soil formation in the upper 20 centimeter,

Profile 4 Fluviatile against cement

Height: 123 m
Thickness of exposure: 125 cm
Kind of exposure: Exposure near the road

Exposure:
0-125 cm: grain size: Dominant size: 2-8 cm
Maximum: 25 cm

Rocktypes: Slates 40 %, ultramafic rocks 30%, sandstone and limestone.

Roundness: Rounded
Degree of weathering: Strong
Special properties: Slight cementation

Profile 5 Beautiful exposure (near the castle of Álora)

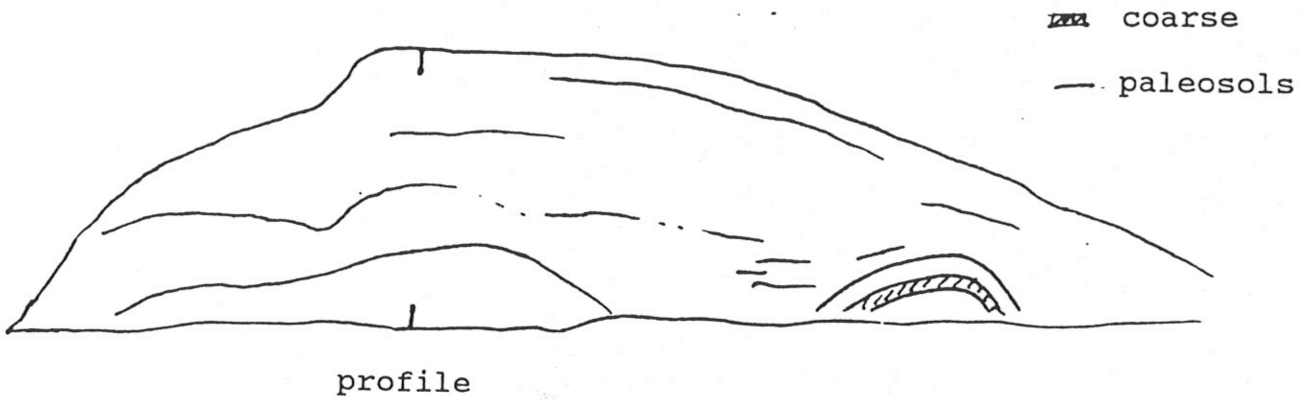
Height: 120 m
Thickness of exposure: 5,5 m
Kind of exposure: Exposure near the railroad

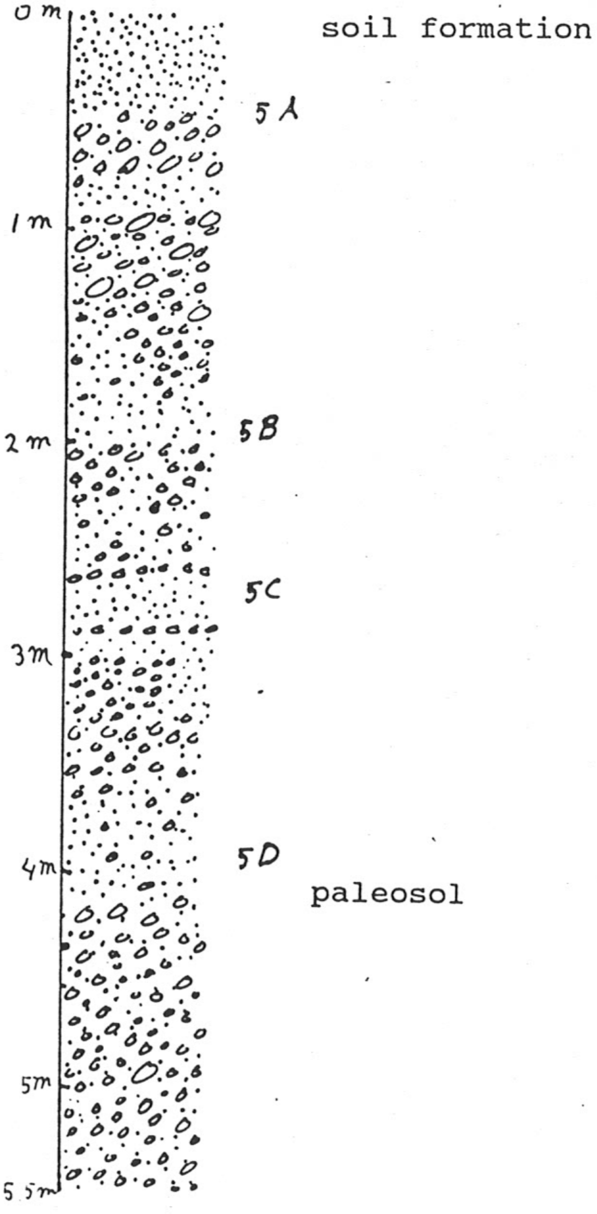
Exposure:
0-550 cm: grain size:
Gravel packet
Dominant size: 2-8 cm
Maximum: 35 cm
Sand packet
Dominant size: 1 cm
Maximum: 10 cm

Rocktypes: Slates, ultramafic rocks (just a little), sandstones, quartzites, gneisses and limestones.

Roundness: Rounded
Degree of weathering: Low
Special properties: In the exposure different layers interchange with one another, as can be seen in the drawing as a result of different former streambeds of the Guadfalhorce. Sand layers interchange with gravel layers. There is slight slope through the profile in the direction of the present Guadalhorce, and occurence of paleosols in the profile. Very beautiful in this exposure are the fining upwards sequences in the different paleosols. colour is oxydixed. Some layers are well sorted while other layers are badly sorted.

cross section



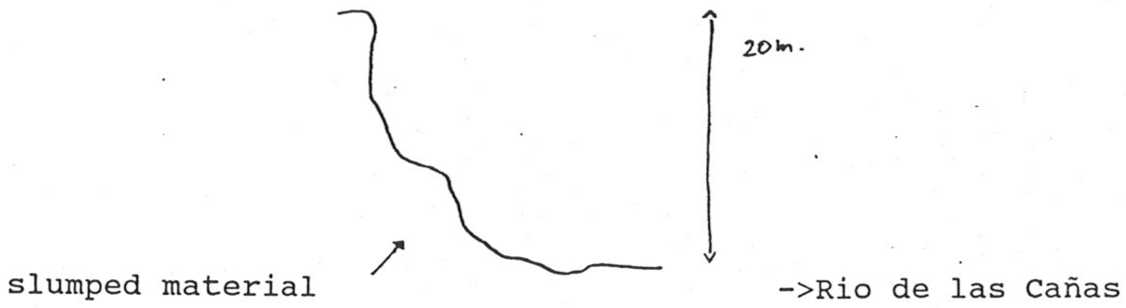

0 m
soil formation
5A
1 m
2 m
5B
5C
3m
4m
5D
paleosol
5m
5.5m

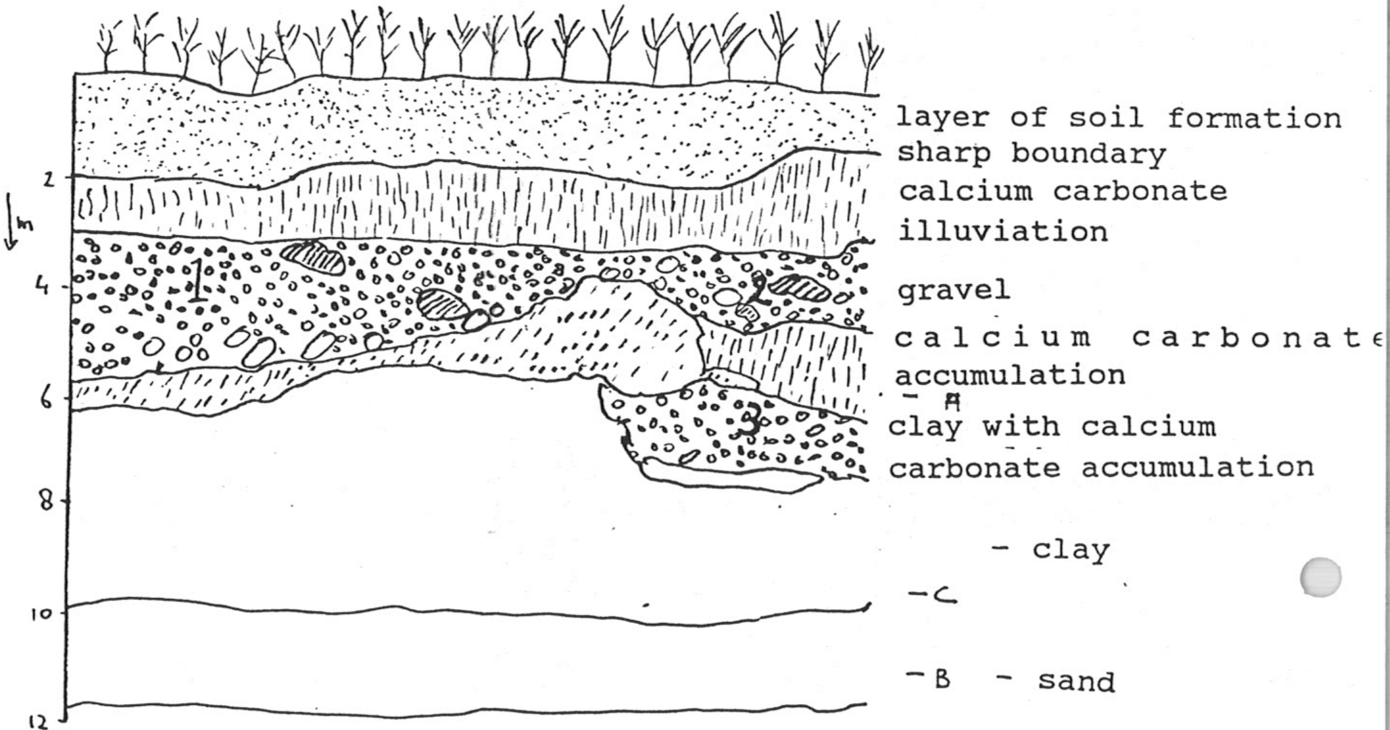
Profile 6 Beautiful exposure

Height: 95 m
Thickness of exposure: ±12 m
Kind of exposure: Exposure near the river de las Cañas

Exposure:
Point 1: grain size: Dominant size: <5 cm
Maximum: 25 cm
Rocktypes: Ultramafic rocks (serpentines)(50%), limestones (30%), gneisses(10%) quartzites and sandstones.
Roundness: Rounded
Degree of weathering: High, especially serpentines and gneisses.
Special properties: The department Soil Science and Geology has taken soil samples of the top soil is exposure. Paleocurrent is visible and is directed in the same direction as the present direction of the Rio de las Cañas. There is also cementation by calcium carbonate.
Point 2: grain size: Dominant size: 5-8 cm
Maximum: 35 cm (limestone)
Rocktypes: Ultramafic rocks (serpentines)(65%), limestones (30%) and only a few gneisses.
Special properties: Material is coarser, especially the serpentines
Point 3 : grain size Same as point 2, only the limestones are bigger: 40 cm.
Special properties: Very strong cementation by calcium carbonate.

cross section




layer of soil formation
sharp boundary
calcium carbonate
illuviation
gravel
calcium carbonate
accumulation
– A
clay with calcium
carbonate accumulation
– clay
– C
– B
– sand
m
2
4
6
8
10
12
1
2
3

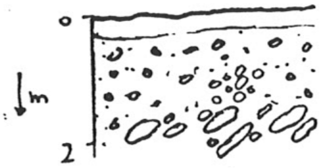
Profile 7 Highest terace, beneath slumps

Height: 155 m
Thickness of exposure: 2 m
Kind of exposure: Exposure near the road

Exposure:
0-2 m: grain size: Dominant size: 2 cm
Maximum: 40 cm

Rocktypes: Ultramafic rocks (50%), sandstones, quartzites, gneisses and limestones.

Degree of weathering: High
Special properties: Paleocurrent is visible and is directed south, but there are no former streambeds in this exposure. On the top of the profile there is soil formation. There is also slight cementation by calcium carbonate.



Profile 9 Maaike and Marnix terrace

Height: 143 m
Thickness of exposure: 1 m
Kind of exposure: Hill

Exposure:
0-5 m: grain size: Medium size: 1 cm
Maximum size: 25 cm
Rocktypes: Ultramafic rocks, sandstones (the bigger stones in this profile), gneisses, slates and limestone.

Roundness: Medium rounded
Degree of weathering: Strong (except, as in much cases, for the sandstones)
Special properties: Cementation by calcium carbonate and existance of "kalkbaarden", soil formation on top of this profile

Profile 10 Marine sand (clay)

Height: 145 m
Kind of exposure: Hill side, nearby exposure 9

Exposure: Marine clay and sand some parts oxydixed other parts reduced

Profile 11 & 12   Zalea (Guadalhorce)

Height: 115 m
Thickness of exposure: 30 m
Kind of exposure: Road and hill, between 90 and 110 no exposure, first the upper part (12) and than the lower part (11)

Exposure:
0-5 m: grain size: Medium size: 8 cm
Maximum size: 50 cm
No soil formation, alluvial fan material
25-30 m: Soil formation (just a little)
Rocktypes: Ultramafic rocks(10%), sandstones (50%), gneisses, quartzites, slates and limestone. Only a few schists, badly sorted

Roundness: Rounded
Degree of weathering: Strong
Special properties: Some sand layers occur and also some clay pebbles.

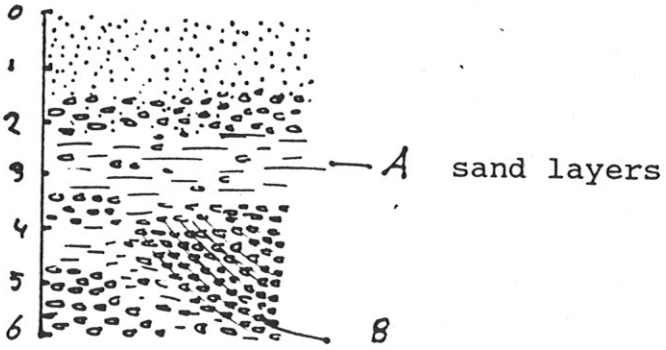
cross section of the exposure

Profile 13   Point 17 of excursion

Height: 55 m
Thickness of exposure: 6 m
Kind of exposure: Human terrace

Exposure:
Rock types: Sandstones, gneissses, quartzites, slates and ultramafic rocks.
Maximum size: 30 cm.

Roundness: Rounded.
Weathering degreee: Medium
Special properties: Top soil red caused by weathering, soil formation. Occurrence of a streambed in the exposure. Also some sandy layers are present in the profile, which consist of coarse grains. Also some cementation by calcium carbonate.



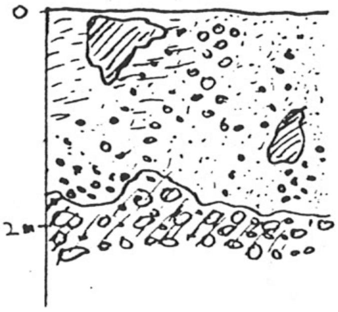
Profile 14 Scorpion

Height: 102 m
Thickness of exposure: 1 m
Kind of exposure: Human terrace

Exposure:
0-1 m: grain size: Coarse marine sand
Special properties: Secundary calcium carbonate. The reason for the description of this terrace is the fact that in 1991 students found shells in this exposure.

Profile 15 Fluvial gravel count

Height:	95 m
Thickness of exposure:	2.5 m
Kind of exposure:	Terrace formed by human activity
Exposure:	
0-2.5 m: grain size:	Upper part: Medium size: 2-8 cm Maximum size: 20 cm Lower part: Medium size: 4-16 cm Maximum size: 25 cm
Rocktypes:	Dominant are slates and limestones but also sandstones, gneisses. Only a few ultramafic rocks.
Roundness:	Rounded
Degree of weathering:	Strong
Special properties:	Former streambeds, paleocurrent transverse of the exposure, strong cementation by calcium carbonate and also secundary accumulation of calcareous material (Dutch "kalkbaarden").

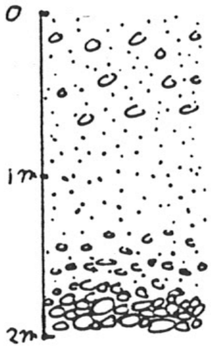


Profile 16 Fluvial exposure in flysch

Height: 102 m
Thickness of exposure: 2 m
Kind of exposure: Exposure near the road

Exposure:
0-0.96 m: grain size: Medium size: 2-4 cm (gravel)
0.96-1.22 m: Coarse sand
1.22-1.25 m: Gravel layer: 1-4 cm
1.25-1.39 m: Coarse sand
1.39-2 m: Medium size: 4-16 cm (stones)
Rocktypes: Sandstones, slates, limestones, quartzites, gneisses and ultramafic rocks.

Roundness: Rounded
Degree of weathering: Medium to strong
Special properties: No former streambeds or paleocurrents



Profile 17 Alluvial fan

Height: 130 m

Thickness of exposure: 45.5 m

Kind of exposure: Exposure is built out of two parts; the first and upper 10 meters belong to a slump and the lowest 16 meters are near the present river, we have found nothing in between, so there is a big gap of about 19 meter.

Exposure: The exposure is very complex, it has many layers of different kinds of material. First a description of the upper part, than one of the lower part.

0-10 m: grain size: Dominant size: 2-8 cm
Maximum: 20 cm

Rock types: Sandstones, limestones, slates, schists and a lot of conglomerates.

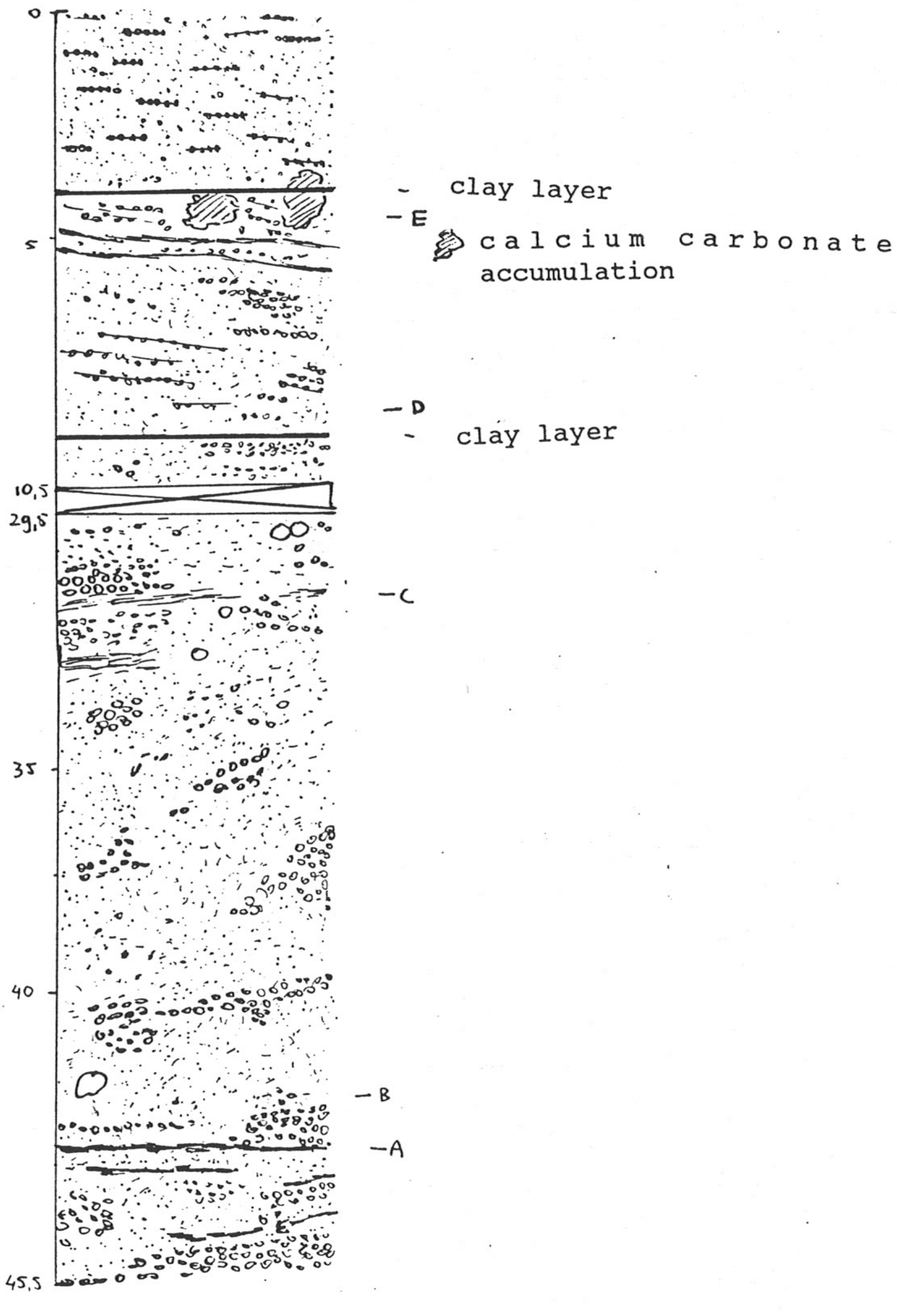
Special properties No ultramafic material, the material is rather angular, no soil formation, degree of weathering is low, small layers of marine clay interchanged with layers of sand (coarse). Colouring by oxydation/reduction, cementation. Big fragments of conglomerates.

30-46 m: grain size: Depends on layer
Sand layers: maximum size: 4 cm

dominant size: 1-2 cm
Gravel layers: maximum size: 40 cm
dominant size: 2-8 cm
Coarse sand layers: maximum size: 6 cm
dominant size: 2-4

Special properties: Sand is mixed with stones (up to 30 cm). Layers are rare, mostly it is mixed to a bad structure. Sand is abundant.

Rock types: Sandstones, gneisses, quartzites, conglomerates, schists and slates, no ultramafic material


0
5
10,5
29,5
35
40
45,5
clay layer
E
calcium carbonate accumulation
D
clay layer
C
B
A

Profile 18 Flu-flysch bridge Guadalhorce

Height:	95 m
Thickness of exposure:	3 m
Kind of exposure:	Exposure near the river
Exposure:	
0-1 m: grain size:	Dominant size: 4-16 cm Maximum: 25 cm
1-2.7 m: grain size:	Dominant size: 4-8 cm Maximum: 20 cm
2.7-3: grain size:	Dominant size: 0-2 cm Maximum: 4 cm
Rock types:	Sandstones, marble stones, limestones, slates, schists and conglomerates. Very little ultramafic rocks (<2%)
Roundness:	Rounded
Degree of weathering:	Medium
Special properties	Some layering in the lower part of the profil (lowest 30 cm). Material in the profile is typical Guadalhorce material.

Profile 19 Bauke footballground

Height: 150 m
Thickness of exposure: 6 m
Kind of exposure: Border of a footballground

Exposure:
Special properties: Little delta system in which clay and sand interchange. The exposure is made below the surface in a quiet sedimentation environment with a tide smaller than 0.5 meter. The surf is far away. It was probably a meandeing system with sandy material in the less quiet environments and clay on the more quiet places. The sortation is very bad. The sand is angular and the clay is oxydized. The weathering degree is low and the dominant rock type is schist.

Profile 20 Drawings in the curve of the road

Height: 140 m
Thickness of exposure: 5 m
Kind of exposure: Road. The exposure consists out of two parts, a marine and a fluviatile part.

Exposure:
0-5 m: grain size: Sand layer
Medium size: 0-2 cm (50%), ±20 cm (25%)
Maximum size: 40 cm
Rock types: (Garnet-)schists (50%), quartzites, limestone and a little bit of ultramafic material.

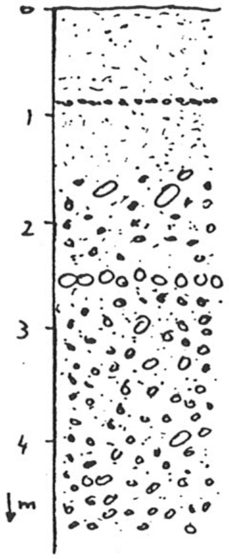
Weathering degree: High
Special properties: Area with tidal influences, sediment load of the river is big at that time. At the moment the river reaches the sea, which lies somewhere in the neighbouhood of exposure 20, the river can not hold its sediment and drops in in the mouth of the river. Sand is deposited at the less quiet environments and clay at the more quiet places. The sand is angular and is beach sand. There are gravel strings in the sand layer. Betweeen the contact of the greavel with the sand ther is an occurence of calcium carbonate.

Profile 21 Beautiful exposures between Pizarra and Zalea

Height: 85 m
Thickness of exposure: 5 m
Kind of exposure: Exposure near railroad

Exposure:
0-5 m: grain size: Medium size: 2-8 cm
Maximum size: 30 cm
Some stone layers occur with stones between 20-40 cm. And also a sand layer with coarse sand is present in the profile
Rocktypes: Sandstones, quartzites, conglomerates, slates and limestones.

Roundness: Rounded
Weathering degree: Low
Special properties: Soil formation on top (red colour by weathering). Just a little bit ultramafic material. Cementation occurs. Existance of "kalkbaarden".



Profile 22 Beautiful exposures between Pizarra and Zalea

Height: 75 m
Thickness of exposure: 12 m
Kind of exposure: Exposure down until it reaches the river, probably the same terrace as 26

Exposure:
Rocktypes: Sandstones, schists, quartzites, slates, gneisses and limestones.
Size of the stones: Average: 20 cm
Maximum: 40 cm

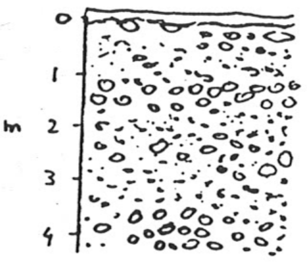
Roundness: Rounded
Weathering degree: High
Special properties: No ultramafic material. Little soil formation on top, very big gravel packet, cementation by calcium carbonate, paleocurrents in the same direction as the present river.

Profile 23 Cerrajon (marine cover)

Height: 157 m
Thickness of exposure: 4 m
Kind of exposure: Top of a hill

Exposure:
0-4 m: grain size: Medium size: 2-8 cm
Maximum size: 20 cm
Rocktypes: Ultramafic rocks (not much), sandstones, gneisses, slates and limestone.

Roundness: Medium rounded
Weathering degree: High
Special properties: Soil formation on top, existance of "kalkbaarden", sand is rather homogeneous, former streambeds are visible. Contact between fluviatile and marine material



Profile 24 Vega Ribera (rain/farmer)

Height:	95 m
Thickness of exposure:	2.5 m
Kind of exposure:	Road cut

Exposure:

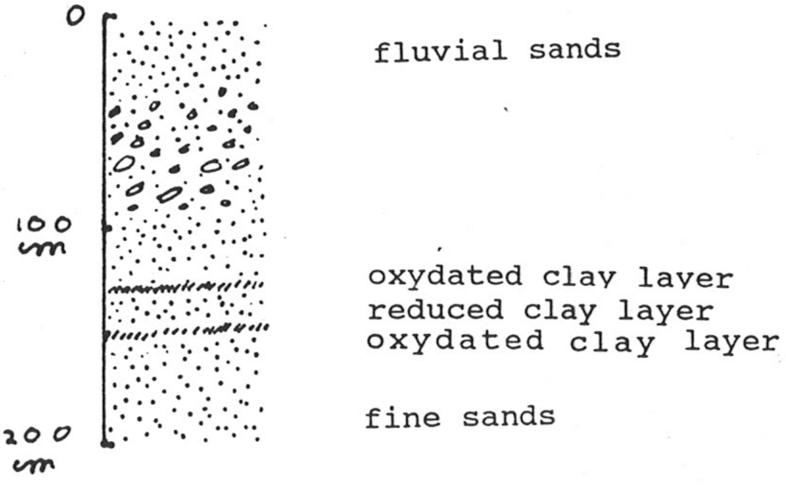
0-2.5 m: grain size:	Medium size: 10 cm Maximum size: 50 cm
Rocktypes:	Ultramafic rocks (just al little bit), sandstones, gneisses, quartzites.
Special properties:	Probably alluvial fan material, badly sorted

Profile 25 Cerrajon (fluviatile cover)

Height: 154 m
Thickness of exposure: 2 m
Kind of exposure: Top of a hill, below the exposure there is a lot of alluvial fan material

Exposure:
0-2 m: grain size: Medium size: 2-4 cm
Maximum size: 15 cm
Kind of material: Fluviatile sand, layered and only a few stones.
Rocktypes: Sandstones, ultramafic rocks, limestones

Weathering degree: High, most of the material is rotten
Special properties: Clay shows reduced and oxydized properties

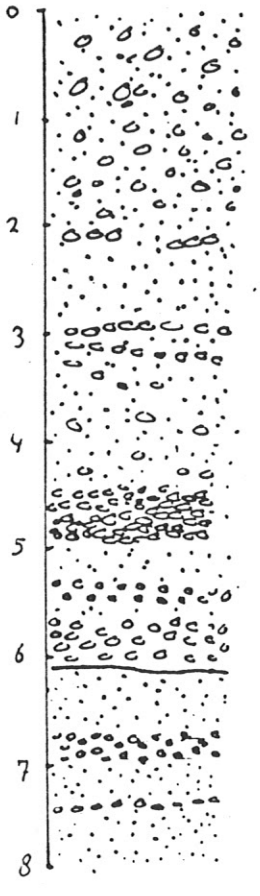


Profile 26 Near the bridge of Pizarra

Height: 75 m
Thickness of exposure: 10 m
Kind of exposure: Near the river, probably the same terrace as 22

Exposure:
Grain size: gravel(top): Medium size: 2-8 cm
Maximum size: 20 cm
(lower): Mediumsize: 2 cm
Maximum: 10 cm
Rocktypes: Sandstones, a little bit of ultramafic rocks, limestones and slates

Weathering degree: Low, but most of the ultramafic rocks are rotten.
Roundness: Rounded
Special properties: Brown top soil. Stony surface. In the profile there are some enrichments and cementations of calcium carbonate. Gravel layers interchange with stony layers and sandy layers. Some layers are badly sorted, while other layers are well sorted. Also some clay pebbles occur

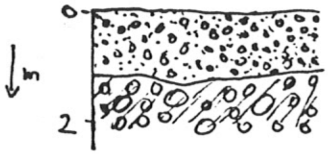


Profile 30 Crossroad direction Cártama

Height:	65 m
Thickness of exposure:	2 m
Kind of exposure:	Terrace made by human activity

Exposure:

0-1.2 m: grain size:	Medium size: 2-6 cm Maximum size: 15 cm
1.2-2 m: grain size:	Medium size: 2-8 cm Maximum size: 25 cm
Kind of material:	Fluviatile sand, layered and only a few stones.
Rocktypes:	Sandstones, slates, quartzites and limestone.
Weathering degree:	Medium, surface coloured red by weathering.
Special properties:	Stony surface, cementation by calcium carbonate



Profile 32 Pizarra-south

Height: 56 m
Thickness of exposure: 2 m
Kind of exposure: Exposure near to the road

Exposure:
Rocktypes: (Garnet-)gneisses, slates, sandstones and a schists.

Special properties: Badly sorted.

Profile 33 Paco the orange cutter

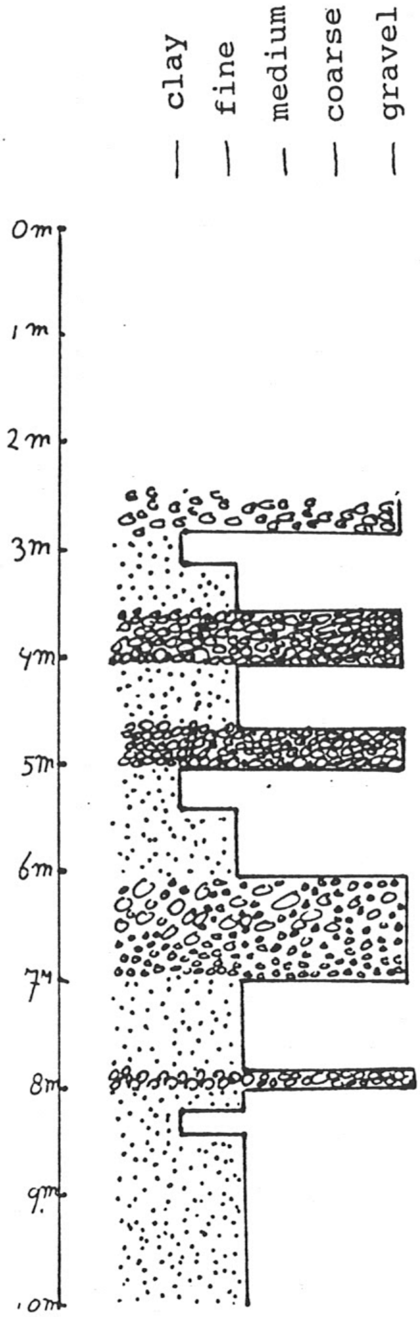
Height: 54 m
Thickness of exposure: 5 m
Kind of exposure: Made by people for agricultural purposes

Exposure:
Rocktypes: Gneisses, slates, schists, limestones, sandstones and a few ultramafic rocks.

Roundness: Medium rounded
Degree of weathering: Low to medium
Special properties: Badly sorted, big packet of stones.

Profile 34 End of valley of Arroyo del Buho

Height:	151 m
Thickness of exposure:	15 m (described only the lower 6 meter)
Kind of exposure:	Road cut
Exposure:	
Rocktypes: (in the gravel)	Gneisses, schists, clay pebbles
Special properties:	Some cracks occur throughout the profile and shells are abundant. Some layers consist of (beach)sands, while other layers contain more clay. The sands are angular and therefore the conclusion can be drawn that the material only traveled over a short distance and that the mountains where it derived from should be nearby. Some sand layers are cemented and the whole profile is rich in calcium carbonate. In the profile there are also some gravel layers, probably due to the fact that at the moment of sedimentation the river which transported this gravel mounded in the sea and lost its load immediately at this spot. Colours varying from red to grey. Some clay layers are reduced while other layers are oxydized.

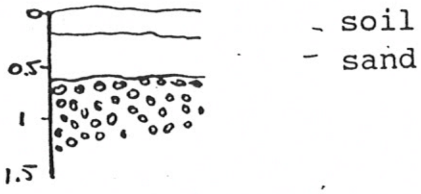


Profile 38 Casa Palma

Height: 54 m
Thickness of exposure: 1.5 m
Kind of exposure: Exposure near the road

Exposure:
0-0.25 m Top soil, dark colour (brown)
0.25-0.5 m Marine sand
0.5-1.5 m:grain size: Medium size: 2-8 cm
Maximum size: 30 cm
Rocktypes: Sandstones, ultramafic rocks, limestones slates and a lot of gneisses.

Roundness: Rounded
Weathering degree: High, most of the material is rotten, except for the gneisses.

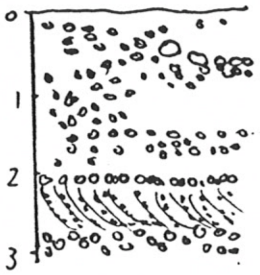


Profile 39 Casa la Colonial

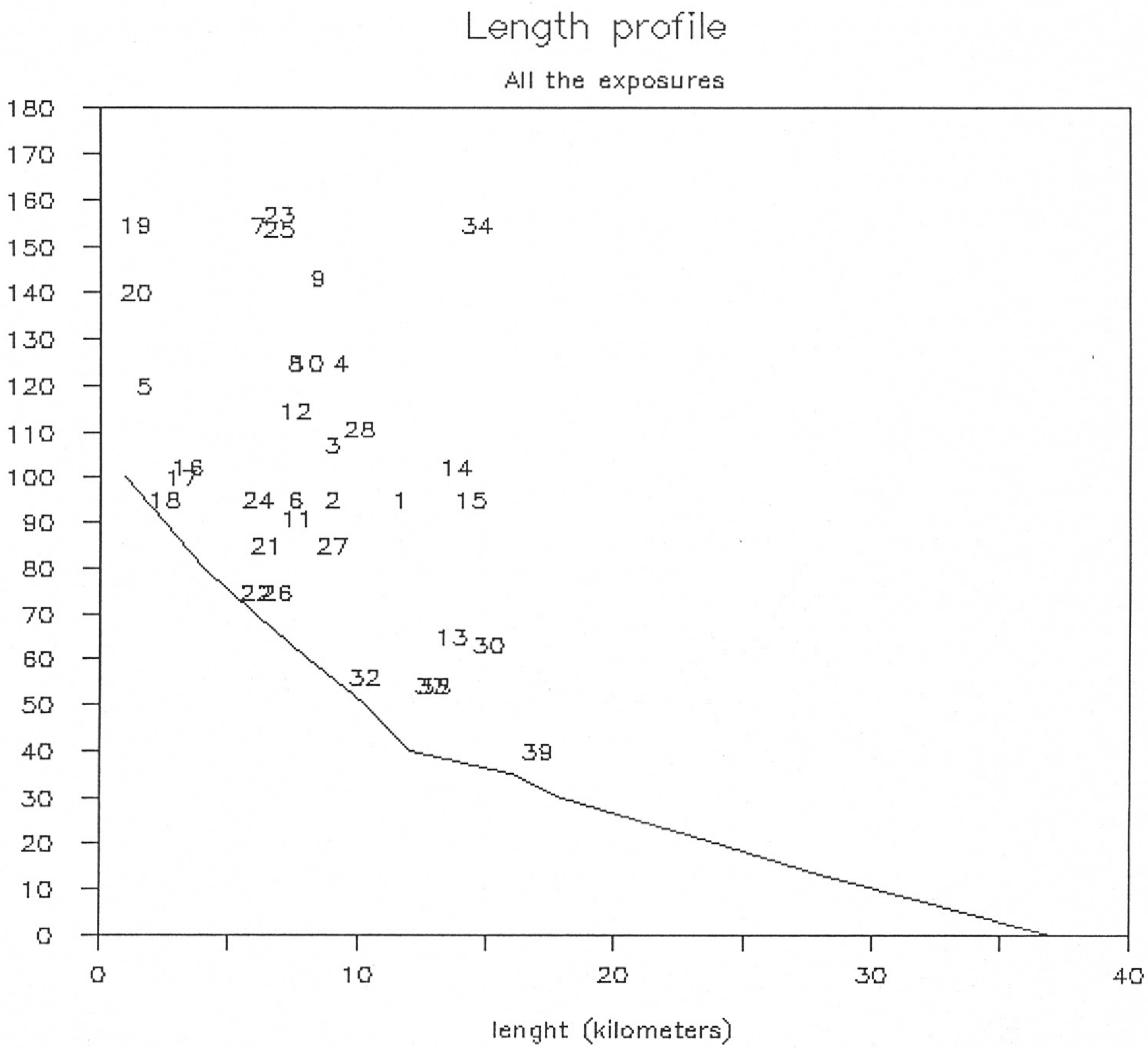
Height: 40 m
Thickness of exposure: 3 m
Kind of exposure: Ditch

Exposure:
0-3 m: grain size: Medium size: 2-8 cm
Maximum size: 25 cm
Rocktypes: Sandstones, no ultramafic rocks, limestone and (garnet-)gneisses.

Roundness: Rounded
Weathering degree: High, most of the material is rotten.
Special properties: Soil formation. Cementation by calcium carbonate. Evidence of animal activity. Also a meandering system is visible in the profile in which the younger sediments lie to the right from the older sediments.

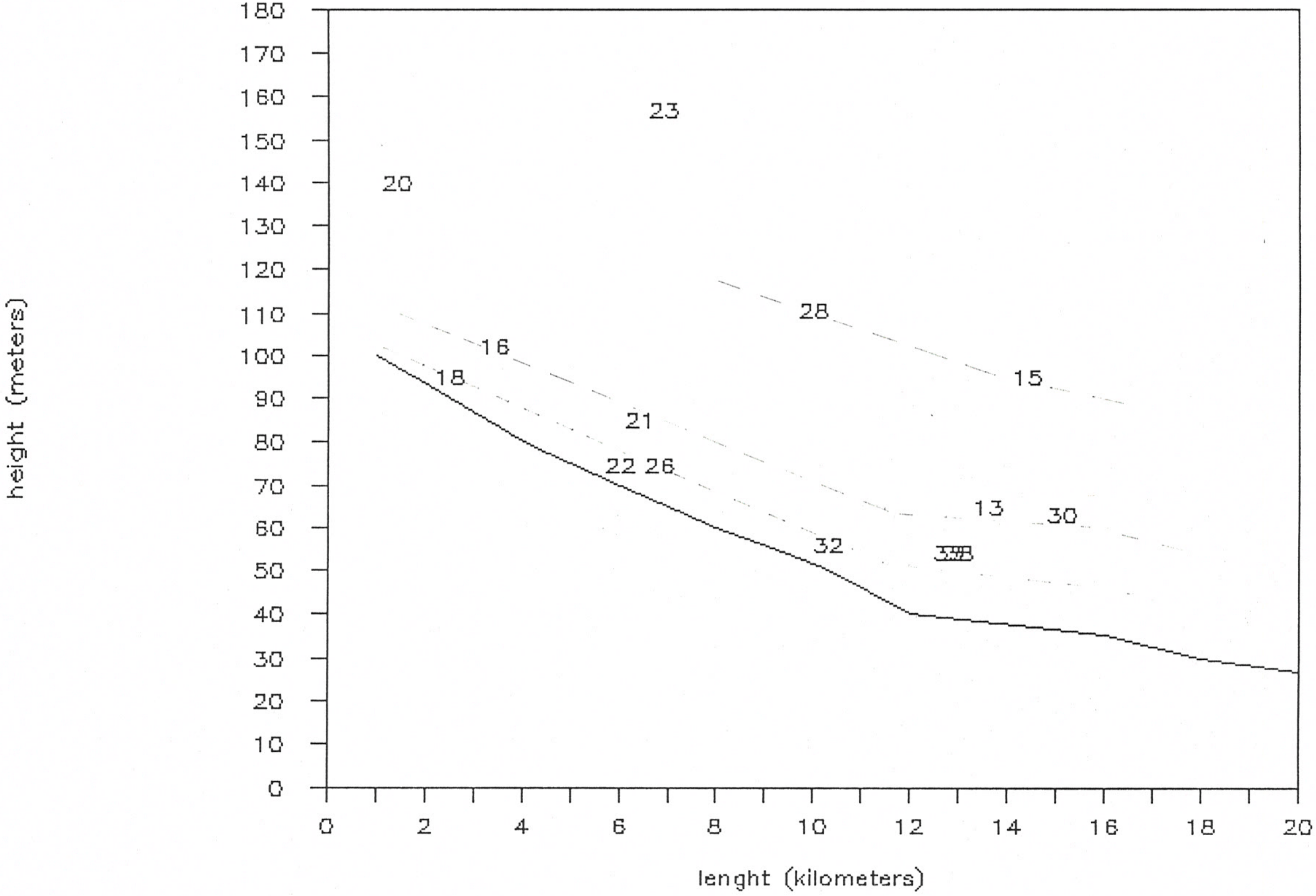


Appendix II


Length profile
All the exposures
height (meters)
lenght (kilometers)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
0
10
20
30
40
19
20
5
16
17
18
23
7
25
9
80
4
12
3
28
24
6
2
11
21
27
22
26
1
14
15
34
13
30
32
33
39

Length profile

Guadalhorce exposures



Appendix III

XRFS ANALYSIS

X-ray fluorescence analysis (XRFS) is a standard analytical tool to obtain quantitative geochemical data. At the Department of Soil Science and Geology a method for determination of trace elements in glass beads of fused soil and sediment samples was developed (Kuijper, 1987). A Sc tube is used to determine both macro and trace elements. In 1989 this method was replaced by another method wherby trace elements are measured with a Rhodium X-ray tube in combination with the measuring of the Compton scattered radiation (internal ratio method). The macro elements are still measured with a Sc tube.
The X-ray fluorescence instrumentation include a Philips PW1410 wavelenght-dispersive spectrometer, LiF200 and LiF220 analyzing crystal, scintillation and gas flow-proportional counters and an automatic sample changer (Veldkamp, 1991).

Appendix IV

XRFS-analysis for major and minor comp.

ample	SiO2 %	TiO2 %	Al2O3 %	Fe2O3 %	MnO %	MgO %	CaO %
.1	53.79	0.62	10.87	4.27	0.07	2.03	12.16
.2	49.58	0.64	11.91	4.72	0.06	2.25	12.06
.3	52.49	0.59	9.92	4.22	0.07	1.96	12.69
.4	50.49	0.64	11.56	4.62	0.05	2.13	12.06
.5	49.66	0.72	12.43	4.63	0.05	2.21	12.12
.6	58.52	0.46	8.25	3.44	0.07	1.59	11.69
.7	45.99	0.79	14.14	4.88	0.05	2.43	12.28
.8	57.12	0.52	9.22	3.80	0.08	1.77	11.44
.9	48.52	0.70	11.89	5.03	0.08	2.32	12.58
.10	47.46	0.66	11.81	4.77	0.09	2.13	13.14
.11	70.32	0.26	4.20	1.68	0.04	0.94	9.97
.12	73.61	0.20	3.67	1.39	0.04	0.86	10.30
.13	48.73	0.68	11.96	4.76	0.09	2.45	12.27
.14	65.82	0.17	3.56	1.47	0.05	1.12	13.33
.15	54.83	0.56	10.30	4.27	0.06	1.84	11.82
.16	69.78	0.12	2.97	1.18	0.04	1.01	11.90
.17	47.84	0.71	13.15	4.52	0.05	2.32	12.39
.18	51.30	0.62	11.29	4.51	0.08	2.03	12.18
.19	67.56	0.30	5.00	2.10	0.05	1.03	11.24
.20	50.77	0.71	13.19	4.77	0.05	2.21	11.52
.21	59.80	0.51	8.25	4.86	0.06	1.60	10.20
.22	47.72	0.75	13.15	5.16	0.08	2.39	11.85
.23	64.32	0.37	6.13	2.70	0.05	1.28	11.04
.24	51.98	0.68	11.53	4.55	0.07	2.07	12.09
A	50.13	0.50	11.03	7.12	0.14	2.81	11.53
	58.85	0.44	8.84	4.79	0.07	3.79	9.15
A	54.49	0.64	10.37	4.30	0.13	1.51	11.92
B	49.85	0.38	6.43	2.93	0.16	2.73	17.55
C	64.90	0.56	9.33	4.02	0.18	1.79	7.94
D	67.09	0.69	11.56	4.90	0.18	1.79	3.45
A	68.59	0.57	9.98	5.43	0.09	5.04	1.91
B	74.25	0.29	4.88	1.94	0.05	1.10	8.55
C	57.67	0.52	9.19	3.55	0.07	1.91	11.20
	64.43	0.58	11.73	5.86	0.10	5.09	2.13
	55.96	0.45	9.80	6.13	0.27	5.36	7.21
.2	68.33	0.56	10.28	4.90	0.06	2.82	3.61
.3A	62.94	0.29	6.00	2.69	0.08	1.07	13.19
.3B	42.38	0.68	9.73	5.31	0.06	3.26	17.93
.4	70.19	0.17	3.51	1.12	0.03	0.98	12.36
.5	19.57	0.27	3.65	1.89	0.04	0.96	41.08
.6	59.86	0.33	5.80	2.80	0.12	1.48	14.60
.7A	49.15	0.41	6.94	3.98	0.24	7.92	12.66
.7B	52.36	0.39	7.05	3.54	0.23	5.83	12.15
.7C	65.49	0.48	8.68	3.90	0.07	2.24	6.76
.7D	52.84	0.36	6.84	3.32	0.17	6.03	12.00

< # means less then lower limit of detection

XRFS-analysis for major and minor comp.

sample	NaO %	K2O %	P2O5 %	BaO %	L.o.I. %	SUM %
A1	0.15	2.01	0.11	0.04	14.23	100.36
A2	0.30	2.17	0.13	0.04	14.53	98.39
A3	0.13	1.89	0.11	0.04	14.19	98.29
A4	0.13	1.92	0.12	<0.03	14.39	98.13
A5	0.18	2.16	0.12	0.03	14.62	98.92
A6	0.09	1.46	0.09	<0.03	12.60	98.31
A7	0.19	2.37	0.13	0.03	15.31	98.59
A8	0.15	1.64	0.09	<0.03	13.04	98.89
A9	0.22	2.10	0.13	0.03	14.62	98.21
A10	0.22	2.11	0.14	0.03	15.51	98.07
A11	<0.04<	0.82	0.06	<0.03	9.72	98.01
A12	<0.04<	0.67	0.05	<0.03	9.89	100.65
A13	0.16	2.18	0.12	<0.03	14.67	98.09
A14	<0.04	0.56	0.04	<0.03	11.90	98.04
A15	0.07	1.80	0.11	0.04	13.62	99.32
A16	<0.04<	0.53	0.04	<0.03	10.90	98.39
A17	0.06	2.38	0.13	0.04	14.98	98.57
A18	<0.04	2.02	0.12	0.03	14.31	98.54
A19	<0.04<	1.00	0.07	<0.03	11.01	99.34
A20	0.10	2.24	0.13	0.04	14.44	100.17
A21	<0.04	1.53	0.12	<0.03	11.88	98.87
A22	0.11	2.33	0.14	<0.03	15.05	98.76
A23	0.08	1.26	0.08	<0.03	11.19	98.51
A24	0.13	1.93	0.12	<0.03	14.23	99.43
A	0.23	1.38	0.11	0.04	13.86	98.88
	0.36	1.31	0.07	<0.03	11.09	98.79
A	<0.04<	1.18	0.07	0.04	14.15	98.69
B	<0.04	0.78	0.07	0.05	17.58	98.55
C	<0.04<	1.19	0.08	0.04	10.39	100.37
D	<0.04<	1.42	0.06	0.03	7.51	98.67
A	0.19	1.34	0.06	<0.03	6.24	99.45
B	<0.04<	0.89	0.06	<0.03	8.94	100.94
C	0.07	1.62	0.10	0.03	12.96	98.90
	0.27	1.73	0.06	<0.03	7.26	99.26
	0.21	1.17	0.06	0.03	12.07	98.74
2	<0.04	1.28	0.08	<0.03	7.18	99.12
3A	0.14	0.99	0.06	<0.03	11.76	99.23
3B	0.28	1.39	0.09	0.05	17.87	99.04
4	<0.04<	0.62	0.02	<0.03	10.98	99.95
5	<0.04<	0.47	0.02	0.09	30.30	98.27
6	0.12	0.97	0.07	0.04	12.24	98.42
7A	0.36	0.80	0.07	<0.03	17.05	99.60
7B	0.16	0.91	0.08	<0.03	16.10	98.81
7C	<0.04	1.40	0.08	<0.03	9.16	98.32
7D	0.15	0.78	0.06	<0.03	16.80	99.40

< # means less then lower limit of detection.

XRFS-analysis for major and minor comp.

sample	SiO2 %	TiO2 %	Al2O3 %	Fe2O3 %	MnO %	MgO %	CaO %
17E	39.52	0.21	3.93	2.20	0.26	5.83	22.86
18	59.54	0.54	9.59	4.15	0.10	1.59	9.69
19A	60.55	1.07	19.08	6.32	0.10	2.21	0.65
19B	59.08	0.95	17.81	6.94	0.10	1.96	1.61
20	66.49	0.25	4.66	1.91	0.12	1.01	12.17
20B	51.79	0.34	6.31	3.62	0.07	0.93	19.05
21A	55.71	0.36	7.15	3.20	0.09	1.84	14.19
21B	58.10	0.37	7.32	3.30	0.09	1.91	14.54
22	63.92	0.48	9.16	4.65	0.11	1.31	8.49
23	65.04	0.57	10.67	5.31	0.13	2.13	5.24
24	44.12	0.40	7.31	3.61	0.11	1.21	20.48
25A	70.23	0.35	5.92	3.12	0.20	1.09	8.11
25B	59.85	0.69	10.13	3.18	0.08	2.28	9.11
26A	70.93	0.26	5.36	2.18	0.06	0.83	8.99
26B	65.86	0.33	6.71	2.74	0.11	1.33	10.17
26C	66.08	0.31	6.22	2.92	0.12	1.28	10.47
27	63.07	0.51	8.27	3.69	0.06	2.46	8.79
30	44.98	0.46	9.07	5.11	0.08	2.30	17.12
32	58.14	0.33	6.57	4.05	0.11	4.92	10.89
34A	70.15	0.38	6.46	2.60	0.11	1.39	7.70
34B	62.03	0.59	10.06	3.90	0.08	2.24	7.51
34C	75.34	0.65	11.55	4.25	0.07	1.48	0.22
37	64.97	0.34	5.72	2.36	0.06	0.73	12.10
38	58.66	0.54	9.09	6.57	0.06	6.34	5.86
21B	62.45	0.35	6.90	3.14	0.08	1.13	12.52

< # means less then lower limit of detection.

XRFS-analysis for major and minor comp.

sample	NaO	K2O	P2O5	BaO	L.o.I.	SUM
	%	%	%	%	%	%
17E	0.18	0.50	0.05	0.05	23.45	99.05
18	0.15	1.50	0.12	0.05	11.51	98.54
19A	0.56	3.65	0.17	0.04	5.12	99.52
19B	0.33	3.48	0.16	0.05	5.73	98.19
20	<0.04<	0.76	0.06	0.03	10.67	98.08
20B	<0.04	0.82	0.05	0.04	15.64	98.70
21A	<0.04	1.06	0.06	0.04	14.50	98.20
21B	<0.04	1.09	0.07	<0.03	11.65	98.49
22	0.36	1.39	0.10	<0.03	9.32	99.33
23	0.59	1.52	0.10	<0.03	7.15	98.48
24	<0.04<	0.99	0.08	0.05	19.68	98.05
25A	0.08	1.00	0.07	<0.03	8.36	98.54
25B	0.13	1.65	0.12	0.04	11.47	98.73
26A	0.05	0.94	0.07	<0.03	8.33	98.03
26B	0.11	1.10	0.08	<0.03	10.12	98.68
26C	0.14	1.02	0.08	<0.03	9.97	98.63
27	0.15	1.17	0.08	<0.03	10.60	98.88
30	<0.04	1.23	0.12	0.04	17.83	98.37
32	0.24	0.89	0.07	<0.03	11.99	98.18
34A	0.15	1.25	0.06	<0.03	8.26	98.53
34B	0.22	1.85	0.10	<0.03	9.85	98.46
34C	0.47	2.07	0.10	<0.03	2.92	99.14
37	<0.04<	0.79	0.05	<0.03	11.31	98.35
38	0.33	1.52	0.10	<0.03	9.25	98.35
21B	0.15	1.08	0.06	0.03	11.65	99.56

< # means less then lower limit of detection.

XRFS-analysis for trace-elements.

sample	Ba ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Nb ppm
A1	354	28	94	22	14	29	13
A2	274	<20	77	44	15	31	11
A3	262	<20	66	23	16	29	13
A4	250	<20	72	18	16	17	<10
A5	304	<20	77	28	15	26	16
A6	253	<20	57	15	12	16	11
A7	286	21	84	31	18	27	10
A8	237	23	58	19	13	22	11
A9	252	<20	74	19	16	21	13
A10	274	<20	76	24	16	<15	12
A11	214	44	33	12	<10	<15	12
A12	193	56	26	12	<10	<15	11
A13	272	<20	77	34	18	34	10
A14	177	34	27	13	<10	<15	<10
A15	357	48	87	27	15	16	14
A16	172	33	18	11	<10	<15	<10
A17	266	24	85	21	18	28	14
A18	238	25	73	17	15	18	14
A19	226	38	40	14	11	<15	<10
A20	293	<20	81	25	18	20	14
A21	275	55	67	18	12	23	13
A22	277	26	74	24	18	24	13
A23	245	33	42	44	11	<15	13
A24	281	30	71	21	17	20	15
3A	276	43	732	15	11	27	10
4	296	39	321	15	11	<15	<10
5A	331	<20	123	11	13	33	16
5B	323	<20	160	<10	<10	20	11
5C	416	<20	174	14	<10	27	13
5D	445	<20	225	15	15	25	17
6A	311	27	763	15	13	29	17
6B	239	31	33	15	<10	<15	13
6C	294	<20	58	14	10	25	12
7	354	31	482	17	14	<15	10
9	349	48	766	19	12	19	11
12	269	78	150	17	14	27	13
13A	241	34	90	15	<10	<15	<10
13B	270	47	283	15	<10	25	16
14	175	33	28	<10	<10	<15	<10
15	132	35	99	<10	<10	16	<10
16	288	<20	71	<10	<10	<15	<10
17A	198	23	283	11	<10	16	<10
17B	211	43	265	<10	<10	20	<10
17C	266	20	67	22	13	26	13
17D	206	73	150	14	<10	<15	10

< # means less then lower limit of detection.
> # out of range of regression line.

RFS-analysis for trace-elements.

ample	Ni ppm	Pb ppm	Rb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm
1	49	24	80	328	114	54	193
2	30	26	95	354	133	64	177
3	29	22	77	313	118	38	221
4	34	22	76	342	118	61	165
5	37	26	97	343	141	61	190
6	26	18	64	267	86	28	175
7	39	29	101	330	154	66	175
8	32	40	66	270	99	34	174
9	35	26	93	333	125	66	178
10	33	26	81	338	123	58	183
11	80	10	36	177	48	22	139
12	81	11	29	172	38	26	121
13	36	27	95	308	147	57	180
14	62	13	18	184	32	18	88
15	51	23	88	288	110	53	177
16	65	10	21	158	29	11	80
17	32	21	103	346	140	58	175
18	39	25	87	292	118	57	182
19	77	11	40	190	58	28	130
20	33	23	97	316	141	70	192
21	94	25	64	207	104	67	193
22	39	27	101	305	140	68	184
23	71	17	56	197	68	33	186
24	42	26	82	287	125	55	191
A	448	32	52	116	99	58	128
	345	20	55	152	86	42	129
A	52	23	49	106	117	38	229
B	72	17	27	182	69	<10	154
C	82	25	56	135	100	30	190
D	79	33	75	117	131	47	224
A	365	28	69	122	114	53	197
B	53	15	42	156	59	21	215
C	28	22	79	252	97	33	203
	425	28	88	100	114	49	157
	460	32	51	110	89	56	116
2	167	19	65	144	110	55	169
3A	125	18	42	164	57	<10	99
3B	231	27	55	173	124	39	225
4	32	17	25	145	32	<10	88
5	65	11	24	67	40	<10	75
6	77	19	36	174	55	19	102
7A	200	18	34	187	74	20	124
7B	200	19	40	169	72	29	136
7C	73	23	65	138	89	41	171
7D	131	13	34	147	70	26	130

< # means less then lower limit of detection.
> # out of range of regression line.

XRFS-analysis for trace-elements.

sample	Ba ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Nb ppm
17E	156	31	190	<10	<10	<15	<10
18	310	47	98	23	14	26	15
19A	614	52	96	63	27	45	15
19B	547	20	82	62	23	59	12
20	232	26	44	<10	<10	19	<10
20B	252	<20	104	<10	<10	<15	<10
21A	222	37	103	13	<10	23	<10
21B	257	45	109	21	10	19	<10
22	355	29	198	26	13	<15	11
23	332	41	206	18	15	26	15
24	252	62	197	13	10	<15	11
25A	292	52	121	<10	<10	<15	10
25B	377	<20	86	21	13	29	22
26A	227	31	114	17	<10	<15	<10
26B	293	176	170	14	10	19	<10
26C	278	42	112	12	<10	18	<10
27	303	121	282	12	14	<15	14
30	232	39	454	<10	12	19	11
32	274	56	366	19	10	<15	<10
34A	266	28	88	<10	<10	<15	12
34B	272	<20	89	11	13	<15	11
34C	355	26	59	13	18	22	11
37	214	28	48	<10	11	24	<10
38	285	32	476	<10	13	<15	12
21B	251	53	126	<10	<10	<15	10

< # means less then lower limit of detection.
> # out of range of regression line.

XRFS-analysis for trace-elements.

ample	Ni ppm	Pb ppm	Rb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm
7E	168	12	31	184	42	10	91
8	101	34	59	159	101	74	188
9A	69	39	166	91	221	176	245
9B	51	39	160	111	190	184	214
0	70	14	35	138	45	18	88
0B	55	18	30	127	62	<10	118
1A	53	23	38	195	68	30	136
1B	58	20	45	205	85	34	143
2	110	61	58	132	96	55	142
3	183	34	68	150	103	52	168
4	119	23	35	148	78	59	159
5A	120	22	43	120	73	35	207
5B	69	24	69	161	125	37	299
6A	99	22	39	113	55	39	101
6B	162	20	44	117	61	58	105
6C	83	19	43	134	63	29	110
7	191	21	60	203	88	68	227
0	276	31	63	96	84	40	133
2	248	24	39	172	69	49	99
4A	70	25	56	142	71	40	131
4B	45	28	77	223	108	82	192
4C	67	23	96	92	110	79	172
7	42	15	32	130	61	11	144
8	264	45	69	114	105	39	128
1B	116	22	43	159	63	36	112

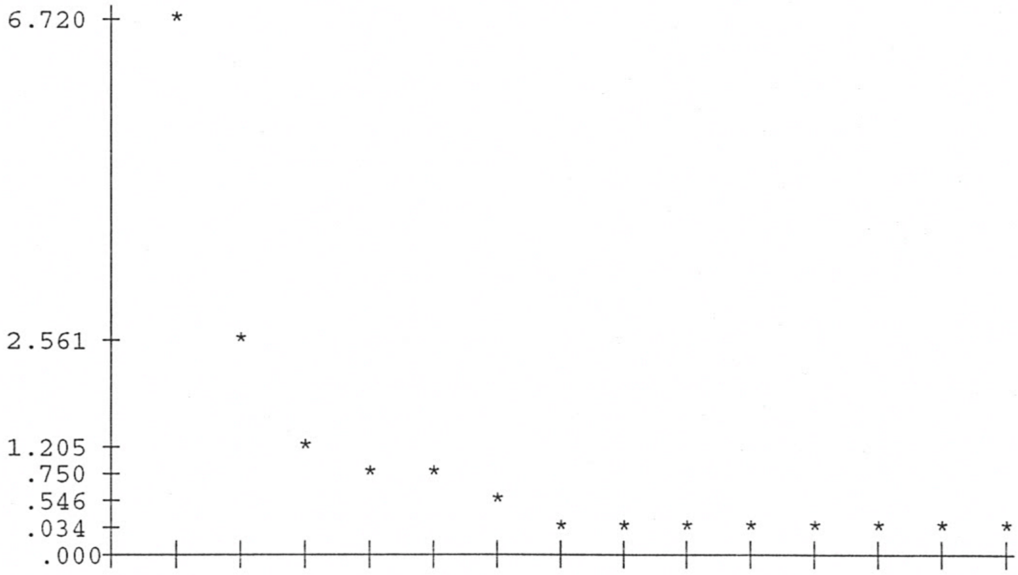
< # means less then lower limit of detection.
> # out of range of regression line.

Conversion list and data of the exposures

exposure	code	x-coord	y-coord
A	T	347.40	4066.77
3	Rh	345.55	4068.62
4	Rh	344.92	4067.94
5	T	347.93	4075.77
6	Cl	346.07	4070.97
7	Ch	345.29	4071.53
9	A6	345.66	4069.50
12	T	345.28	4075.77
13	A4	350.03	4065.54
14	T	350.10	4064.68
15	A5	350.43	4064.61
16	A4	348.21	4073.98
17	T	347.43	4074.34
18	A3	348.49	4074.77
19	C	348.95	4075.78
20	A7	348.78	4075.76
21	A4	346.78	4071.51
22	A3	347.17	4071.69
23	A6	344.98	4070.66
24	T	346.08	4071.66
25	C	345.02	4070.62
26	A3	346.92	4071.36
27	Rl	346.59	4068.70
30	A4	351.18	4065.10
32	A3	348.34	4067.62
34	T	351.25	4069.29
38	A3	349.05	4065.53

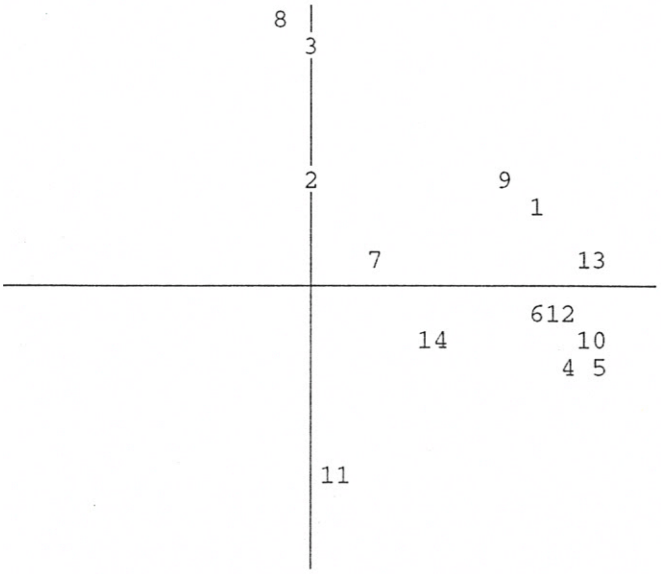
Appendix V

```
        - - - -   F A C T O R   A N A L Y S I S   - - - -

raction  1  for Analysis  1, Principal-Components Analysis (PC)

itial Statistics:

iable       Communality  *  Factor   Eigenvalue  Pct of Var   Cum Pct
                         *
               1.00000   *     1      6.72020       48.0        48.0
               1.00000   *     2      2.56105       18.3        66.3
               1.00000   *     3      1.20481        8.6        74.9
               1.00000   *     4       .99758        7.1        82.0
               1.00000   *     5       .74998        5.4        87.4
               1.00000   *     6       .54573        3.9        91.3
               1.00000   *     7       .34297        2.4        93.7
               1.00000   *     8       .27739        2.0        95.7
               1.00000   *     9       .22323        1.6        97.3
               1.00000   *    10       .15664        1.1        98.4
               1.00000   *    11       .09264         .7        99.1
               1.00000   *    12       .05759         .4        99.5
               1.00000   *    13       .03637         .3        99.8
               1.00000   *    14       .03382         .2       100.0

        - - - -   F A C T O R   A N A L Y S I S   - - - -
```



```
          - - - -   F A C T O R   A N A L Y S I S   - - - -

PC Extracted    3 factors.

tor Matrix:

          FACTOR  1      FACTOR  2      FACTOR  3

            .80160         .31766         .01224
          -.22729          .41980        -.34922
          -.03645          .89364         .17687
            .80164        -.07400        -.36145
            .90908        -.08409        -.20279
            .77228         .02220         .03975
            .56563         .00187         .69852
          -.17296          .91153         .07198
            .61159         .42132        -.00262
            .94747        -.03674        -.14542
            .30948        -.63988         .01517
            .96372         .03584         .03981
            .86247         .19942        -.34499
            .75446        -.10975         .49292

          - - - -   F A C T O R   A N A L Y S I S   - - - -

al Statistics:

iable        Communality  *  Factor   Eigenvalue   Pct of Var   Cum Pct
                          *
                 .74361   *     1       6.72020       48.0        48.0
                 .34984   *     2       2.56105       18.3        66.3
                 .83120   *     3       1.20481        8.6        74.9
                 .77876   *
                 .87462   *
                 .59849   *
                 .80787   *
                 .86598   *
                 .55156   *
                 .92019   *
                 .50545   *
                 .93163   *
                 .90264   *
                 .82422   *
```

```
           - - - -   F A C T O R   A N A L Y S I S   - - - -

tated Factor Matrix:

           FACTOR  1      FACTOR  2      FACTOR  3

             .77786         .21608         .30307
            -.00595         .39412        -.44099
             .04686         .90693         .08049
             .85483        -.21892        -.00981
             .89104        -.22083         .17861
             .69217        -.06725         .33893
             .25142         .02579         .86255
            -.03489         .92723        -.07071
             .62744         .33928         .20682
             .91210        -.17131         .24272
             .17098        -.66513         .18390
             .86879        -.07723         .41336
             .94898         .04475         .00867
             .48284        -.13446         .75697

           - - - -   F A C T O R   A N A L Y S I S   - - - -

ctor Transformation Matrix:

            FACTOR  1      FACTOR  2      FACTOR  3

CTOR  1       .91100        -.12222         .39387
CTOR  2       .16445         .98352        -.07517
CTOR  3      -.37819         .13325         .91609
```



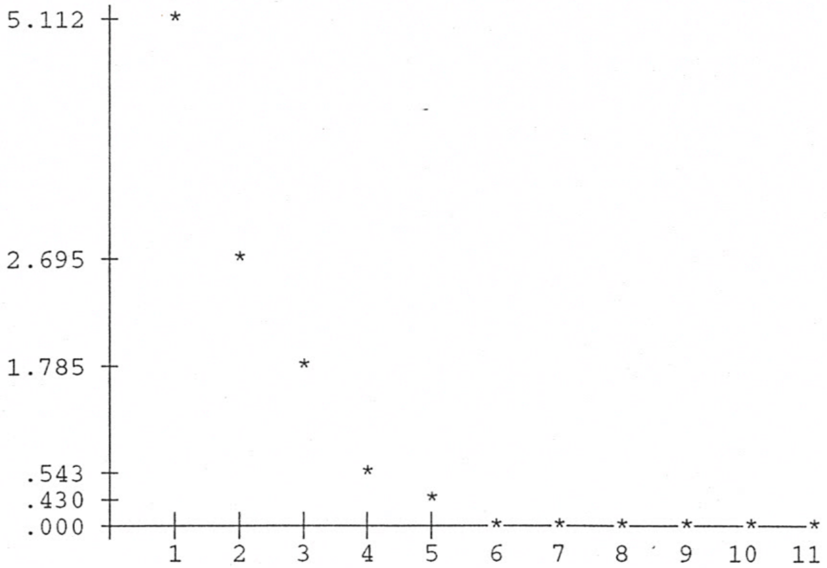
```
 1   BA   .778    .216
 2   CO  -.006    .394
 3   CR   .047    .907
 4   CU   .855   -.219
 5   GA   .891   -.221
 6   LA   .692   -.067
 7   NB   .251    .026
 8   NI  -.035    .927
 9   PB   .627    .339
10   RB   .912   -.171
11   SR   .171   -.665
12   V    .869   -.077
13   ZN   .949    .045
14   ZR   .483   -.134
```

```
            - - - -   F A C T O R   A N A L Y S I S   - - - -

rizontal Factor  1   Vertical Factor  3     Symbol Variable   Coordinates

                   |                              1   BA    .778   .303
                   |   7                          2   CO   -.006  -.441
                   |      14                      3   CR    .047   .080
                   |                              4   CU    .855  -.010
                   |                              5   GA    .891   .179
                   |              12              6   LA    .692   .339
                   |             6                7   NB    .251   .863
                   |             1  10            8   NI   -.035  -.071
                   |11         9     5            9   PB    .627   .207
                   3                             10   RB    .912   .243
------------------------------------------       11   SR    .171   .184
                 8 |               413           12   V     .869   .413
                   |                             13   ZN    .949   .009
                   |                             14   ZR    .483   .757
                   |
                   2
                   |
                   |
                   |
                   |
                   |
```

```
            - - - -   F A C T O R   A N A L Y S I S   - - - -

rizontal Factor  2   Vertical Factor  3     Symbol Variable   Coordinates

                   |                              1   BA    .216   .303
                   7                              2   CO    .394  -.441
              14   |                              3   CR    .907   .080
                   |                              4   CU   -.219  -.010
                   |                              5   GA   -.221   .179
                12 |                              6   LA   -.067   .339
                 6 |                              7   NB    .026   .863
              10   |   1                          8   NI    .927  -.071
    11       5     |     9                        9   PB    .339   .207
                   |                 3           10   RB   -.171   .243
------------------------------------------       11   SR   -.665   .184
             4    13                 8           12   V    -.077   .413
                   |                             13   ZN    .045   .009
                   |                             14   ZR   -.134   .757
                   |
                   |       2
                   |
                   |
                   |
                   |
                   |
```

```
          - - - -   F A C T O R   A N A L Y S I S   - - - -

:tor Score Coefficient Matrix:

            FACTOR  1     FACTOR  2     FACTOR  3

              .12522        .10876        .04697
              .10577        .12672       -.29117
             -.00308        .36341        .10611
              .21738       -.08297       -.22567
              .18149       -.07126       -.09844
              .09364       -.00112        .07484
             -.14247        .06769        .56422
              .01249        .36116        .01783
              .11078        .15039        .02149
              .17173       -.04743       -.05396
             -.00389       -.24968        .04846
              .12045        .00064        .08570
              .23802        .02274       -.21762
             -.05950       -.00135        .42224

          - - - -   F A C T O R   A N A L Y S I S   - - - -

/ariance Matrix for Estimated Regression Factor Scores:

            FACTOR  1    FACTOR  2    FACTOR  3

:TOR  1      1.00000
:TOR  2      -.00000      1.00000
:TOR  3       .00000       .00000      1.00000


          - - - -   F A C T O R   A N A L Y S I S   - - - -

ılysis Number  1  Listwise deletion of cases with missing values

:raction  1  for Analysis  1, Principal-Components Analysis (PC)

.tial Statistics:

:iable      Communality  *  Factor   Eigenvalue   Pct of Var   Cum Pct
                         *
)2              1.00000  *     1      5.11192        46.5        46.5
)2              1.00000  *     2      2.69478        24.5        71.0
:O3             1.00000  *     3      1.78482        16.2        87.2
:O3             1.00000  *     4       .54259         4.9        92.1
)               1.00000  *     5       .42980         3.9        96.0
)               1.00000  *     6       .22010         2.0        98.0
)               1.00000  *     7       .14545         1.3        99.4
)               1.00000  *     8       .04549          .4        99.8
)               1.00000  *     9       .01254          .1        99.9
)5              1.00000  *    10       .00925          .1       100.0
                1.00000  *    11       .00326          .0       100.0
```

```
        - - - -   F A C T O R   A N A L Y S I S   - - - -
```

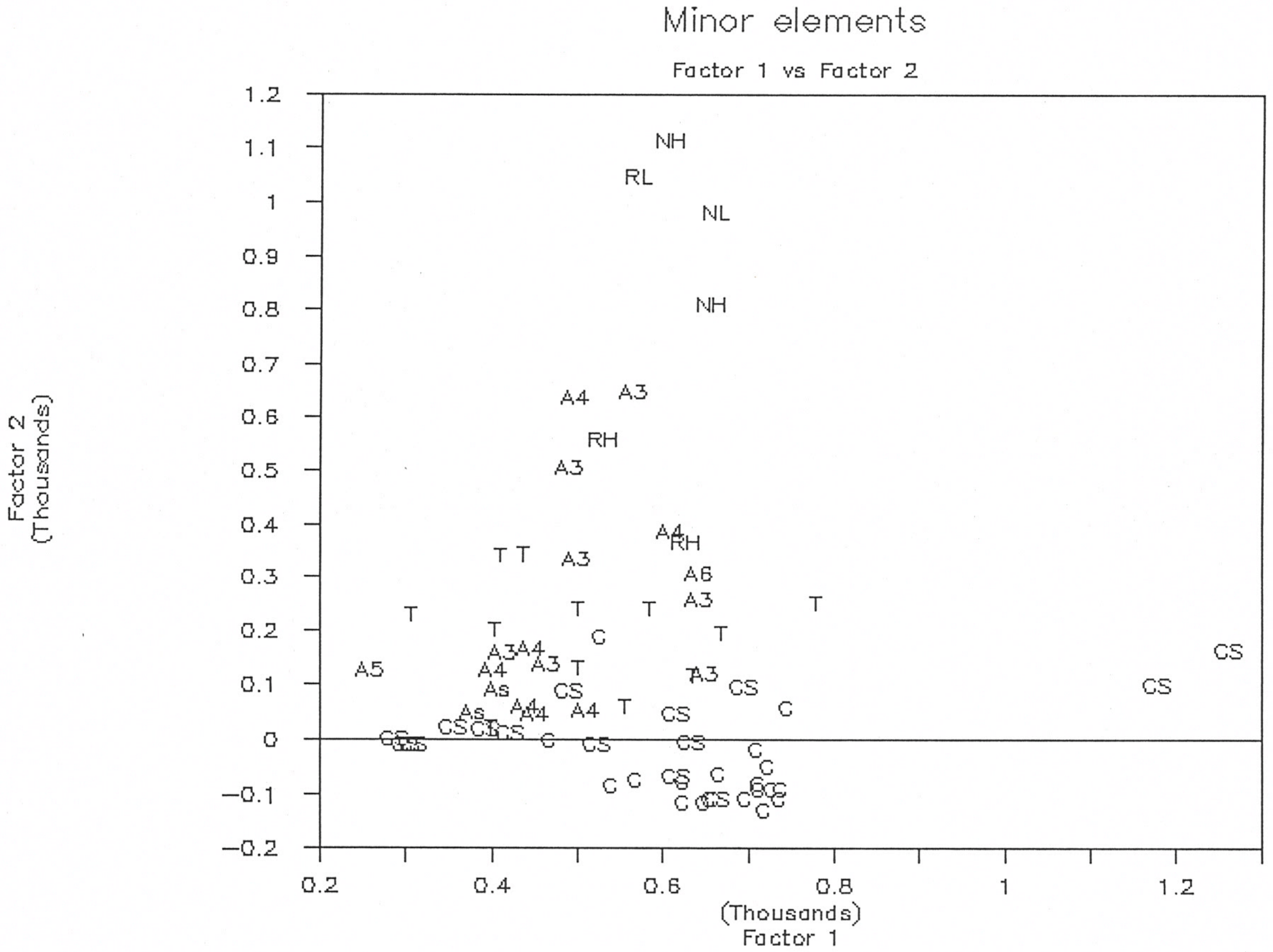


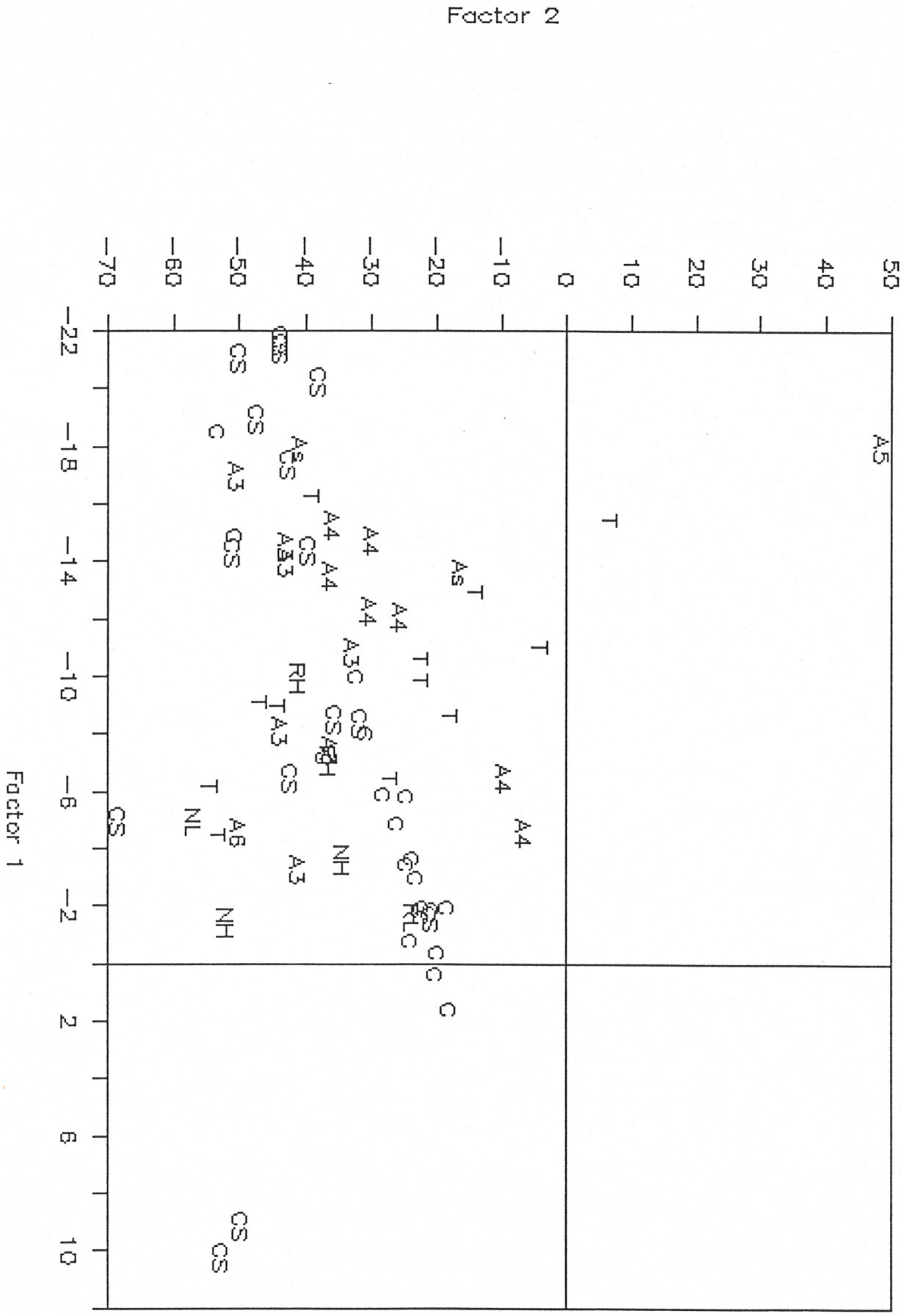
```
        - - - -   F A C T O R   A N A L Y S I S   - - - -

 PC Extracted    3 factors.

tor Matrix:

              FACTOR  1     FACTOR  2     FACTOR  3

2              -.13199       -.98705        .02733
2               .94574        .12358       -.15544
O3              .97059        .11328       -.10402
O3              .87493        .16109        .20968
               -.00234        .16250        .83256
                .25394        .26267        .81749
               -.54082        .79131       -.22551
                .65639       -.09533        .35959
                .93199        .04731       -.27776
5               .86266        .19583       -.29033
               -.30318        .94616       -.04556
```

```
           - - - -   F A C T O R   A N A L Y S I S   - - - -

al Statistics:

iable       Communality  *  Factor   Eigenvalue   Pct of Var   Cum Pct
                         *
2                .99243  *     1       5.11192        46.5        46.5
2                .93386  *     2       2.69478        24.5        71.0
O3               .96570  *     3       1.78482        16.2        87.2
O3               .83541  *
                 .71956  *
                 .80177  *
                 .96951  *
                 .56924  *
                 .94800  *
5                .86682  *
                 .98921  *

            - - - -   F A C T O R   A N A L Y S I S   - - - -

imax   Rotation  1,  Extraction  1,  Analysis  1 - Kaiser Normalization.

arimax converged in    5 iterations.

ated Factor Matrix:

            FACTOR  1     FACTOR  2     FACTOR  3

2             -.29869       -.93508       -.16984
2              .96520       -.04332        .01921
O3             .97791       -.06569        .07123
O3             .83471       -.04633        .36950
              -.13060        .03649        .83736
               .13710        .08546        .88072
              -.34836        .90642       -.16298
               .55208       -.27388        .43524
               .96195       -.09671       -.11535
5              .92214        .06275       -.11198
              -.12598        .98360        .07665

            - - - -   F A C T O R   A N A L Y S I S   - - - -

tor Transformation Matrix:

             FACTOR  1     FACTOR  2     FACTOR  3

TOR  1          .96790       -.19649        .15673
TOR  2          .16800        .96958        .17801
TOR  3         -.18694       -.14596        .97147
```

```
izontal Factor  1   Vertical Factor  2     Symbol Variable   Coordinates

              11   |                             1   SIO2   -.299  -.935
           7       |                             2   TIO2    .965  -.043
                   |                             3   AL2O3   .978  -.066
                   |                             4   FE2O3   .835  -.046
                   |                             5   MNO    -.131   .036
                   |                             6   MGO     .137   .085
                   |                             7   CAO    -.348   .906
                   |                             8   NAO     .552  -.274
                   |                             9   K2O     .962  -.097
               5   | 6              10          10   P2O5    .922   .063
-------------------+---------------------       11   LI     -.126   .984
                   |               4 3
                   |                 9
                   |         8
                   |
                   |
                   |
                   |
                   |
                   |
             1     |


        - - - -   F A C T O R   A N A L Y S I S   - - - -

izontal Factor  1   Vertical Factor  3     Symbol Variable   Coordinates

                   |                              1   SIO2    -.299  -.170
               5   | 6                            2   TIO2     .965   .019
                   |                              3   AL2O3    .978   .071
                   |                              4   FE2O3    .835   .369
                   |                              5   MNO     -.131   .837
                   |         8                    6   MGO      .137   .881
                   |               4              7   CAO     -.348  -.163
                   |                              8   NAO      .552   .435
                   |                              9   K2O      .962  -.115
              11   |                 3           10   P2O5     .922  -.112
-------------------+---------------------        11   LI      -.126   .077
                   |
           7 1     |                10
                   |
                   |
                   |
                   |
                   |
                   |
                   |
```

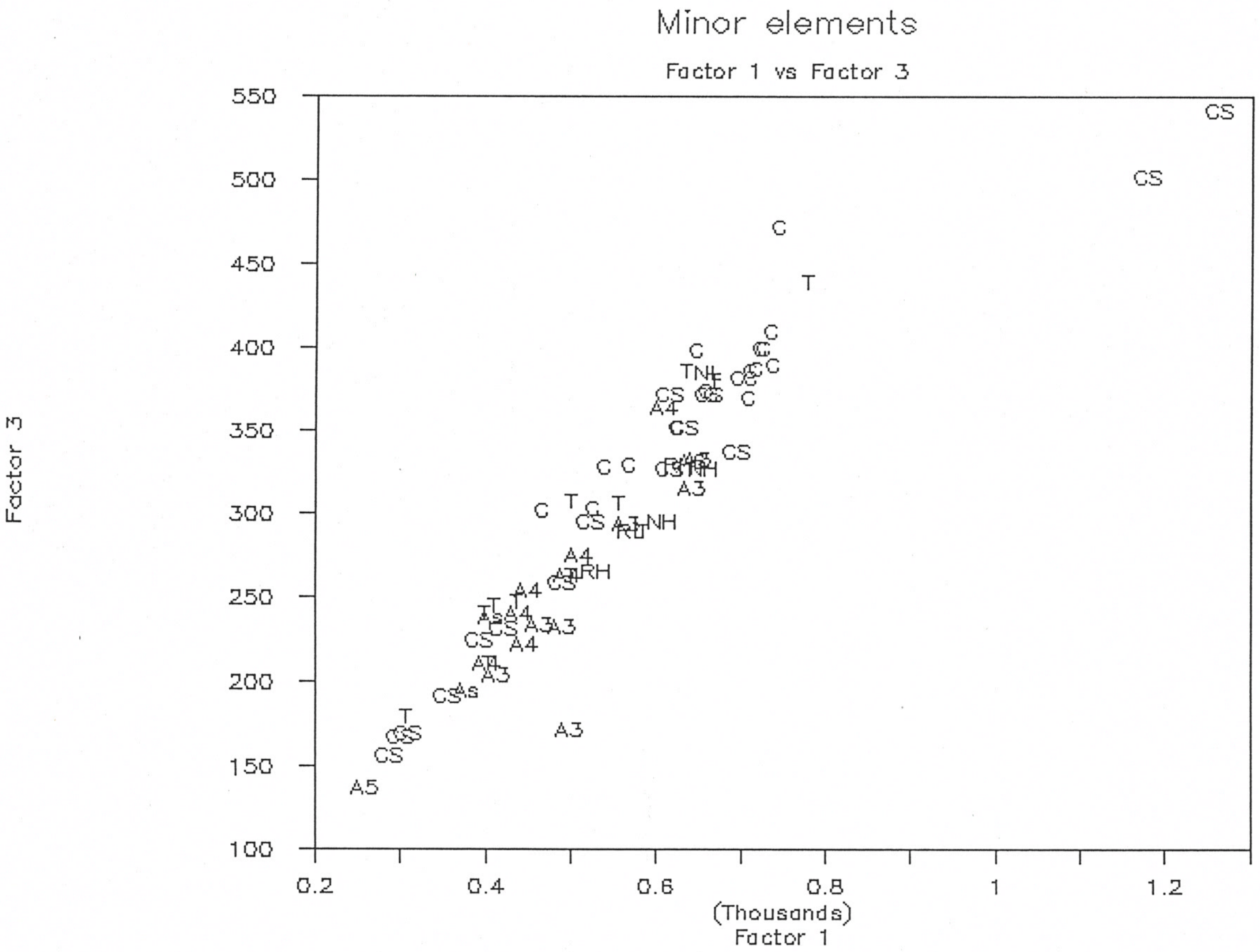
```
           - - - -   F A C T O R   A N A L Y S I S   - - - -

izontal Factor  2   Vertical Factor  3    Symbol Variable   Coordinates

                  |                                1   SIO2    -.935  -.170
                  6                                2   TIO2    -.043   .019
                  |                                3   AL2O3   -.066   .071
                  |                                4   FE2O3   -.046   .369
                  |                                5   MNO      .036   .837
            8     |                                6   MGO      .085   .881
                4 |                                7   CAO      .906  -.163
                  |                                8   NAO     -.274   .435
                  |                                9   K2O     -.097  -.115
                3 |                11             10   P2O5     .063  -.112
------------------+----------------------         11   LI       .984   .077
                  |
                910                  7
                  |
                  |
                  |
                  |
                  |
                  |
                  |
                  |

           - - - -   F A C T O R   A N A L Y S I S   - - - -

tor Score Coefficient Matrix:

            FACTOR  1     FACTOR  2     FACTOR  3

)2           -.08939       -.35230       -.05437
)2            .20305        .02082       -.04745
O3            .20173        .01196       -.01938
O3            .15374        .00718        .15159
)            -.07751       -.00953        .46382
)            -.02116        .01789        .47009
)            -.02945        .32394       -.08705
)             .08068       -.08894        .20955
)             .20851        .00391       -.11949
)5            .20595        .06105       -.11864
              .00635        .35581        .02841

           - - - -   F A C T O R   A N A L Y S I S   - - - -

ariance Matrix for Estimated Regression Factor Scores:

            FACTOR  1    FACTOR  2    FACTOR  3

TOR  1       1.00000
TOR  2        .00000      1.00000
TOR  3       -.00000      -.00000      1.00000
```


Minor elements
Factor 1 vs Factor 2
Factor 2
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
0.2
0.4
0.6
0.8
1
1.2
(Thousands)
Factor 1
NH
RL
NL
NH
A4
A3
RH
A3
A4
RH
T T
A3
A6
A3
T
T
T
T
T
A5
A3
A4
A4
A3
T
C
As
CS
A3
CS
C
CS
A4
A4
T
CS
As
CS
CS
CS
C
CS
CS
CS
C
C
C
CS
C
C
C
CS
C
C



Major elements

Factor 1 vs Factor 2


Minor elements
Factor 1 vs Factor 3
Factor 3
550
500
450
400
350
300
250
200
150
100
0.2
0.4
0.6
0.8
1
1.2
(Thousands)
Factor 1
CS
CS
C
T
C
TNH
CS
A4
CS
CS
C
C
A3
C
T
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CS
NH
A4
RH
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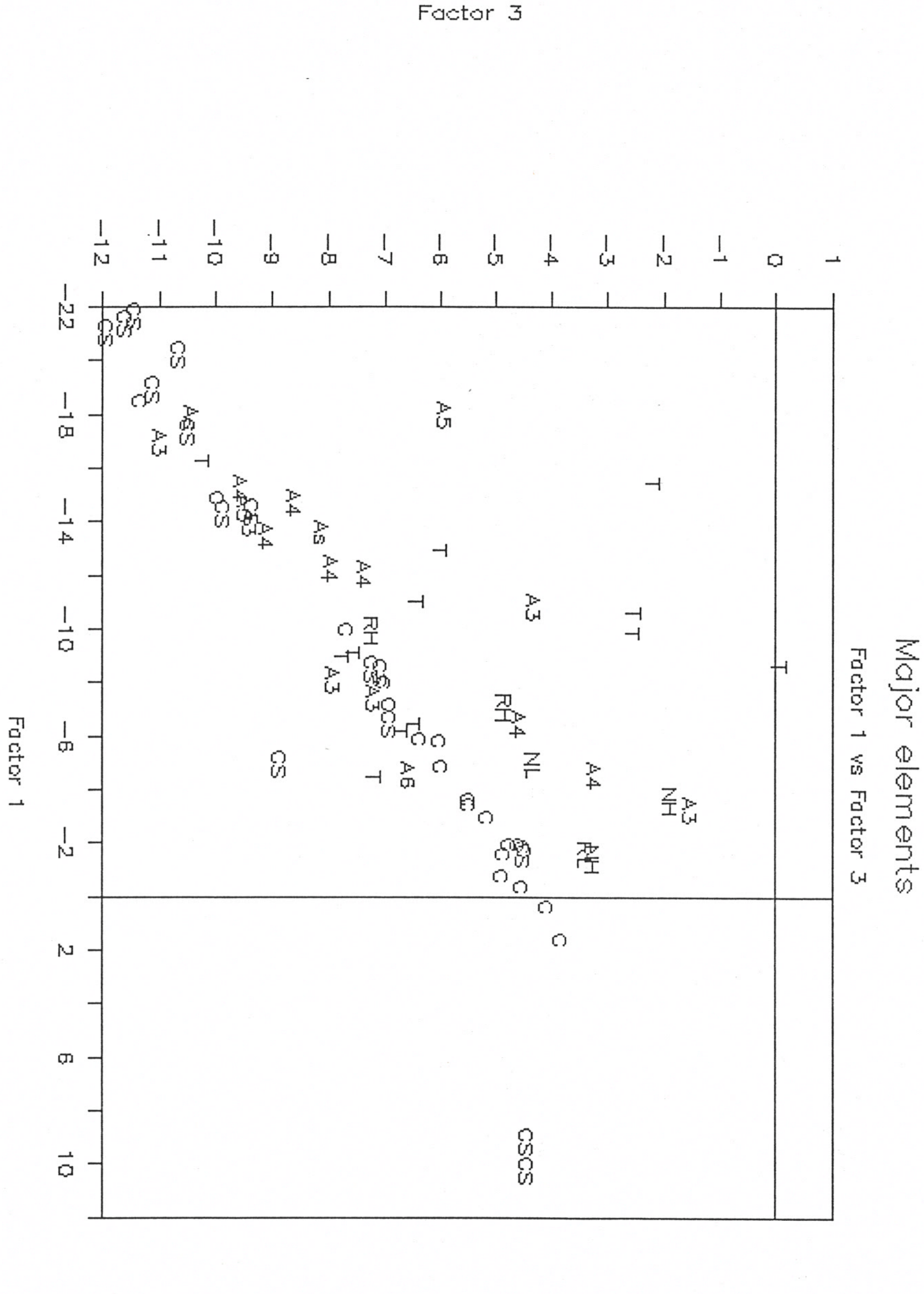
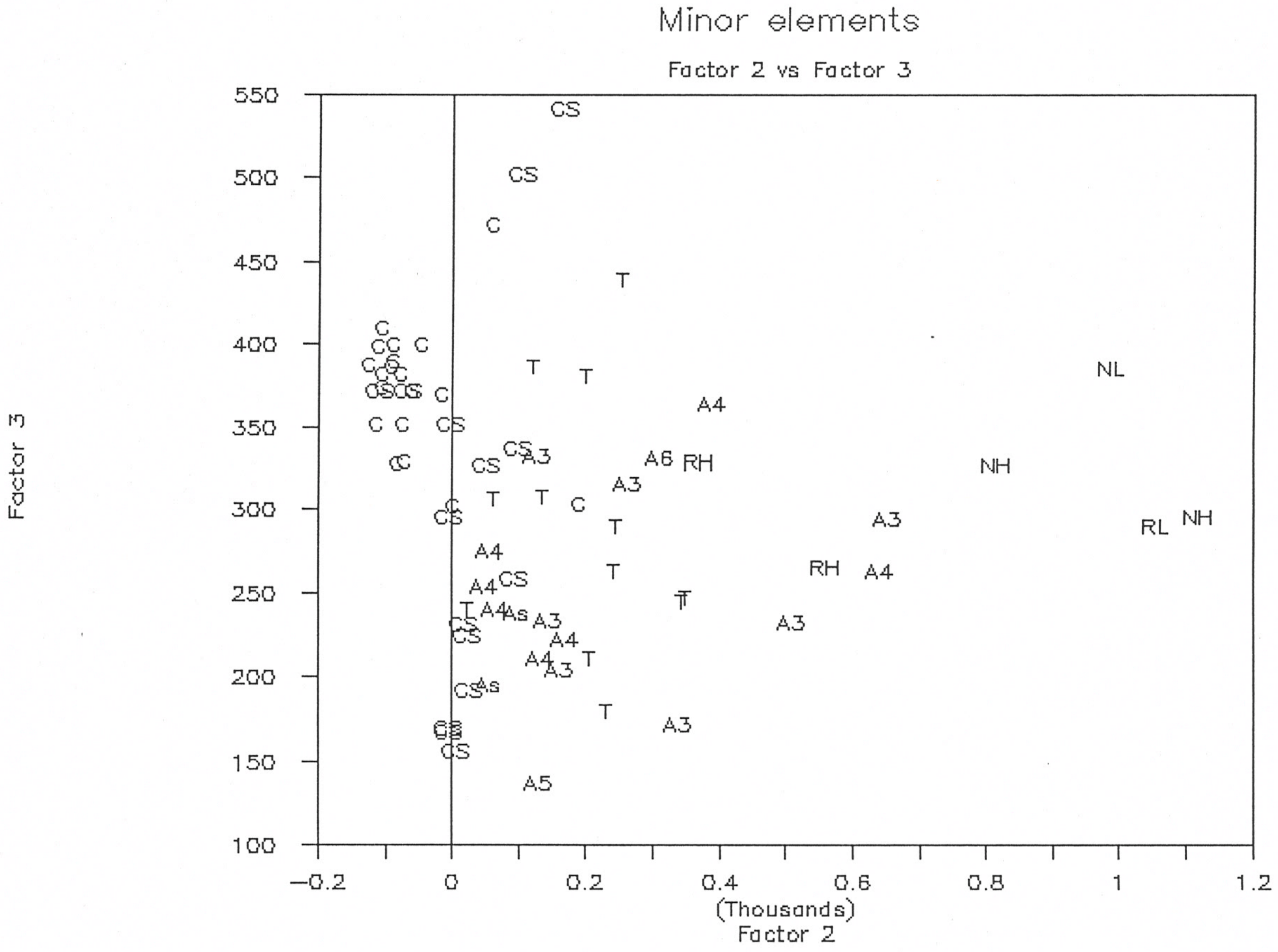
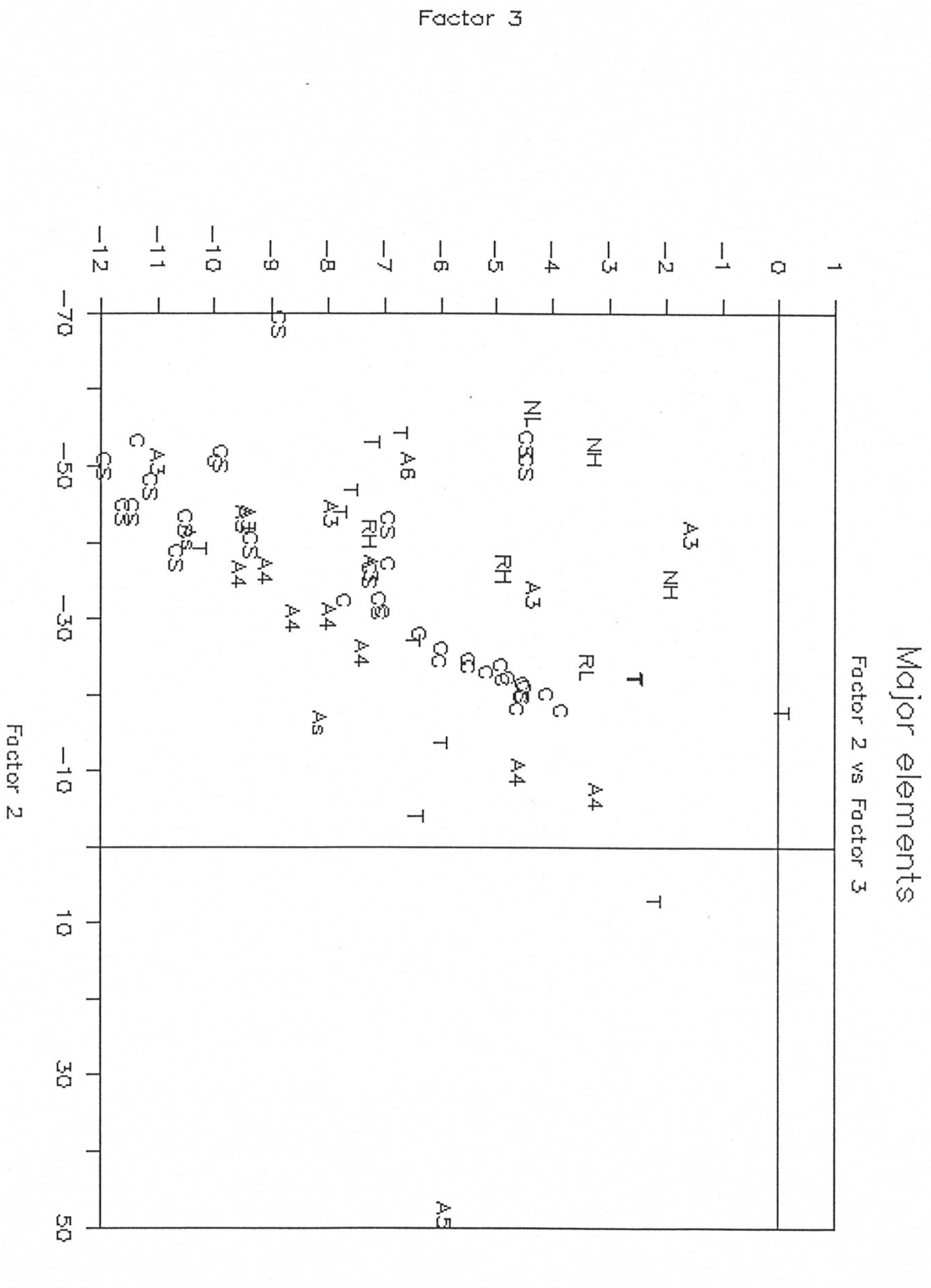
CS
A3
A5
A3



Major elements
Factor 1 vs Factor 3


Minor elements
Factor 2 vs Factor 3
Factor 3
550
500
450
400
350
300
250
200
150
100
−0.2
0
0.2
0.4
0.6
0.8
1
1.2
(Thousands)
Factor 2
C
CS
T
A3
A4
A5
A6
As
RH
NH
NL
RL


Major elements
Factor 2 vs Factor 3
Factor 3
Factor 2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−11
−12
−70
−50
−30
−10
10
30
50
CS
C
A3
A4
A5
A6
T
NH
NL
RH
RL
As

Appendix VI

```
(********************************************************************)
(*    GUABAL                                                        *)
(*    Module Global: definiering en het declareren van de globale   *)
(*          variabelen van het programma terras                     *)
(*          - de tijd                                               *)
(*          - de entiteit rivier                                    *)
(*          - de entiteit landschap                                 *)
(*          - de processen                                          *)
(*    Guadalhorce Spanje: 1992 Joep Crompvoets & Jos Hegmans        *)
(********************************************************************)

[ENVIRONMENT('FLU.BAL')]MODULE FLUBAL;

CONST
      TMAX=2000;  (* De eindtijd in duizenden jaren             *)
                  (* moet deelbaar door 100 zijn!                *)
      TMIN=2;           (* De begintijd in duizend jaar          *)
                  (* TMIN <= TIJD <= TMAX                        *)

      XMAX=100;   (* Het relief bestaat uit x,y,z                *)
      YMAX=100;   (* coordinaten waarbij                         *)
      ZMAX=500;   (* XMIN <= X <= XMAX                           *)
      XMIN=1;           (* YMIN <= Y <= YMAX                     *)
      YMIN=1;           (* ZMIN <= Z <= ZMAX                     *)
      ZMIN=1;

      XMID=50;    (* De plaats waar de rivier loopt, de          *)
                  (* laagste plaats in een dwarsprofiel          *)

(*****************************************************************)
(*                                                               *)
(* Simulatieconstanten  Simulatieconstanten  Simulatieconstanten *)

      ZMID=65;    (*De beginhoogte van relief op xmin,ymin       *)
      INIHOOGTE = 8;    (* ZMID - INIHOOGTE = de beginhoogte van *)
                  (* het relief op plaats XMID,YMIN              *)

      XMETER = 10000;   (* Een dwarsprofiel in meters            *)
      YMETER = 10000;   (* Een lengteprofiel in meters           *)
      ZMETER = 500;     (* De hoogte in meters                   *)

      QTEKGEM1 = 0.09;(* De gemiddelde tektoniek in              *)
                  (*                meters/2000 jaar             *)
      QTEKGEM2 = 0.09;
      QTEKGEM3 = 0.09;
      QTEKAMPL = 0.000000003;(* De variatie in tektoniek m/1000 j.*)
      QTEKPERIOD = 2000;(* De periode van de tektoniek in 1000j  *)
      QTEKHOEK = 0.000025;(* De mate van scheve opheffing in     *)
                  (* meters/1000 jaar                            *)
      QGEM = 95;  (* nu 13.5 m3/s het gemiddelde debiet in m3/sec *)
      QAMP = 80;  (* de variatie in debiet in m3/sec             *)


      INLGEM = 0.12E-3;(* de gemiddelde inlast in m3/sec         *)
      INLAMP = 0.1E-3;(* de variatie in inlast in m3/sec         *)
      FLUX = 5;
      PRECC = 96; (* de perioden van de Milankovitch curve       *)
```

```
      ECC = 41;   (* in 1000 jaar                                *)
      TILT = 23;
      ORBECC = 413;
      A = 1.0;    (* de amplitude van een periode van            *)
      B = 1.0;    (* de Milankovitchcurve; verhoudings-          *)
      C = 1.0;    (* getallen, dimensieloos                      *)
      D = 0.0;
                  (* constanten om de maximale last te berekenen *)
        MB= 7.96E-5;    (* meander bedload                       *)
        MS= 2.2E-8;     (* meander suspended load                *)
        MD= 3E-6; (* meander dissolved load                      *)
        VB= 5.23E-4;    (* verwilderd bed load                   *)
        VS= 1.9E-8;     (* verwilderd suspended load             *)
        VD= 3.2E-6;     (* verwilderd dissolved load             *)

      CHEMIN = 1; (* minimale geochemische waarde sediment       *)
      CHEMAX = 100;     (* maximale geochemische waarde sediment *)

      UIT1MAX = 20;     (* tijdsinterval in duizend jaar, waarna *)
                  (* de schrijfopdracht gegeven wordt voor       *)
                  (* een relief x,z,t                            *)
      UIT2MAX = 1950;   (* tijdstip voor een relief x,y,z        *)
                  (* waarop deze wordt weggeschreven             *)

(* Simulatieconstanten  Simulatieconstanten  Simulatieconstanten *)
(*                                                               *)
(*****************************************************************)

TYPE
            (* foutmeldingen                                     *)
            (* ZETMIN: indien Z = ZMIN op plaats xmid,ymax       *)
            (* ZETMAX: indien Z = ZMAX op plaats xmin,ymin       *)
            (* DWARSERO:XMID,de plaats waar de rivier loopt,     *)
            (*    is niet de laagste plaats in een dwars         *)
            (*    profiel tijdens de erosie                      *)
            (* DWARSSED: idem, tijdens de sedimentatie           *)
            (* DUMERO:de DUMEROSIE,een restwaarde,is te groot    *)
            (* OKAY: Er is geen foutmelding                      *)
      FOUTRIJ = (ZETMIN,ZETMAX, DWARSERO, DWARSSED,DUMERO,OKAY);

VAR
      X,          (* X is dwarsprofiel in coordinaateenheden     *)
      Y,          (* Y is lengteprofiel in "                     *)
      Z,          (* Z is hoogte        in "                     *)
      OUD,        (* erosie capaciteit tester en geheugen voor   *)
                  (* regelmatige erosie/sedimentatie             *)
      GLACIAAL,   (* variabele om lengte glaciaal te bepalen     *)
      TIJD: INTEGER;    (*    TIJD in duizend jaar               *)

                  (* De entiteit rivier met de attributen:       *)
      RIVIER :RECORD
            Q:    REAL; (* debiet in m3/sec                      *)
            INLAST:     REAL; (* inlast in m3/sec                *)
            CHEM: INTEGER; (* geochemische eigenschappen
                                      sediment                   *)
            MEANDER: BOOLEAN;(* de vorm van de rivier            *)
            VERWILDERD: BOOLEAN;
            M50:  REAL; (* de korrelgrootte in mm                *)
```

```
        S:     REAL; (* het verhang van de
                                    rivierbedding m/m            *)
        BREEDTE:REAL;      (* de breedte van de
                                    stroomvlakte in m            *)
        MAXLAST:REAL;      (* de maxlast in m3/sec               *)
        QEROSIE:REAL;    (* de erosie van de rivier in m3/sec    *)
        END;

              (* de entiteit landschap met de attributen         *)
  LANDSCHAP:  RECORD
        QTEKTONIEK: REAL;(* de tektoniek in een tijdstap
                                   in meter                      *)
        HOOGTE :INTEGER; (* het verschil in hoogte tussen het
                            hoogste terras (xmin,ymin) en
                            de rivier*) bedding (xmid,ymin)
                            in grideenheden                      *)
        DALBREEDTE:INTEGER;(* de valleibreedte in grideenheden*)
        S:     INTEGER;(* het verhang van het relief in
                          grideenheden relief(xmid,ymin) -
                          relief(xmid,ymax)                      *)
        QEROSIE:INTEGER;(* de erosie in een tijdstap in
                           grideenheden                          *)
        END;


  RELIEF: ARRAY[XMIN..XMAX,YMIN..YMAX] OF
        RECORD
              ZET: INTEGER;(* de hoogte van een gridpunt         *)
              STRATIG: PACKED ARRAY[1..10] OF TMIN..TMAX;
                    (* de stratigrafie onder een gridpunt        *)
              GEOCHEM: PACKED ARRAY[1..10] OF CHEMIN..CHEMAX;
                    (* chemostratigrafie onder een gridpunt      *)
        END;

              (* de processen                                    *)
  TEKTONIEK,
  EROSIE,
  INSNIJDING,
  KANT,
  SEDIMENTATIE:      BOOLEAN;

  FOUT: FOUTRIJ;(* foutvariabele                                 *)

END (* GUABAL *).
```