Aeolian Origin of Some Wetlands in the Douro Basin, the High Moraña Region (Avila, Spain)

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SUMMARY

The present paper analyses some wetlands within the southern region of the Douro Basin emphasizing their aeolian origin, based on geomorphological mapping, physical, chemical and mineralogical soil analyses and sedimentary studies of the soil parent materials. To prove the aeolic origin of the surrounding forms of the wetlands, also technics of scanning electronical microscopy are used. From the whole set of technics used the doubtless aeolian origin of the mentioned wetlands is evident, refusing other interpretations suggested for them.

KEY WORDS: Wetlands, aeolian origin, scanning electronical microscopy.

RESUMEN

El presente trabajo analiza algunos humedales y más específicamente su origen eólico en el área sur de la cuenca del Duero, basándose en los estudios de cartografía geomorfológica, análisis físico-químicos y mineralógicos de los suelos y análisis sedimentarios del material en el que éstos se asientan. Para demostrar el origen eólico de las formas circundantes a los humedales también se utilizan técnicas de microscopía electrónica de barrido. De la constelación de técnicas empleadas se pone de manifiesto el indudable origen eólico de los mencionados humedales, por encima de otras intrepretaciones que se han sugerido para ellos.

PALABRAS CLAVE: Humedales, origen eólico, microscopía electrónica de barrido.

RÉSUMÉ

Le travail present fait l'analyse de certaines zones humides de la région sud du Basin du Duero, remarquand leur origin éolien, sur la base de la cartographie géomorphologique, des analyses physiques, chimiques et minéralogiques des sols et des analyses sedimentaires de la roche-mère. A fin d'assurer l'origin éolien des formes du relief des environs des zones humides on a utilicé des techniques du microscope electronique de scanning. Après l'utilisation des techniques employées l'origin éolien des zones humides citées est évident, rejettant d'autres interpretations.

MOTS CLÉS: Torres humides, origin éolien, microscope electronique du scanning.

INTRODUCTION AND STATE OF THE ART

A large number of wetland sites are associated with the Tertiary sedimentary basins of the Iberian Peninsula. These hygrochores (Sanz Donaire, 1992) have been known since the beginning of this century (Dantín Cereceda, 1929), but have been restudied in the last 20 years (Plans, 1969; Montes & Martino, 1987). Examples have also been studied from the Ebro Basin (Quirantes, 1965;Ibáñez Marcellán, 1973, 1975), from the Tagus Basin (Vaudour,1979; González Bernáldez et al., 1989), Guadiana Basin (Peinado Martín Montalvo, 1989, 1994; Pérez González, 1989a, 1988b, 1995; Sanz Donaire, 1993, 1995, 1996, 1997; Sanz Donaire & Sánchez Pérez de Évora, 1993; Sanz Donaire, Díaz Álvarez & Sánchez Pérez de Évora, 1994) and from the Guadalquivir Basin (Grande Covian, 1982; Sanz Donaire & Pérez González, 1991; Pérez González, García Rodríguez & Sanz Donaire, 1992).

Many of the above authors relate the origin and natural functioning of these wetlands to an appropriate source material: karstified limestones, pseudokarstic features due to solution in gypsum and other saline rocks underneath the surface, remnants of old oxbow lakes and abandoned fluvial channels, depressions created at the lithological contact between two different rocks, tectonic graben depressions, or to clayey and sandy silts denudated by piping.

A climatic origin has also been suggested: Saharan summer drought; the continental character of the inner part of the Meseta, surrounded by highlands which inhibit the free entry of moisture by the westerlies; scarce annual rainfall (less than 600 mm); high seasonal pluvial regime; high potential evapotranspiration especially during the summer, controlling the shrinkage of water bodies decay; and the extremely long period of summer sunshine lowering the water table.

The surface hydrology, which depends on climatic conditions, but which is also controlled by the elevation above sea level, stands out as another possible origin of ponds and depressions. Some areas within the innermost parts of Spain remain endorheic, with no outlet to the sea.

The levelled or flat topography is a result of the tectonic stability of the Tertiary sedimentary basins. Horizontal, continental sediments remain undisturbed and explaining the mesa-like landforms, and vast fluvial plains.

Until 1970, the level of groundwater had not dropped since there was sufficient to recharge the aquifers naturally.Closeness of piezometric levels to surface has facilitated ponds, lakes, flood plains and natural meadows to continue to exist over a long time period. During the last 20 years overexploitation of groundwater has caused many wetlands to disappear or to change completely to other water regimes under stress. Since groundwater inputs are no longer active, the only way in which aquifers have been recharged has been through surface runoff, and floods, in a semiarid country, where most rivers and tributary streams do function as water sinkholes, feeding the general water table.

The unchanging land use has produced a progressive desiccation of wetlands, because hygrochores were thought to be unhealthy, at least according to the National Water Act of 1870. Most wetlands were thus reduced in extension, changed by channeling, and embankment. They were drained, especially during and after the 1940s in order to eradicate malaria.

In recent years the dry seasons in the wetlands have increased dramatically: hyperexplotation has followed overexplotation,with Spanish aquifers becoming aquivacua(empty of water)! The best agricultural production was possible only through groundwater depletion, and rural incomes increased considerably.

It is the aim of this paper to emphasize the importance of aeolian agents in building up hilly ridges which delineate depressions where the best conditions for the location and functioning of wetlands are found. This is achieved through the study of aeolian landforms and sediments associated to some hygrochores within the High Moraña region in the Spanish province of Avila. Selection of sites was made taking into account the sharpness of aeolian landforms in this region which represent a large northern fringe on the contact between ancient crystalline basement rocks of the Spanish Sistema Central and sedimentary basin of the Douro river, where over 40 riverine, palustrine and lacustrine wetland complexes may be found.

THE GEOGRAPHICAL CONTEXT

North of the crystalline and metamorphic basement rocks of the Spanish Sistema Central (which rises to 2592 m above sea level) the depression of the Arevalillo-Espinarejo Rivers, lies within the sedimentary basin — locally a tectonic graben— of the main Douro River (Fig.1). Many rivers, such as the Adaja, flow northwards into the Douro following deep faults alignments which affect the whole area of Tertiary sediments. Some very old fanglomeratic fluvial sediments, called «rañas», accompany the south-to-north orientation of the rivers. These «rañas» are remnants of Plio-Pleistocene alluvial fans which developed during the final stage of the filling up in the Douro basin.

At the point of contact between Tertiary arkosic and sandy sediments and the Hercynian basement, the subsequent depression delineates a ENE-WSW band parallel to the fault scarp. This depression is called locally the Moraña

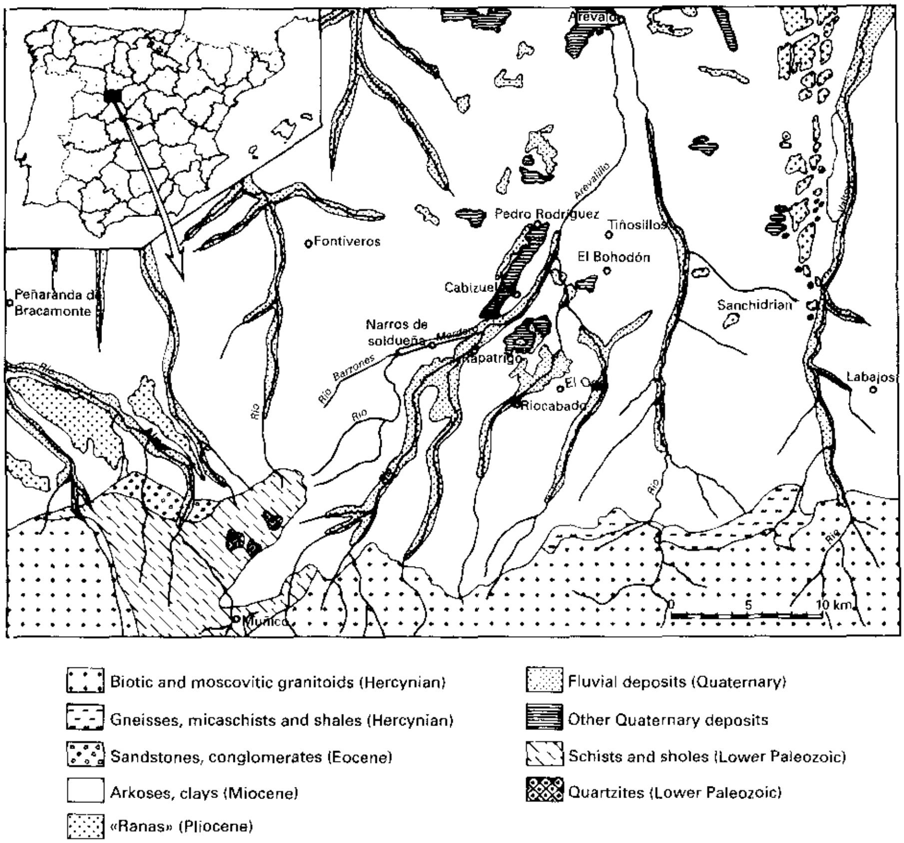

Fig. 1.

region and was built up mainly by fluvial agents during the ancient and mid-Quaternary times. It is on a quite flat, slightly north-eastward tilted plain crossed by the braided course of the Arevalillo river. Some old channels connect those meadows situated closest to river systems. Since 1957 man-made canalization of the Arevalillo and tributaries has reorganized the whole drainage system, so that alluvial plains are no longer linked to streams. The channel has been ditched constantly and used as a non-stop sand pit because of its natural tendency to refill.

GEOMORPHOLOGIC SCHEMATIC MAP

As shown in fig. 2 and 3, geomorphic features of the surroundings of the village of Papatrigo are summarized as follows:

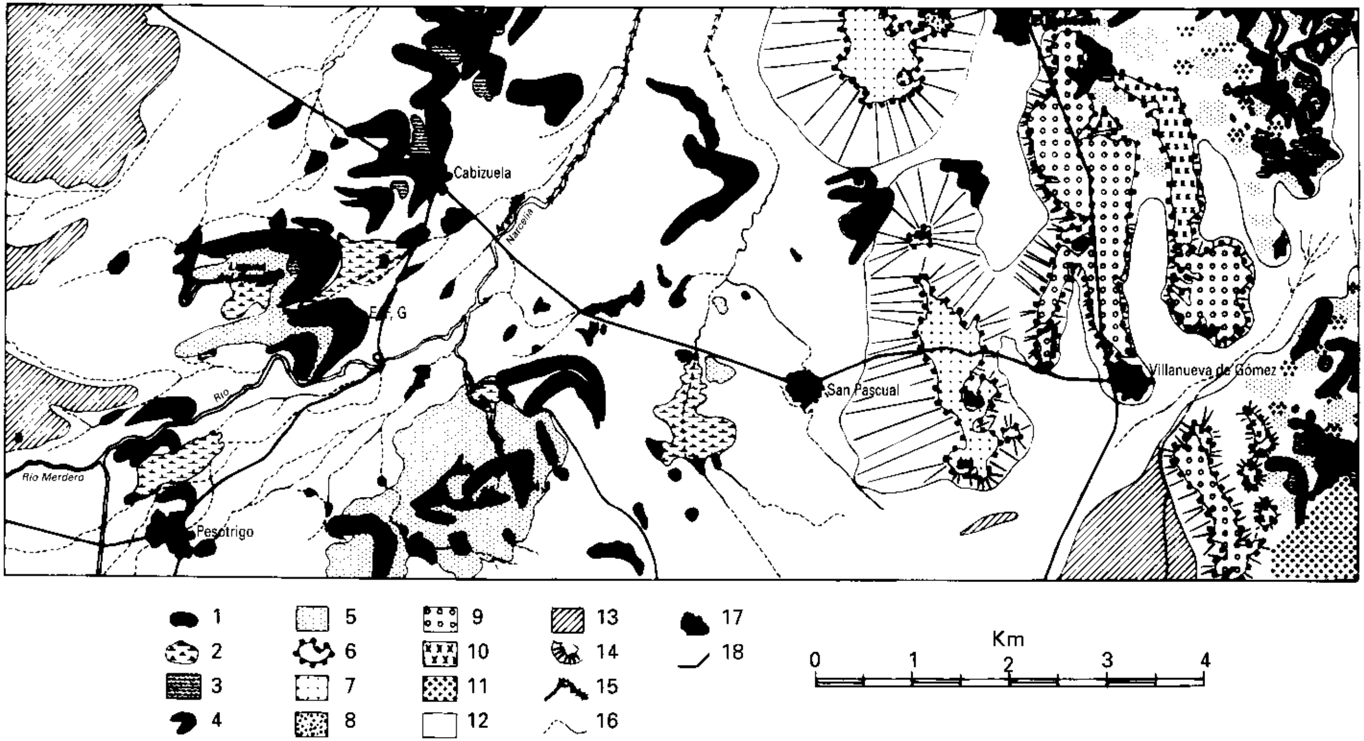

Fig. 2. (*Legend*). 1. *Seasonal ponds.*–2. *Meadows.*–3. *Interdunal depressions.*–4. *Aeolian dunes.*–5. *Coversands.*–6. *Terrace scarps.*–7. *7th terrace.*–8. *6th terrace.*–9. *5th terrace.*–10. *4th terrace.*–11. *3th terrace.*–12. *Flat topography.*–13. *Hilly topography.*–14. *Hillslopes around terraces.*–15. *Embanked and dissected waterways.*–16. *Seasonal waterways.*–17. *Villages.*–18. *Roads.*

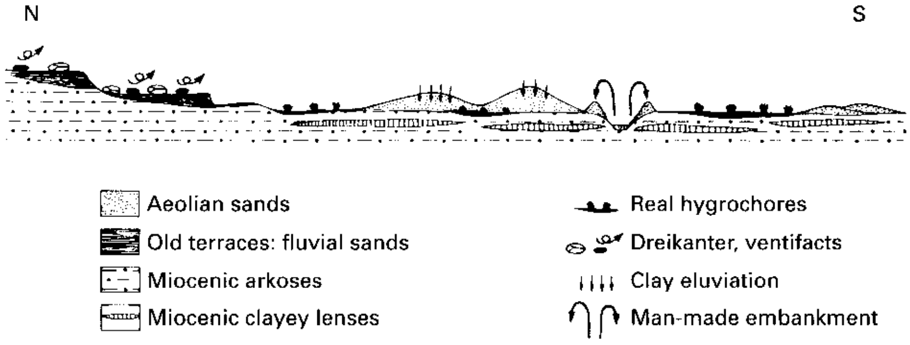

Fig. 3.

i) South to north flowing Adaja river, which is responsible for the accumulation of gravel and sand deposits in, at least, 7 terraces. Only 4 levels have been mapped in this figure, but two levels lie underneath and one level above the highest recognized in this map. Terraces show a soil catena rising from alluvial soils in the first terrace through brown soils toward old leached brown soils in the uppermost terrace. Some pebbles and cobbles suffered brownish weathering duricrusts in the older terraces, and even ferruginization of raña-like sediments.

ii) The main fluvial plain has left blank sands, although some soil texture differences could appear. At certain sites natric-like horizons may be found, well correlated to shallow wetlands. Deposition of smectite-rich sediments at the edges of Miocene alluvial fans has caused natric horizons to develop. Nevertheless, most of the alluvial plain is sandy.

iii) At the hilly margins of fluvial plain , some remnants of sandy flat terraces can be found, showing gravelly brown soils. Many pebbles and cobbles are ventifacts, typical *dreikanters* and *zweikanters* with aeolian smoothed surface texture.

iv) Cover sands and parabolic dunes are spread over the flood-plain. Typical crests on parabolic dunes are located directly near the front of advancing sand. The slip face is leeside. The height of dunes never rises more than 10 m above the general topographic level. Pines forests (*Pinus pinaster*, *Pinus pinea*) grow on sand dunes, although some vineyards also prefer these warm sandy soils rather than cold clayey alluvial natric horizons. The dunes cover usually the flat top of the third Adaja river terrace and the alluvial flood plain of Papatrigo-Cabizuela. No dunes are found on younger terraces, so that sand deflation seems old. The incipient development of soils in sand dunes emphasizes this supposition.

v) The Adaja river and its tributary, Arevalillo, have dissected a deep trench with only 2 narrow terraces along the stream. Dissection is considered to be recent Quaternary. If deflation would have been active during this period of time, a fluvial trench would have acted as an aeolian sediment natural trap.

WETLAND TYPES AND CHARACTERISTICS

Hygrochores in the Moraña Region can be classified (Sanz Donaire & Díaz Álvarez, 1992) into three groups (Fig. 2 and 3):

I) Broad flat meadows surrounded by rushes, which are irrigated to enhance grass production. These meadows were located until 1957 at the river sides and flooded naturally. Since 1957 irrigation is necessary to provide water supply, because of the man-made embankments along the river. Their typical shape is irregular but with a lineal trend. Locally they are called «prados» (meadows) or «vegas» (alluvial plains).(number 1 in fig. 2)

II) Shallow depressions or holes that trend to maintain a water body after heavy rainfall. Although they have been told to be fed by saline or brackish ground water (Rey Benayas, 1991), our opinion is to consider only rainfall as the main water input today. Maybe, in the past, when water level was not deep enough because no heavy groundwater exploitation had taken place, some of those holes or ponds could have had water incomes from below. High alkalinity may be due to vadose water flow in the soil, and to the presence of carbonates in dry seasonal lands. General flatness inhibits lateral ion migration, so that salts remain in water and soil. The shape of these wetlands is irregular, amoeboidal with a circular or elliptical trend. Names like «**sal**obrales», «**sal**mueras», «**sal**güeros», «bohodones», etc. are locally used and emphasize salt content. So does halophytic vegetation as *Pucinellia festuciformis*, *Plantago maritima* and rarely *Camphorosma monspelliaca* which also have xeric character.(number 2 in fig. 2)

III) Interdunal depressions which are almost never filled with water, but where the underlying ground is less buried by cover sands or blown dunes. This last type mainly occupies the eastern-most area mapped, where the dissecting Adaja river drains all interstitial water in the soil and ground water, flowing about 25 m deeper than the third or fourth terraces upon which dunes were deposited.(number 3 in fig. 2).

Such depressions have a curved shape, fitting parabolic dunes. When these depressions with no outlet are excavated until general terrace ground, soil moisture is enough to allow *Scirpus holoschoenus* species to grow, independently from water table. If not, no vegetation is found.

The general vegetation landscape on sandy and arkosic soils is based on pines, *Pinus pinea*, *Pinus pinaster* and grasses, *Corynephorus canescens* and typical mediterranean plants: *Retama shaerocarpa*, *Adenocarpus hispanicus*, *Lavandula stoechas*, *Thymus mastichina*, etc.

WATER ANALYSIS RESULTS AND COMMENTS

The water from the **Laguna del Hoyo** was once analysed (samples taken in April), because only after heavy equinoctial rainfall this pond became filled with water. Because of strong winds, the water body was reduced to a 20-30 cm shallow sheet a week after rainfall ceased. The Laguna del Hoyo represents a «salobral» type of wetland over a very fine sand and clayey ground where water has difficulty to seep. It is located at 40º 53' 35" N, 4º 49' 10" W (European Datum), 885 m high.

Here are the results of water analysis listed:

Tabla 1

Alkalinity	780 ppm (as $CaCO_3$)	Heavy metals	–
Salinity	140 ppm (as Cl.)	*p*H	8.5
Combined Chlorine	0.32 ppm	Turbidity	170 F. T. units
Nitrates	–	Dissolved CO_2	–
Nitrites	–	*Dissolved O_2*	*0.5 ppm (= 4 %)*
NH_3 Nitrogen	3.1 ppm	Fluoride	0.53 ppm
Iron	5.6 ppm	Silica	2.95 ppm
Potassium K^+	18.3 ppm	Total Hardness	44 ppm (as $CaCO_3$)
Phosphates	0.15 ppm	Calcium Hardness	28 ppm
Sulfides	0.12 ppm	Magnesium Harness	16 ppm
Sulfates	51 ppm	Redox	51 mV

The oxygen content in the bottom sediment of the Laguna was 0.4 ppm (= 3% to saturation); redox value —177 mV, and pH of saturated paste made with saline crust over the banks of Laguna, 9.8 (9.4 in a 30 cm deep soil sample).

The eutrophication process is best shown by the appearance of vast quantities of algae, which were even on the top of the bitter saline crust at the bank of the pond.

Processes in water, sediment and soil around the Laguna give severe reducing conditions. Denitrification should have finished as all nitrogen present is due to ammonia, in a large value. The sulfate reduction is being carried out, even in a watershed where very small quantities of sulphur are available. Winds should be responsible for the absence of dissolved CO_2. Respiration of microorganisms had already consumed all free oxygen available at the initial stages of water accumulation (Drever, 1988). Redox value correlates with other chemical parameters. pH values in soil and water are analogous to high alkalinity and total hardness. Shallow water actually dissolves previous crust and when further rainfall comes in, dilution is possible. Alkalinity owes its high level to the presence of carbonates, bicarbonates and/or hydroxides.The values of pH and hardness suggest calcium bicarbonate or sodium carbonate. Less chloride content should be noticed, so that salinity due to sodium chloride —which is neutral— cannot be taken into account. After this analysis, soils approach solonetz processes rather than solonchaks. In most of the profiles, an albic leached E surface horizon overlies an argillic (natric?) horizon showing columnar structure.

SEDIMENT SAMPLES STUDY

In order to closer characterize the formerly described landforms (Fig. 2), sites were selected and samples collected at:

a) Alluvial fan deposit, Miocene in age, used as a reference and source rock (parent material)
b) Sandy river terrace sediment, laid down by the Arevalillo river.
c) Present sandy channel sediment transported by fluvial agent (Arevalillo river).
d) Bottom sediment of the **Laguna del Hoyo** wetland.
e) Surface sample of a parabolic dune covered by pines.
f) Subsurface sample of the same parabolic dune.
g) Deep sand of the same parabolic dune.
h, i) Subsurface deposits of cover sands at the **Montalvo** woodland.

Detailed description of sample sites offer further information on transport agent, way of deposition, source area and diagenesis.

a) Located at 40° 47' 48" N, 4° 51' 20" W (European Datum), on the road from **Avila** to **Salamanca**, km 136.300, artificial outcrop of about 3 m, where Recent Tertiary horizontal layers of sand, arkose, gravels and boulders underlie a brown carbonate rich earth. Soil shows a typical Ah-Bw-Cck profile; carbonates are filling veins, crossing into a full grid. Granitic boulders over 40 cm in diameter have completely become a saprolite because of its «in situ» weathering.

Sediment structure is clearly of a palaeochannel and different «cut and fill» scours may be recognized. There is no doubt about its fluvial origin.

b) Located at 40° 52' 40" N, 4° 53' 38" W, 935 m high, WNW of **Narros de Saldueña**, on the path from this village to **Collado Contreras**. Outcrop shows a 1.7 m deep sandy-arkosic body, with some fine layers of pebbles and cobbles (centil=41 cm). 15 fine horizontal laminae of an average thickness of 11 cm are present having normal grading. Each sheet finishes upwards in a clayey, iron rich level. According to Miall's facies code, lithofacies are Sr and Sh, with ripples and parting lineation. It is a fluvial sand transported and deposited by the **Merdero** or **Arevalillo** river in a bank-like terrace, 20 m over present river level, with moderately pedogenic development.

c) Located 40º 53' 17" N, 4º 48' 19" W, 878 m, on the road from **Papatrigo** to **Cabizuela** where the bridge crosses fluvial stream. Sand bottom of the channel of the **Arevalillo** river, 1.5 km downstream from the end of canalization. Fluvial sand dune.

d) Located 40º 53' 35" N, 4º 49' 14" W, 880 m high. Sample was taken from the inner core of a pedological auger reaching 55 cm depth. Although sample was mixed up in order to get an average value of the **Laguna del Hoyo** wetland bottom sediment, it was possible to recognize a repeated sequence of: i) whitish coarse sands, presumably coming from the outwash of aeolian dunes; ii) mottled gray fine sand; iii) organic matter rich layer like i; iv) bed like ii.

e, f, g) Located 40º 53' 22" N, 4º 48' 53" W, 885 m. Windward side of a parabolic sand dune of **El Reganal**. Soil description of sample site shows exact position in the profile:

0-17 cm: A horizon; sandy texture, many pine roots, little organic matter content, 10 YR 6/3 Munsell wet colour, 7.5 YR 8/1 dry colour, with no aggregates, apedal structure, single grained primary particles, non cohesive, loose strength, uncemented horizon. Clear boundary to next horizon. *e* sample.

18-28 cm: Bt horizon; clay loam, 5 YR 4/6 wet colour, moderately developed peds, moderately sticky, moderately firm to strength, uncemented horizon. Diffuse boundary to next horizon. *f* sample.

29-58 cm: C horizon, 7.5 YR 5/8 wet coloured sandy loam, less roots but with eluviation clay from above, entering root paths, weakly developed peds, slightly sticky, weak strength, uncemented horizon. *g* sample.

h, i) Located 40º 53' 00" N, 4º 47' 07" W, artificial 4 m deep outcrop in a trench caved to take sand to add to sticky bottoms of nearby **Lagunas**. Millimetric to centimetric thick beds sometimes of coarse and fine, dark and light sands. Many feldspar cristals visible. Beds dip under 10º to the WSW, inverse grading and carbonatic nodules and mottling at 2 m depth. Homometric fine sand beds rise up from the general background.

This **Montalvo** pine woodland shows soil profiles similar to e,f,g, samples, with A-Bt-C horizons. Bt horizon here may reach 30 cm thickness and shows prismatic structure. h and i samples were taken from different beds within the sand body.

Main available data from samples are listed below in table 2.

SAND GRAINS MINERALOGY

HEAVY MINERALS:

All studied samples are characterized by this main mineral association: biotite (with zircon inclusions) —zircon-tourmaline— epidote-zoisite and sillimanite.

Tabla 2

S	*Gr* %	*C.S.* %	*F.S.* %	*Si* %	*Cl* %	*C.C.* %	*E.C.* μS
a	7.9	42.3	34.7	13.7	9.3	3.56	95.7
b	21.4	57.8	26.2	7.8	8.2	2.03	47.0
c	7.6	89.6	4.8	0.5	5.1	1.12	58.3
d	–	13.7	28.7	17.5	40.1	11.17	85.8
e	18.2	31.3	53.9	4.5	10.3	1.52	45.9
f	–	25.5	45.2	1.8	27.5	0.84	45.9
g	–	18.2	53.1	6.2	22.5	1.48	44.7
h	–	10.8	69.9	3.5	15.8	1.52	48.2
i	–	7.3	75.7	5.8	111.2	3.39	105.8

S = sample; Gr = gravel; C.S. = coarse sand; F.S. = fine sand; Si = silt; Cl = clay; C.C. = calcium carbonate; E.C. = electrical conductivity. Coarse sand is fraction over 0.5 mm; fine sand under 0.5 mm; gravel is refered to 100 % total sample (= sand, silt and clay).

S	*Md* *mm*	*Mo* *mm/%*	*So*	*So* (ϕ)	$S_K(\phi)$	$S_G(\phi)$
a	0.65	0.63/12.1	2.12	1.56	0.29	0.92
b	1.22	2/23.59	1.69	1.06	0.33	0.93
c	1.14	1/23.0	1.35	0.64	0.13	0.99
d	0.24	0.32/10.3 0.08/12.4	2.08	1.31	–0.05	0.76
e	0.52	0.63/13.4 0.40/12.8	1.75	1.28	0.07	1.04
f	0.35	0.43/13.7 0.32/13.7	1.75	1.11	0.03	0.93
g	0.32	0.32/15. 9 0.16/13.3	1.66	1.08	0.03	0.99
h	0.27	0.32/13.3 0.16/16.3	1.62	1.01	0.00	0.96
i	0.29	0.32/18.3 0.16/16.2	1.52	0.82	0.16	0.91

Less abundant are garnets, andalusite, cyanite, staurolite, hornblende, transparent titanium minerals, ilmenite, leucoxene and iron oxides. So, sediments belong to a mineralogical province of old igneous rocks (with some slight influence of metamorphic rocks).

Samples do not show big differences in mineral composition, but sample *a* stands out because of the abundance of metamorphic minerals (cyanite and staurolite)and well conserved crystals (e. g. bipyramidal zircons). Samples from the **Laguna del Hoyo** pond and affected by aeolian action have less unstable minerals, like hornblende, caused by intensive weathering and diagenesis.

LIGHT MINERALS:

Quartz is dominant in light fraction, followed by potassic and calcosodic feldspars and biotites. Muscovite is rarely found. Main differences appear among samples in relation to occurrence percentage of every mineral and conservation stage. Sample *a* has the highest quantity of feldspars (but always more than 50 %); abundant biotite, and muscovite is present. Grains are irregular, angular and show low sphericity. Roundness, sphericity and pitted surface texture increase in grains transported by eolian action. Quartz is not so abundant and biotite is usually slightly weathered. Samples *b* (terrace) and *c* (present channel) offer intermediate characteristics.

It can be concluded that sample *a* —nearest to source material— is best conserved and shows lowest quartz / feldspar rate. On the contrary, grains transported by rivers and wind show higher quartz / feldspar rate. The aeolian agent can be recognized from the dull surface texture.

SCANNING ELECTRON MICROSCOPE QUARTZ GRAINS SURFACE TEXTURE

Quartz grains surface texture results after scanning microscope view are commented below, according to the nomenclature by Kringsley & Doornkamp (1973) and Le Ribault (1979).

Sample *a*: angular and subangular grains with crystal built hexagonal or subhexagonal plates (plate 1). On conchoidal fractures pitted surface (plate 2) showing triangles of pedogenic origin. Many V-notches caused by impacts of other grains during transport. Fluvial origin altered afterwards by edaphic influence.

Sample *b*: subangular grains showing plane faces on which crystals have grown up; many fresh fractures, plastering and mechanical V-shaped features and crescentics marks (plate 3); less pitted surface, but in geometric holes crystals have neoformed. Fluvial history with further «in situ» weathering.

Sample *c*: angular and subangular habit grains made by mechanical contact between saltation load and bottom load and surface. Many impact lunated grooves and alignal V-marks caused by water transported tools (plates 4 and 5); some surface areas were pitted showing orange skin-like appearence, some others are covered by newformed silica crystals ressembling gravestones. Fluvial origin with chemical weathering attack and recrystalization.

Sample *d*: subrounded grains (plate 6), with smoothed texture covered by infinite number of calcium-rich minerals (plate 7). Plane faces by conchoidal fracturing; mechanical holes and geometric caves of pedogenic origin coated with microcrystals. Aeolic origin having suffered intensive diagenetic processes.

Samples *e*, *f* and *g*: subrounded (plate 8) crushed, fractured grains on whose angular cavities iron-rich «roses» may grow (plates 9 and 10). Underneath samples exhibit chemical triangles produced during long-term pedogenesis.

Samples *h* and *i*: best rounded, smoothed outline (plate 11), with dish-shaped concavities are typical of aeolian transported grains. Where carbonates rise to dominate soil profile, pitted, etched surfaces exist. Near to the ground surface, grains exhibit mechanical, conchoidal breakage pattern. In deep samples silica precipitation coating can be seen (plate 12). Sand grains were polished by wind action but diagenetic processes assisted to increase a rounded outline.

DESCRIPTION OF CUMULATIVE CURVES AND FREQUENCY DISTRIBUTION

For a better understanding of sedimentation environment, grain frequency distribution and cumulative curves of all samples have been drawn (Folk, 1966; Petijohn et al. 1972).

Sample *a* shows a poor selection, so that all grain sizes have almost the same frequency. Cumulative curve becomes a straight line exhibiting relictic sand of alluvial fan origin. Sample *b* plots a parabolic or «inverse j» curve because of coarser grain size braking. Sizes over 0.62 mm have been forced to accumulate though the transport of fine grains continued downstream. This behaviour stands out in fluvial deposits where braided channels erode sandy layers and spasmodic flow takes place. Sample *c* from the river Arevalillo is quite similer to already commented sample *b*, as the same fluvial processes are responsible for it. Nevertheless the best selection is present in this fluvial dune sample where cumulative curve rises in grain sizes around 1 mm.

Although at a first sight sample *d* from the Laguna bottom shows a lineal trend, detailed studying discovers two added sigmoidal curves (over 0.2 and under 0.2 mm). The clear bimodal nature of this sample results from two populations mixture. The first one over 0.2 mm should correspond to fluvial sandy deposits but the second one under the 0.2 mm threshold should have been lain by aeolian action. Water body in the **Laguna del Hoyo** has caught not only sediments crept from nearby dunes but also blown out fine sands.

Parabolic dune (labelled *e*, *f* and *g*) and cover sands samples (*h* and *i*) show the same sigmoidal curve trend, although some variability may be present. Following the alphabetical order wind selection increases. All curves exhibit a decrease of

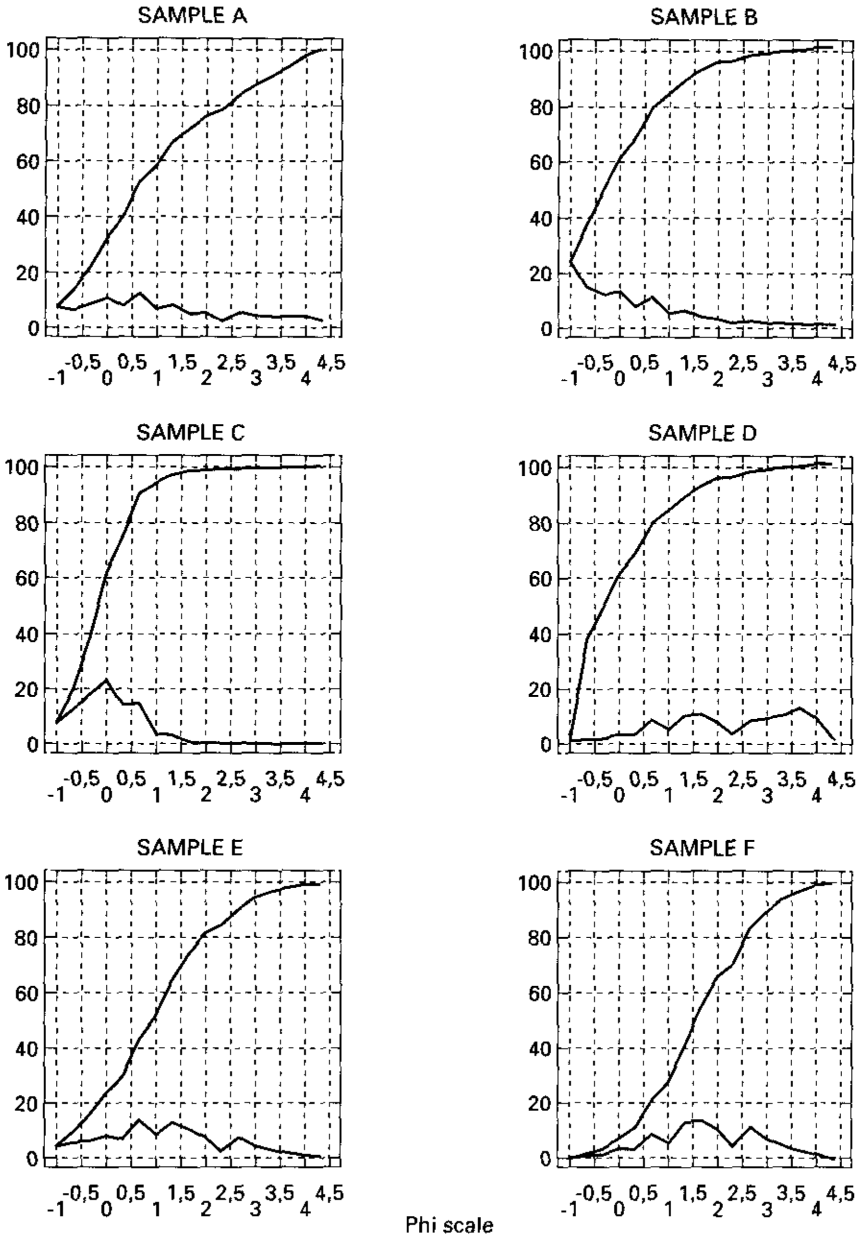

Fig. 4. *Frequency distribution and cumulative curves.*

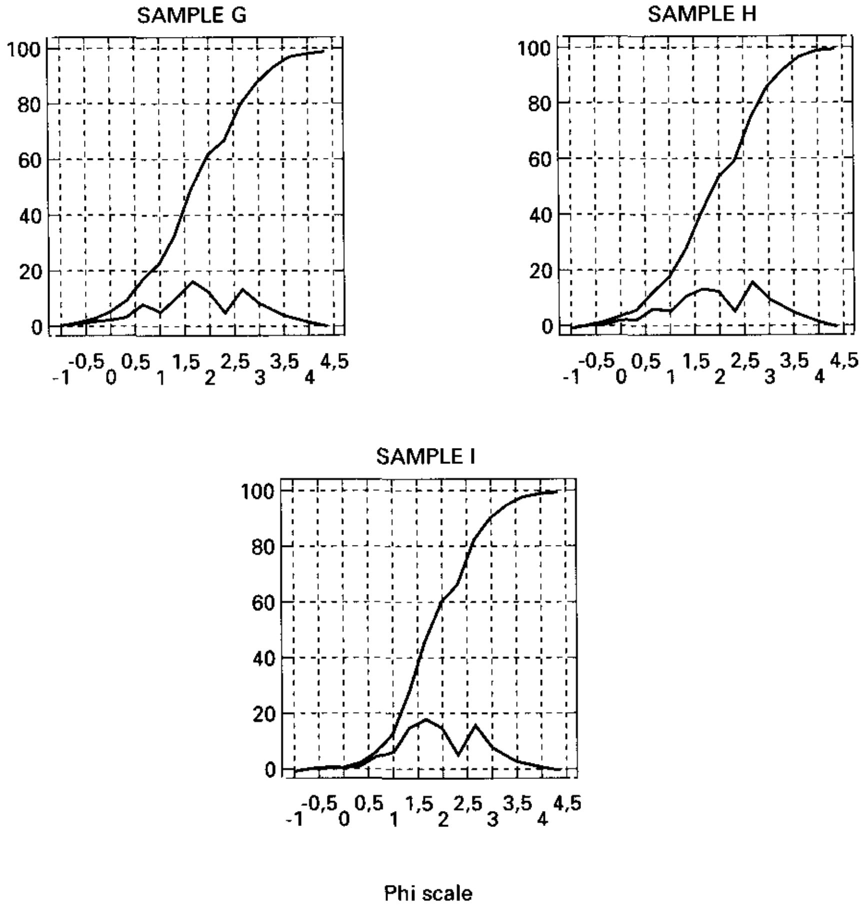

Fig. 5. *Frequency distribution and cumulative curves.*

sediment in fraction 0.25-0.20 mm diameter, which divides sample into two different transport modes: saltation and suspension.

The similarity between curves is so big that measurement has been tempted calculating correlation coefficent of paired values (% values for each sieve). The comparison matrix offers the following results:

Comparisons are based on 17 data pairs. Sample *d* shows a two populations mixture, although correlation coefficent in relation to sample *g* is only 0.60. It rises to 0.995 (98.9%) if only the first 8 values pairs are taken into account. This clearly demonstrates total similarity between coarser populations. The same argument can be used in correlations between sample *d* and *e*: coarse sand correlation becomes 0.76 (instead of 0.18) if calculated for the first 12 data pairs.

Tabla 3

CORRELATION COEFFICENT MATRIX

	a							
b	0.65	b						
c	0.83	0.68	c					
d	–0.18	–0.58	–0.52	d				
e	0.76	0.30	0.38	0.18	e			
f	0.16	–0.31	–0.25	0.59	0.73	f		
g	0.00	–0.37	–0.36	0.60	0.59	0.97	g	
h	–0.14	–0.47	–0.48	0.65	0.42	0.90	0.96	h
i	–0.14	–0.40	–0.49	0.58	0.48	0.93	0.96	0.95

SIMILITARY PERCENTAGE MATRIX

	a							
b	42.9	b						
c	68.2	46.3	c					
d	3.2	33.6	26.8	d				
e	57.8	9.0	14.8	3.1	e			
f	2.8	9.5	6.6	35.6	53.2	f		
g	0.0	13.7	12.8	36.1	34.7	93.8	g	
h	2.0	22.1	23.5	42.3	17.6	81.8	91.8	h
i	2.0	16.0	24.2	33.4	23.5	86.6	93.1	91.0

Differences between *e*, *f* and *g* are caused by luviation of clay, silt and fine sand particles: so, the tails for fractions under 0.25 mm show similar distribution and correlation coefficient rises to 0.992 (98.4%). As it has been already commented, samples *g*, *h* and *i* are closer together despite geographical spread, denoting an aeolic environment for their generation.

According to the correlation matrix, sample *a*, from the old alluvial fan, is similar to *b* and specially *c*. This makes a common fluvial origin patent, but points out how different sedimentation conditions were during Quaternary times from Tertiary and present spasmodic flow. Terraces should have been deposited by ordinary floods differing from present flow. Sample *a* shows no similarity to aeolian sediments. The coincidence between *a* and *e* may be rather because of fine particles eluviation than caused by original deposition.

CUMULATIVE CURVES ON PROBABILITY PAPER

Trying to increase accuracy of sedimentation processes which formed the analysed samples, another graphic representation has been drawn on probability paper (SINDOWSKI,1957, VISHER, 1969). Sample *a* is a relictic sand because its FG trend. Samples *b* and *c* show a MG-KX pattern which is just one part of a more general KV- MG-KX curve of fluvial origin, with some changes in coarser grains. *d* sample from the **Laguna** bottom ressembles a KX-KV-KX curve which is told to be typical for *Watenmeer*-sands, but is found in the hole where two different sediment origin accumulation takes place: Wattenmeer-sands also consist of coarse marine splash and fine fluvial populations. Samples from *e* to *i* exhibit about the same trend, emphasizing aeolian transport on an older fluvial sand.

GRAIN SIZE PARAMETERS AND INDEXES

It is commonly assumed that *circa* 90% of the medians of wind transported sands lie between 0.15 and 0.25 mm diameter. Sample *d* perfectly fits into this group, and *g*, *h* and *i* are very close to it. In the luviated sand dune, decrease of median could be explained by the grain selection of water seeping down the profile. High median values of fluvial-laid deposits show the bigger tractive force of water in relation to wind. Nevertheless, inheritance is present and aeolization takes place on older fluvial sediments.

Bimodality is always present in aeolian blown sands as far as original fluvial sediments have been reworked. All typical fluvial deposits exhibit only one, and usually very high, modal value (Huggett,1989).

Sorting values according to Trask (1932) calculated for aeolian sediments should be grouped under very well sorted samples with figures underneath 1.25. Dune and cover sands come close to it, but the best selection is made by current water generating fluvial dunes (sample *c*). Poor selection is found in samples of alluvial fan and pond sands where all available sizes were caught. Some comments can be pointed out for results of calculated sorting index.

Skewness of grain size distribution curves gives rise to an individual characterization of sample *d*, the only negative one. **Laguna del Hoyo** has functioned as a sediment trap catching all fine sands that were further mixed to creeping coarse dunal sands from nearby outcrops. On the contrary, fluvial sands trend to clear positive skeewness caused by coarse sand movement. Wind dunes have intermediate values.

Graphic Kurtosis makes little difference between surface sample (*e*) from dune, slightly leptokurtic, and the platikurtic rest curves. Bimodal sample *d* is «laminated» into an actual platy curve. Once again, it is caused by the interference of two populations.

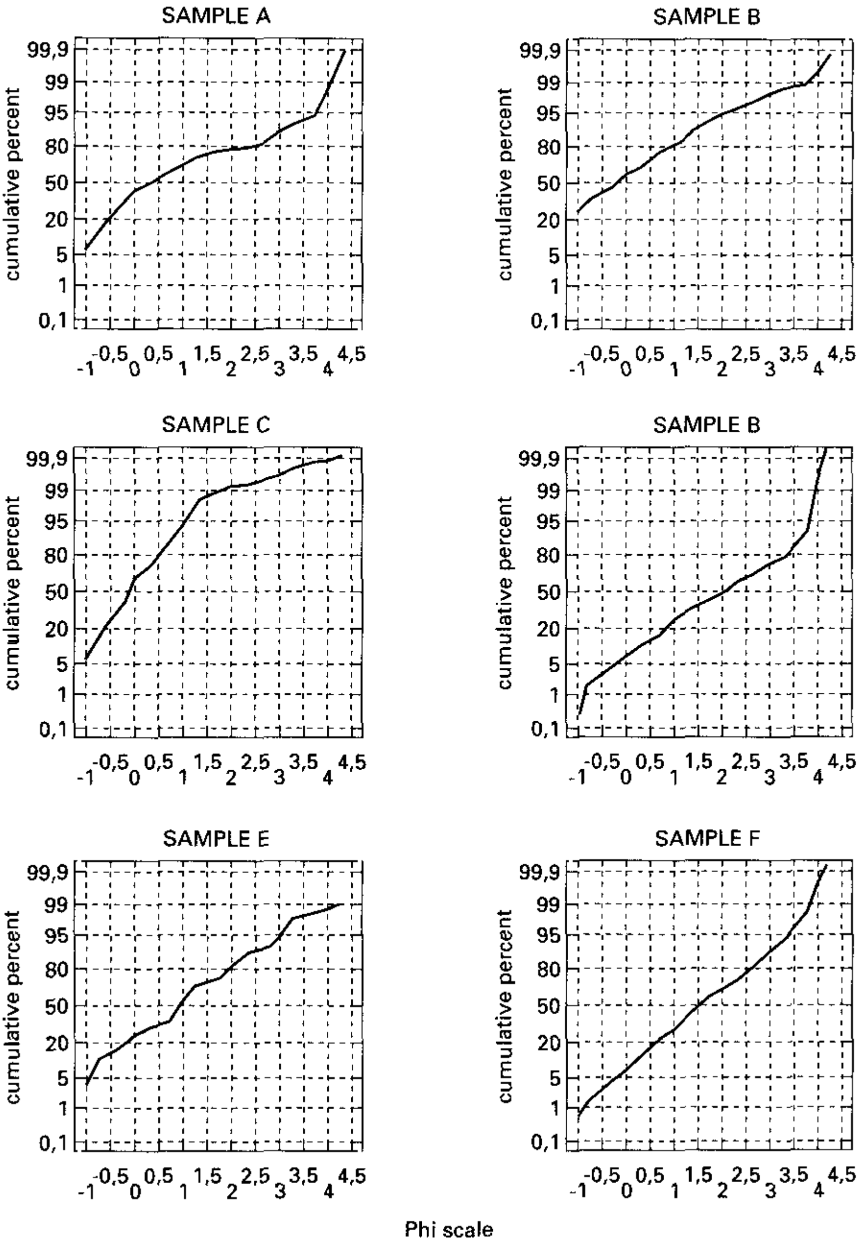

Fig. 6. *Cumulative probabilistic curves.*

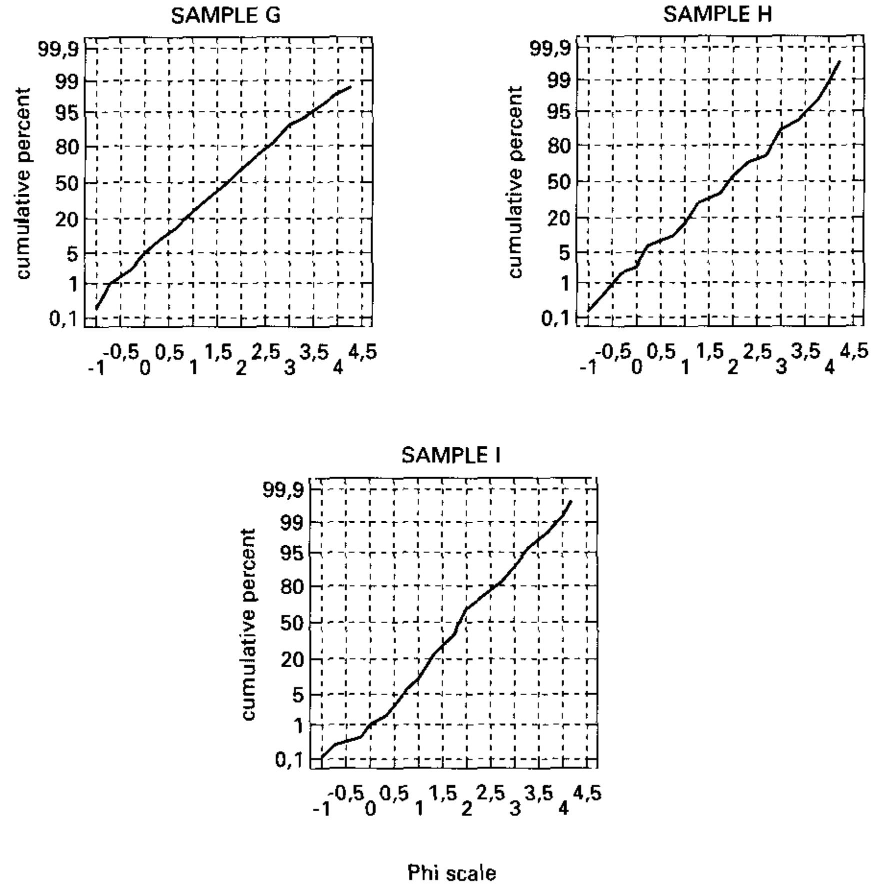

Fig. 7. *Cumulative probabilistic curves.*

LANDSCAPE EVOLUTION AND FORECAST

The Douro Basin is filled up by means of many, large alluvial fans, in a thickness of over 400 m, consisting in arkoses and even conglomerates near to the fault line of the graben. These coarse sediments which are present at **San Pedro del Arroyo** (sample *a*), show big granitic and gneissic rotted blocks submerged in a fine, sandy paste. Final stage of this filling of the Douro Basin is well represented by polymictic conglomerates of quartzitic pebbles, cobbles and granules surrounded by a sandy- clayey reddish matrix, of which it has been told to be similar to other «raña» sediments. These raña remnants are strictly, geographically correlated to paleozoic outcrops, as shown in figure 2: W of the **Almar** river and **Adaja-Voltoya** interfluve.

The Quaternary geomorphology is bound to fluvial terraces separating the catchment areas of the river **Adaja** and **Arevalillo-Berlanas**. These stepped terraces descend towards the Adaja present channel, the main, most competent river, springing at heights over 2.200 m. North of the Merdero-Barzones stream some alluvial sand deposits benches can be found denoting a long Quaternary, braided channels history, when removing Tertiary alluvial fan available sediments in their catchment surface.

Finally a vast flood plain was built up, where most of present and ancient villages were located even tempting quite probable flooding risk. Catastrophic flood inhibition was succeeded when the Arevalillo river was once canalised in 1957. Las Berlanas hamlet was destroyed during the storm on the August, 29th 1959. So most of the villages were located on little heights locally called «cabezos» (e.g. Cabizuela, Cabezas de Alambre).

The Arevalillo River is not almost able to dissect the vast flood plain, but when one approaches the Adaja main river from Cabizuela to Pedro Rodríguez. The different geomorphic behaviours of the Arevalillo and the Adaja catchments can be explained by snow feeding income of the Adaja nivo-pluvial regime in contrast to the rainfall input in Mediterranean pluvial regime of the Arevalillo, as there are no contrasts in lithology.

During Late Quaternary times when frost was normal in the mountains and little cirque glaciers developed in some preexisting amphitheatres, grassland should have covered this region allowing the wind to blow out sandy fluvial deposits and to build up parabolic dunes. Although these dunes have been told to be related to a sparse or dense vegetation cover, it is our opinion that moisture from the underneath flood plain has restricted wind transported sand to move. Soil moisture depends not only on water available but also on convenient fine sediments (clay lenses within the alluvial fan deposits). The higher the sand body, the less dependent on soil moisture, as capillary water can not ascend through the large sand pores. So, huge mounds might be moved forward whilst low accumulations remain stationary. As a result, parabolic sand dunes were shaped. Time run from this moment to present allowed leached soils to develop. The cause for it should be preferently found in sand deposits, rather than in time lap. Cover sands, on the other hand, were partly flooded so that carbonation processes could take place.

Flooding, to some extent, has been the main process affecting this plain, so that very recent alluvial soils were spread over the flat margins of scarsely incised rivers (Arevalillo, Merdero). Slight hydromorphism is governed not only by flooding but also by ground water, as far as parent material is not impervious. The deepening of water table has increased changes in soils and water stress in meadows and other vegetation types. Salinization is therefore becoming more and more important and argillic horizons change to natric when ground water pumping have ruined older fluvisols.

If wind action is responsible for the formation and development of wetlands in this northern fringe of Spanish Central System, at the moment aridification and desertification are progressing as a result of ground water hyperexplotation. Spanish aquifers are becoming «aquivacua» (emptied of water) and desertification is today the most important hazard in Mediterranean Europe. By means of human impacts old, Quaternary wind conditions may advance, destroying the present welfare.

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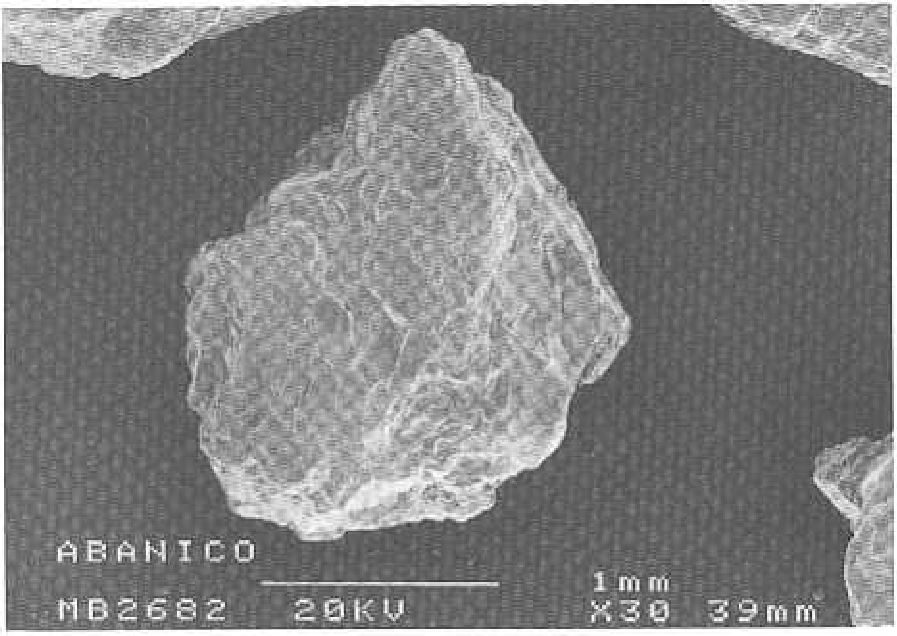

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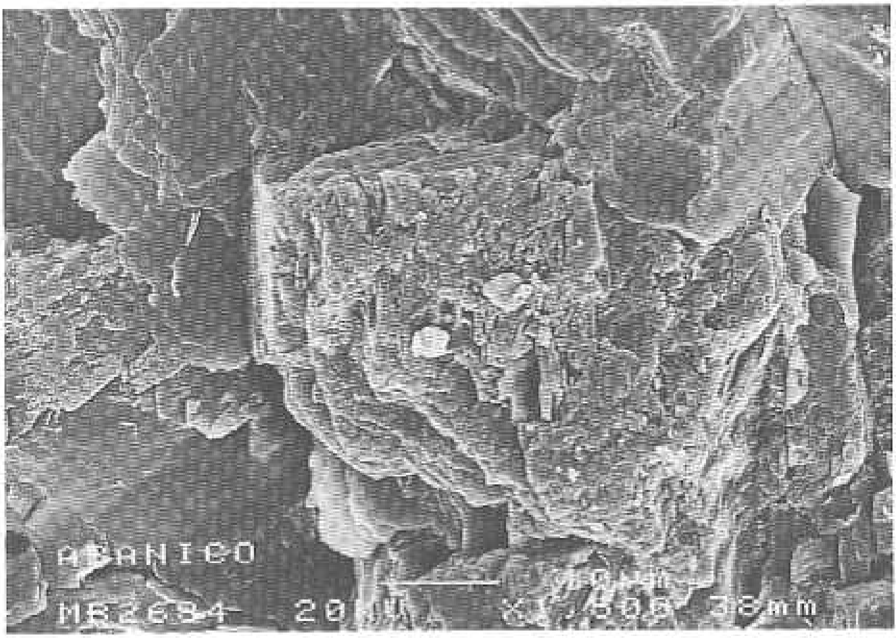

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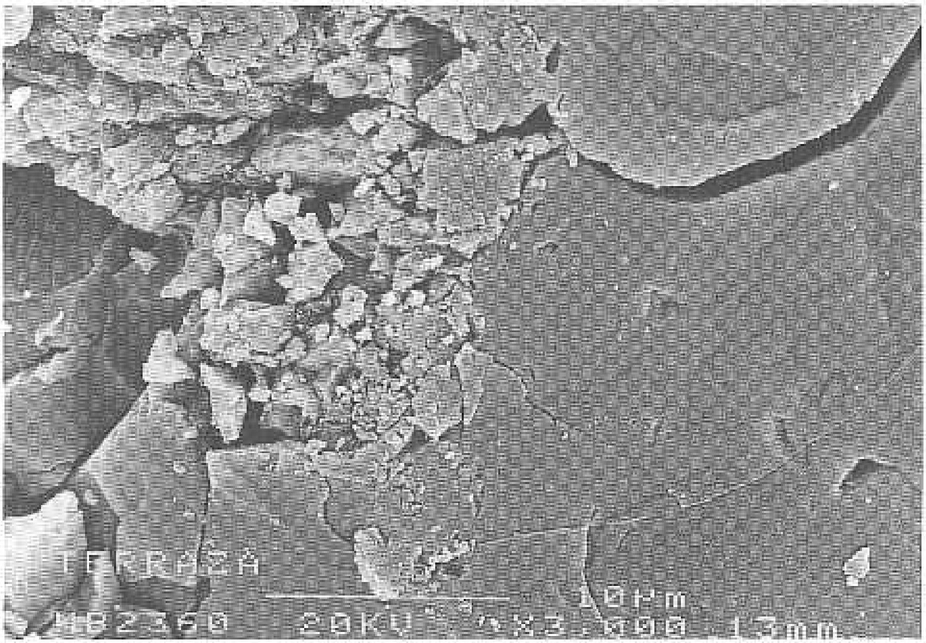

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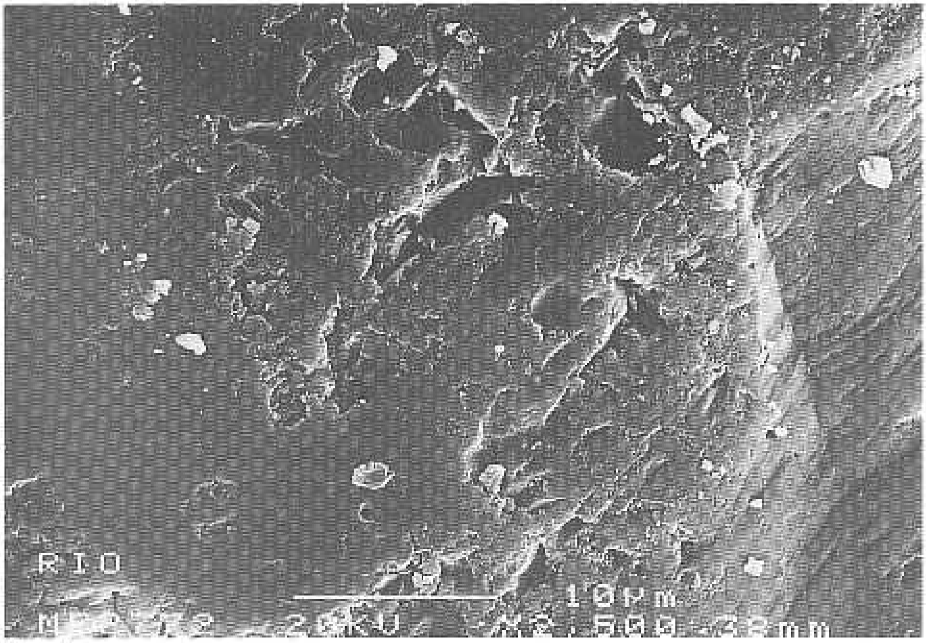

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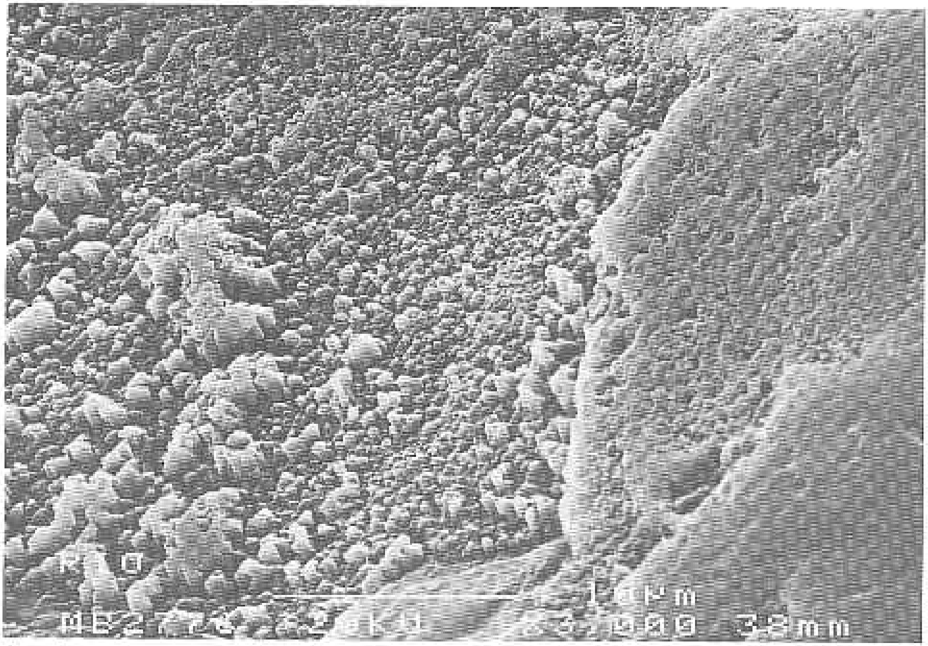

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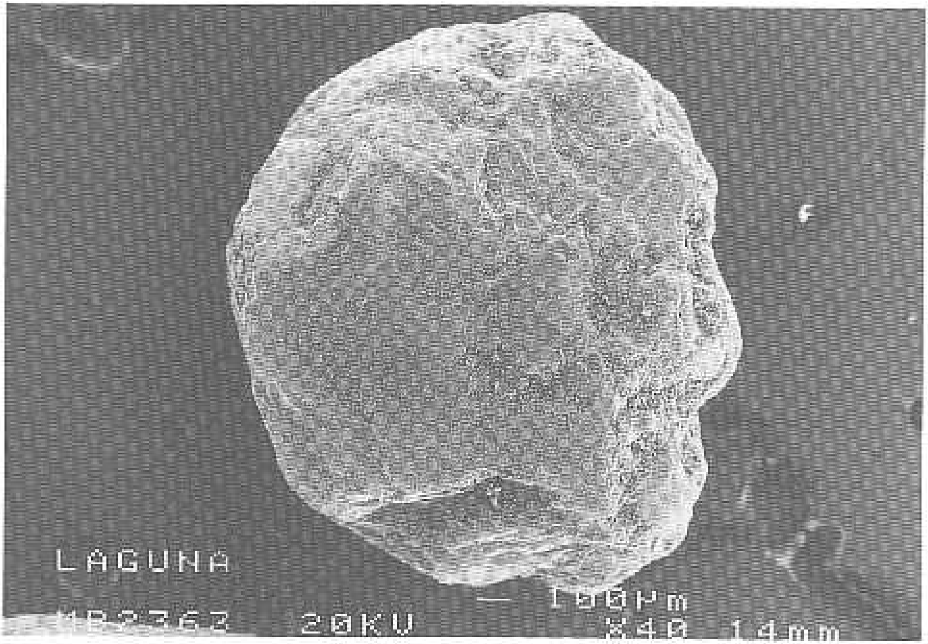

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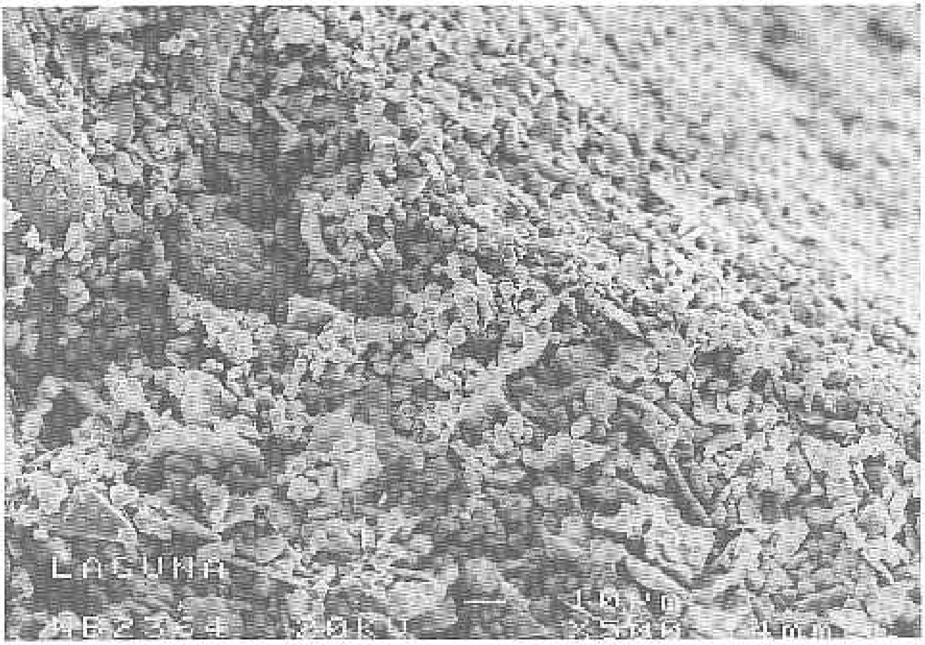

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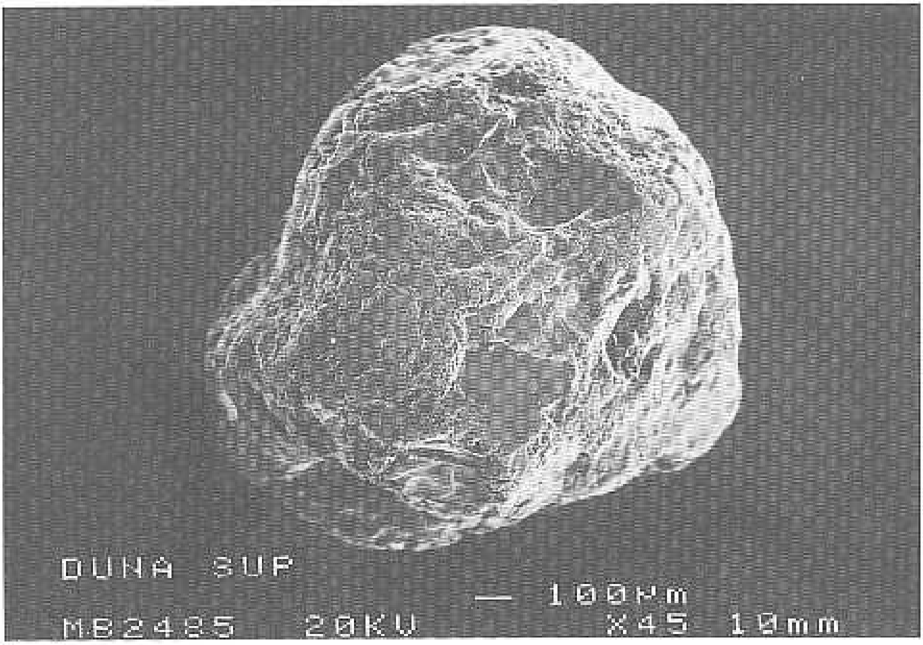

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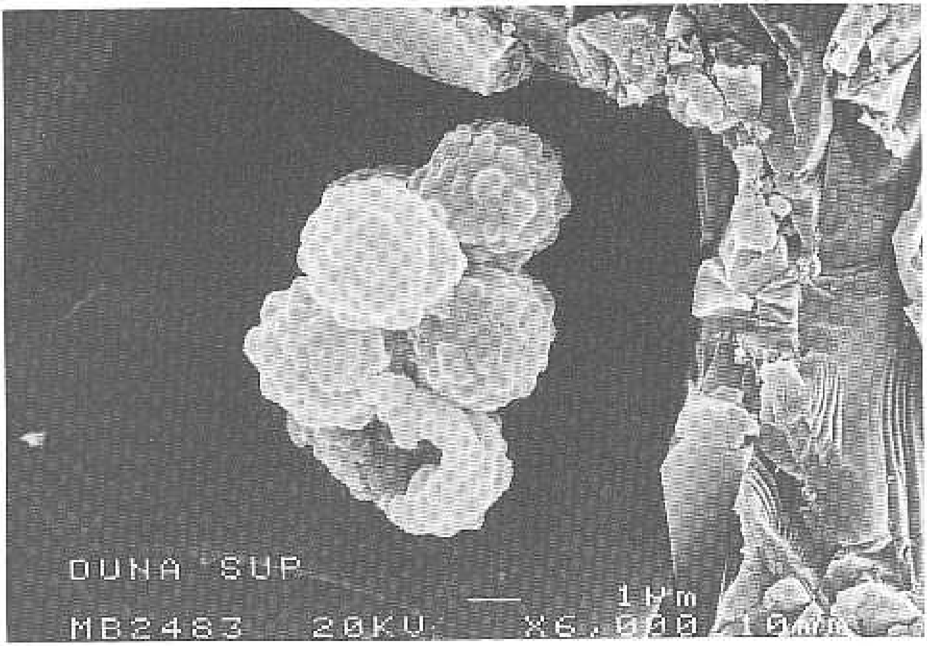

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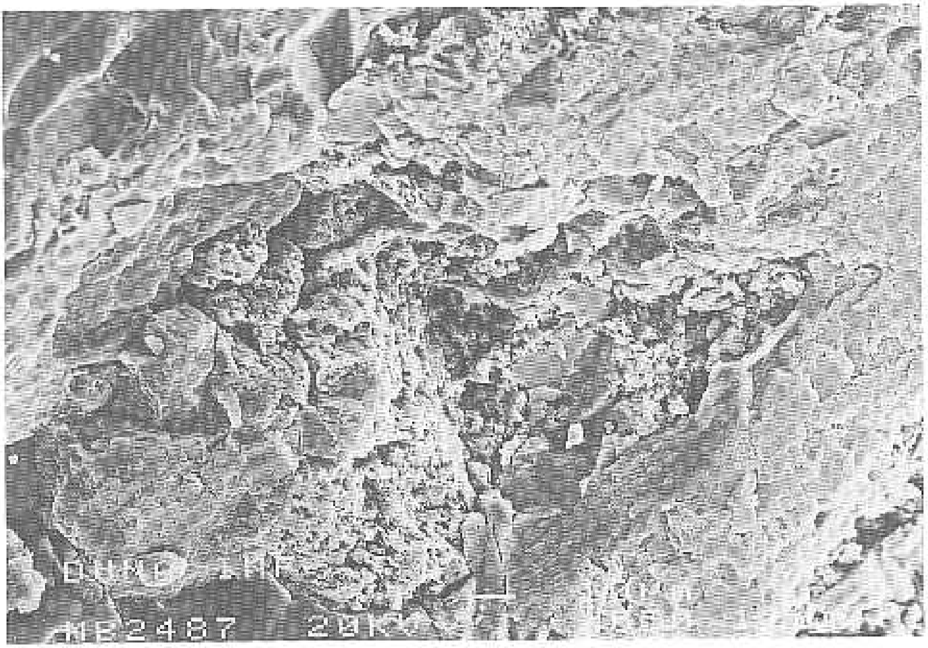

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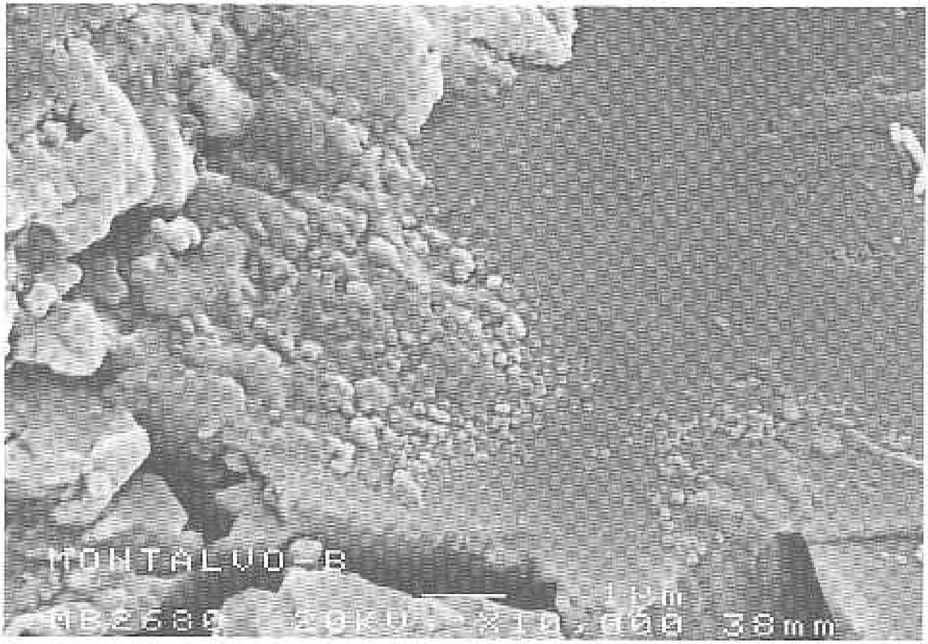

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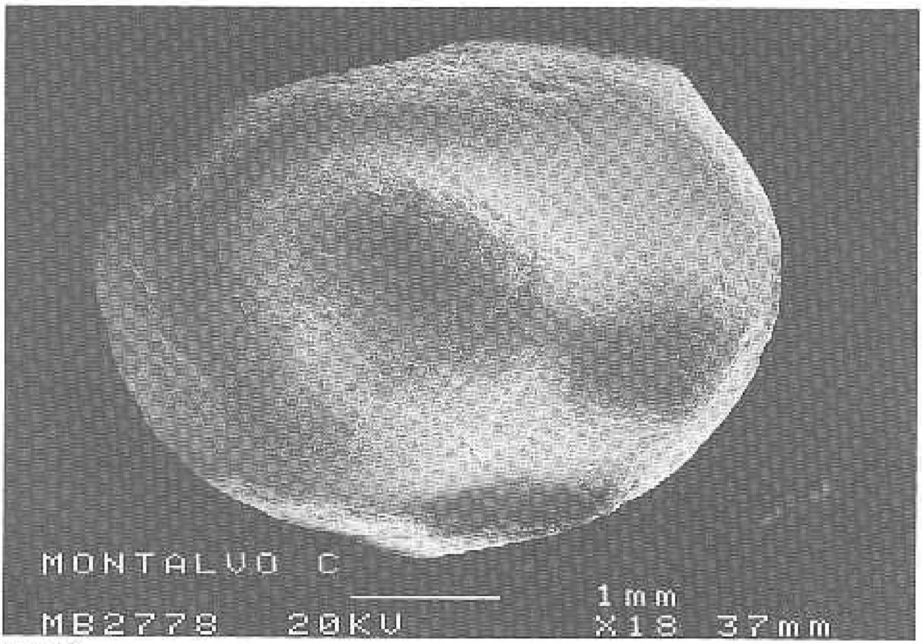

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