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Zinck, J.A. (1988) "Physiography and Soils", ITC Lecture Note SOL.4.1. International Institute for Geoinformation Science and Earth Observation (ITC), Enschede (NL). 156 pp.

This is a scan of the ITC lecture notes of Professor Zinck, who taught the core material of the ITC Soil Survey course from the time of his appointment as Professor of Soil Survey in 1986 until his retirement in 2000. They are centred on his "Geopedological Approach" to soil survey, which has been highly-influential, especially in Latin America, and which provides a unified framework for a mental model of soil mapping.

Clearly, this material is somewhat dated, especially considering the geo-information technology and data sources (satellite imagery, elevation models) available today, but it is used as a reference, for teaching, and as a basis for mapping campaigns. It is provided "as is" with the hope that it will be a useful addition to the soil surveyor's toolkit of ideas.

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SOIL SURVEY COURSES

Subject matter: K6

1988/1989

PHYSIOGRAPHY AND SOILS

J.A. Zinck

GENERAL OUTLINE OF THE LECTURE SERIES

Chapter 1 **SOILS ON THE LANDSCAPE - GENERAL PEDOLOGY**

I. Soil material (levels of organization and properties)
II. Soil formation and evolution
III. Soil classification
IV. Soil cartography

Chapter 2 **APPLICATION OF GEOMORPHOLOGY TO SOIL SURVEY - GEOPEDOLOGY**

I. Importance of geomorphology for soil survey
II. Modes of implementing geomorphology in soil survey
III. Structure of the taxonomic system
IV. Attributes for determining geomorphic taxa
V. Geoform systematics (relief and landform types)
VI. System validation
VII. Application to soil cartography
VIII. Conclusion: Multipurpose use of the system

Chapter 3 **SOIL-GEOFORM ASSOCIATIONS IN DIFFERENT TYPES OF ENVIRONMENT AND LITHOLOGY - SOIL GEOGRAPHY**

I. Depositional environment
II. Erosional environment
III. Structural environment
IV. Lithology types and soils

Chapter 4 **SOIL-GEOFORM RELATIONSHIP MODELS**

I. State factors model (static)
II. Energy model (dynamic open system)
III. Catena model (2-dimensional)
IV. Soilscape model (3-dimensional)
V. Phenetic model (numerical classification)

Chapter 5 **IMPLEMENTATION OF SOIL-GEOFORM RELATIONSHIPS**

I. Different approaches
II. Application to soil genesis studies
III. Application to soil cartography
IV. Application to soil interpretation (soil groupings)
V. Application to database structuring

NOTE

These lecture notes cover Chapter 2 of the complete lecture series. Chapter 1 is treated in a separate booklet. Full development of Chapters 3 to 5 will be available in a near future.

CHAPTER 2 APPLICATION OF GEOMORPHOLOGY TO SOIL SURVEY
INTRODUCTION TO GEOPEDOLOGY

APPROACH	:	GEOPEDOLOGY
METHOD	:	SOILSCAPE ANALYSIS
UNIT CONCEPT	:	GEOFORM + SOIL BODY = SOILSCAPE UNIT

GENERAL OUTLINE OF CHAPTER 2

I. Importance of geomorphology for soil survey

II. Modes of implementing geomorphology in soil survey

III. Structure of the taxonomic system

IV. Attributes for determining geomorphic taxa

V. Geoform systematics (relief and landform types)

VI. System validation

VII. Application to soil cartography

VIII. Conclusion: Multipurpose use of the system

DETAILED OUTLINE OF CHAPTER 2

I. IMPORTANCE OF GEOMORPHOLOGY FOR SOIL SURVEY

Three basic questions: 1) Why is it important?
2) What is it important for?
3) How much is it important?

A. CONCEPTUAL IMPORTANCE OF GEOMORPHOLOGY

1. INTRODUCTION

The question of "why is geomorphology important for soil survey" leads to analyzing the conceptual (theoretical) bases of the relationships between:
- geomorphology and pedology as scientific disciplines;
- geoforms and soils as study objects of these two disciplines.

Many authors have established diagrams illustrating the above-mentioned relationships. Their structure varies according to the purpose of the graphical model.
- J. Tricart (Terre, planète vivante) highlights the central position of the duo geoforms-soils within the structure of the physico-geographical environment (Fig. 1).
- I.S. Zonneveld (Land evaluation and landscape science) proposes a diagram containing the same elements as the one by J. Tricart, but the central position is occupied by the land concept. In this case, the special relationships between geoforms and soils are diluted (Fig. 2).

2. BASIC RELATIONSHIPS

a) Common geointerface position

Geoforms and soils are natural objects which both occur along the interface between earth crust (lithosphere) and air (atmosphere). They are the only ones occupying this unique and priviledged position.
- Rocks (lithosphere) are mainly located underneath.
- Living beings (biosphere) may be present underneath or within, but occur mainly above.
- Air (atmosphere) may penetrate the interface but is essentially above it.

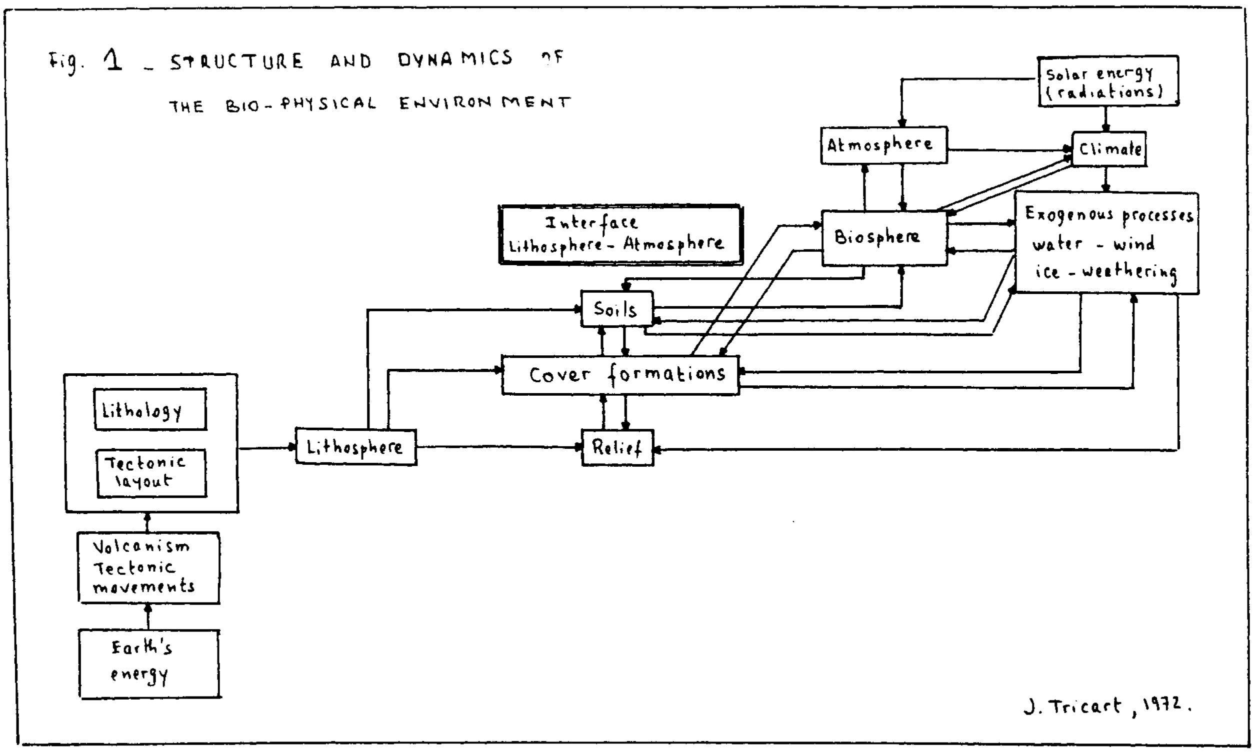
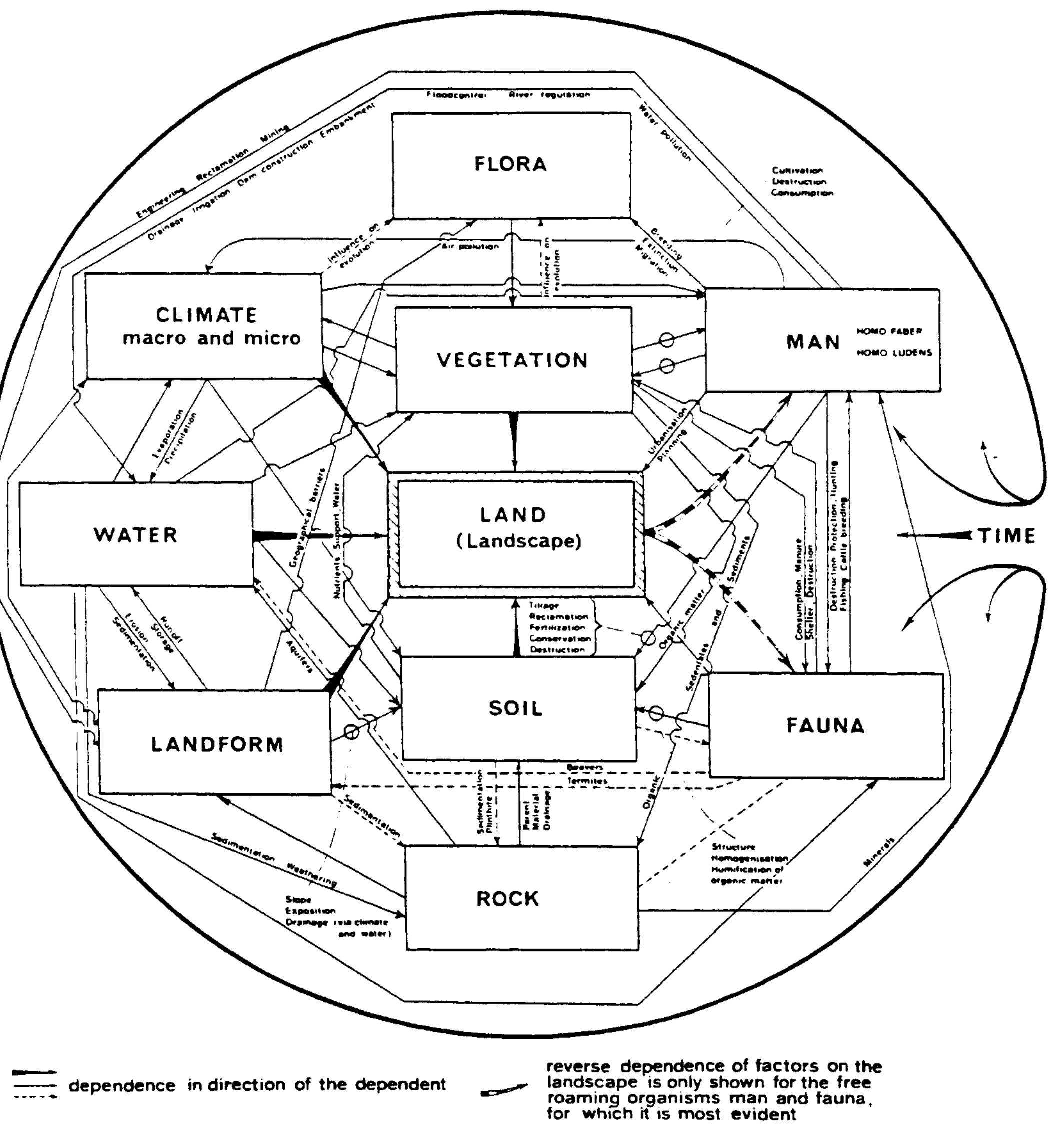


Fig. 2 _ LAND-FORMING FACTORS AND ATTRIBUTES AND THEIR INTERRELATION



(ZONNEVELD, 1972)

b) Common forming factors

Geoforms and soils share the same forming factors which originate from two sources of matter and energy.

* Internal (endogenous) source = energy and matter of the terrestrial globe.
  - Material = rocks characterized by 3 attributes:
    . facies: texture + structure + mineralogy = lithology
    . tectonic layout
    . age = stratigraphy.
  - Energy = internal geodynamics:
    . volcanism
    . tectonic deformations (folds, faults, fractures).

* External (exogenous) source = solar energy (radiations).
  - Acts through earth's atmosphere and influences climate, biosphere and external geodynamics (erosion, transport, sedimentation).
  - Climo-bio-geodynamics contributes to originate, transform and destroy geoforms and soils.

3. CONCLUSION

a) Both geoforms and soils are located between two sources of matter and energy.
b) Both are conditioned by forming factors derived from these two sources of matter and energy and acting through the lithosphere, atmosphere and biosphere.
c) The limits between geoform and soil are diffuse.
  - A geoform has two components:
    . a surface = form or configuration
    . a volume = material.
  - A soil is inserted between these two components:
    . it develops from geomorphic material (parent material)
    . it is conditioned by the dynamics taking place along the surface of the geoform (aggradation, degradation, removal).

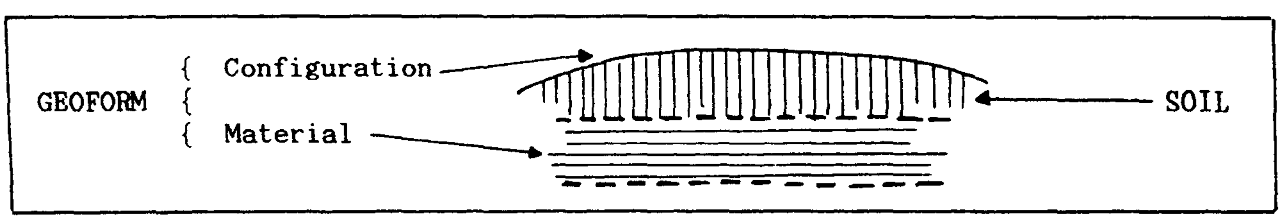


Fig. 3 - GEOFORM - SOIL INTERFACE

B. <u>METHODOLOGICAL IMPORTANCE OF GEOMORPHOLOGY</u>

Soil survey is a complex operation including a set of consecutive activities. Geomorphology provides a fundamental contribution to two of these activities:

- soil mapping
- interpretation of soil genesis.

1. SOIL MAPPING (SOIL CARTOGRAPHY)

Soil mapping is composed of two tasks: soil identification and soil delineation.

a) <u>Soil identification</u> (question: who are they?)

- Is derived from soil description
- Leads to:
  . soil characterization
  . soil classification.
- Contribution of geomorphology: site selection.

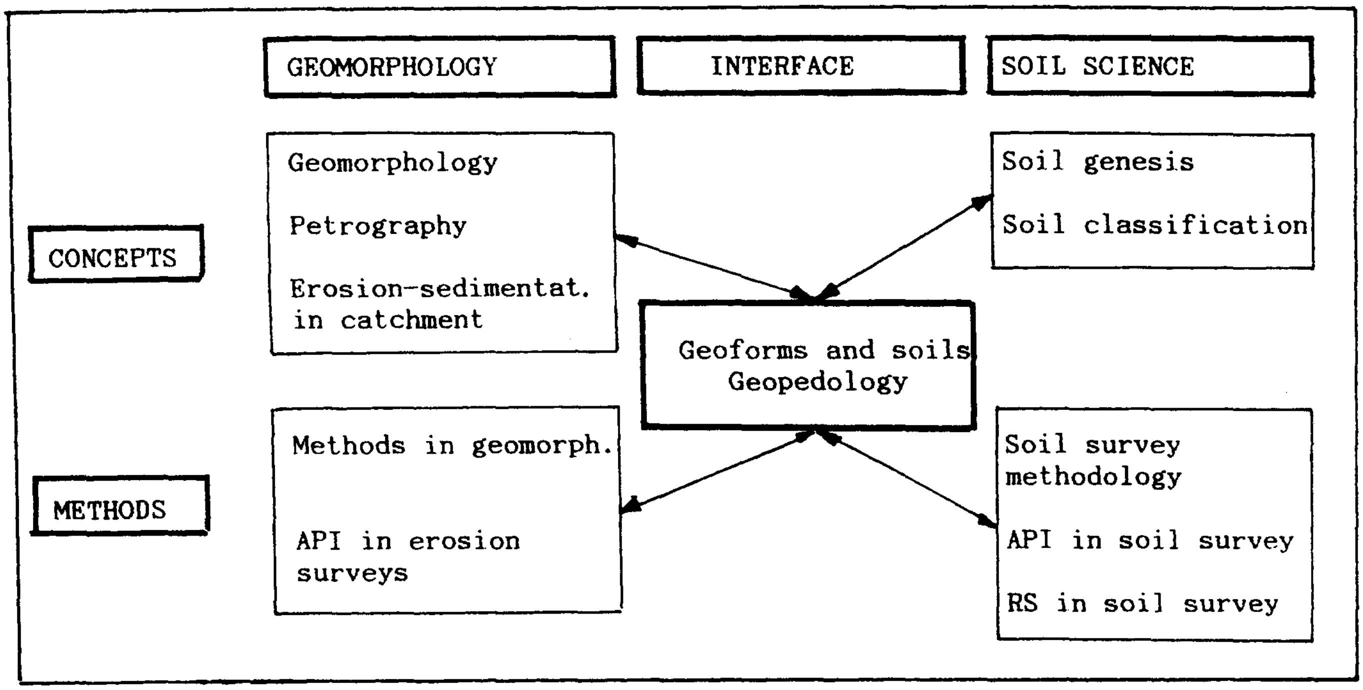
Different approaches can be used for site selection:

- Random: only meaningful if applied within photo-interpretation units previously established using geomorphic criteria.
- Systematic (grid technique):
  . prevailing technique some 3 or 4 decades ago, but still used under dense forest cover
  . too expensive and time-consuming when applied as an operational technique to a whole survey project
  . useful when locally applied to identify spatial soil variability within selected mapping units and establish their degree of purity (geostatistics).
- Oriented: sites are preselected on the basis of geomorphic criteria within photo-interpretation units.

b) <u>Soil delineation</u> (question: where are they?)

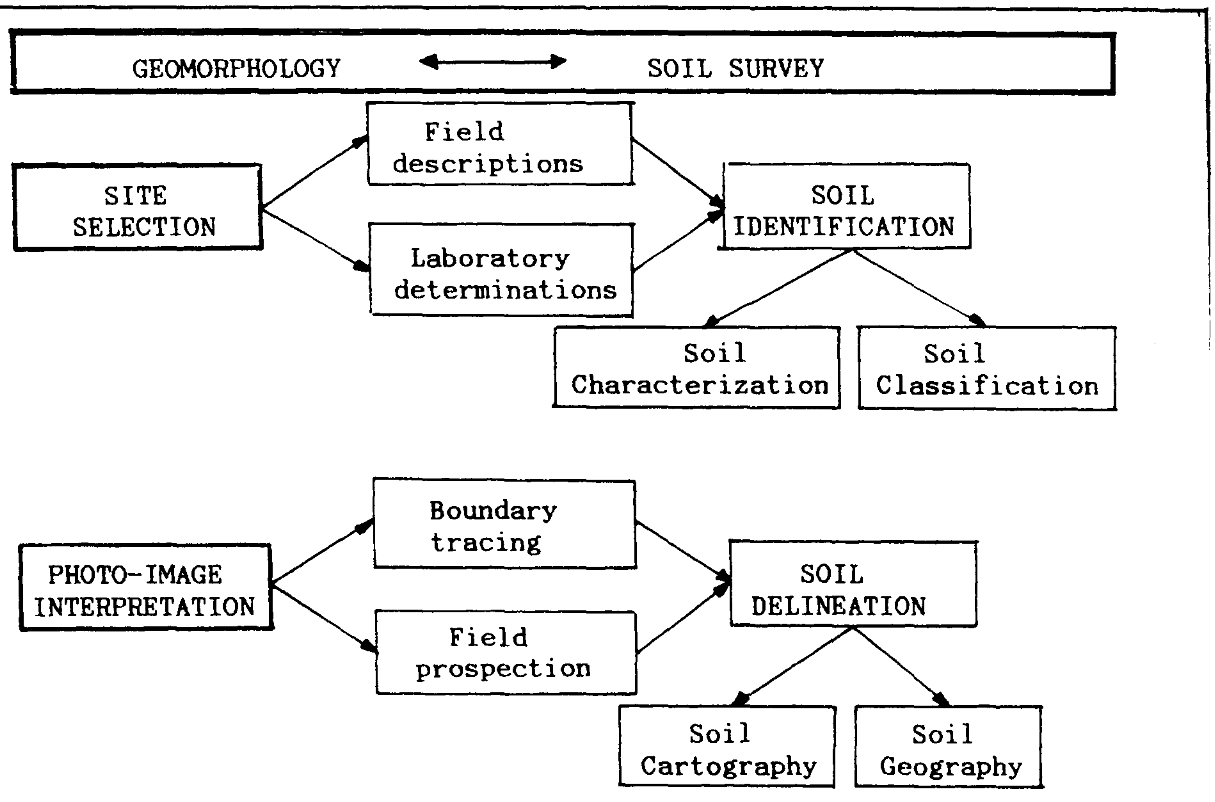
- Is derived from:

Fig. 4 - BRIDGING POSITION OF GEOPEDOLOGY



Note: The above-mentioned subject matters correspond to selected lecture series currently offered to Soil Survey students.

Fig. 5



. photo-interpretation
. field prospection.

- Contribution of geomorphology:
  . selection of sample-areas, transects and traverses
  . tracing of soil boundaries on the basis of conceptual relationships between geoforms and soils (common forming factor models; polypedon-soilscape concepts)
  . identification, monitoring and explanation of soil spatial variability (cf. Elizalde, Viloria, Ovalles).

2. INTERPRETATION OF SOIL GENESIS

Geomorphic processes and environments are used respectively as factors and frameworks of soil formation and evolution.

a) Geomorphic process (morphogenesis)

- Sloping areas (see Figs. 45-48, pp. 48-49, Chapter 1).
  . Catena formation: - erosion and deposition of detritic fragments
    - leaching and accumulation of soluble elements.
  . Concepts of truncated and buried soils.
- Flat areas (see Fig. 50, p. 50, Chapter 1).
  . Formation of structured depositional systems leading to strong topographic, hydrologic and lithologic spatial differentiation.
  . Clear pedodifferentiation in terms of textures and drainage classes.

b) Time factor (morphochronology)

Determined on the basis of geomorphic and soil criteria (degrees of soil development). See pp. 59-62, Chapter 1.

C. OPERATIONAL IMPORTANCE OF GEOMORPHOLOGY

Operational importance geomorphology refers to the quantity of information added to the soil survey information by incorporating geomorphology in the consecutive steps of the soil survey operation.

Two aspects have to be analyzed: the position of geomorphology in and the efficiency of its contribution to soil survey.

1. THE SOIL SURVEY MODEL

Soil survey is an information system which can be represented by a model showing the structure and functioning of the soil survey using system analysis approach.

a) Soil survey structure

- A model structure consisting of 5 categorical levels was obtained using an iteration procedure (Figs.6,7).
- Each level responds to a given generic concept.
- At each level a set of tasks are performed.

b) Soil survey functioning

- The functioning of the system refers to the flows of information circulating through the soil survey.
- A set of matrices relating consecutive levels of the model has been established to allow for analysis and quantification of the information flows, and submitted to the judgement of a team of ten soil surveyors (= expert system). The resulting estimations have been averaged and expressed by 2 elements:
  . the direction of the information flows: by means of arrows;
  . the intensity of the information flows: by means of rating marks (using 2 ranges: 0-2 and 0-9).
- The combination of both criteria (direction and intensity of information flows) leads to a ranking of the individual soil survey tasks (themes) according to their importance for generating information.

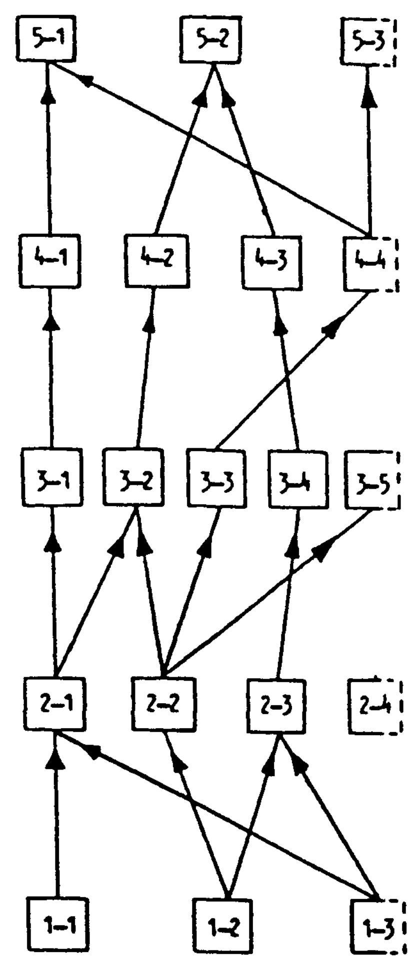
2. POSITION AND EFFICIENCY OF GEOMORPHOLOGY IN THE SOIL SURVEY MODEL

- At level 1 (elementary tasks), geomorphology contributes to photo-interpretation, selection of sample-areas, representative site identification and description, and soil delineation.

- At level 2 (intermediate tasks), the geomorphic synthesis is one of the most fertile themes of the system considering the number of information flows emitted. These flows contribute to a large number of themes at level 3 (30 themes reached). As a consequence, geomorphic synthesis ranks as the most efficient theme of level 2, together with topography (Fig. 7).

Fig. 6 - SCHEMATIC STRUCTURE OF THE SOIL SURVEY MODEL

CATEGORICAL LEVELS OF THE SYSTEM			CLASSES OF THEMES
HIERARCHY		GENERIC CONCEPT	RELATIONSHIPS
EXTERNAL AREA Sphere of influence of S.S.	LEVEL 5	FINAL EXTERNAL OBJECTIVES Regional planning concerns of society	
	LEVEL 4	PRIMARY EXTERNAL OBJECTIVES Physical planning projects for local and regional environments	
UPPER FRONTIER - SOIL SURVEY OUTPUTS			
INTERNAL AREA Strict domain of S.S.	LEVEL 3	FINAL TASKS Multiple purpose soil interpretations	
	LEVEL 2	INTERMEDIATE TASKS Synthesis of soil information Characterization of soils and environments	
	LEVEL 1	ELEMENTARY TASKS Collection of basic soil data	
LOWER FRONTIER - SOIL SURVEY INPUTS			



A. Zinck, 1977.

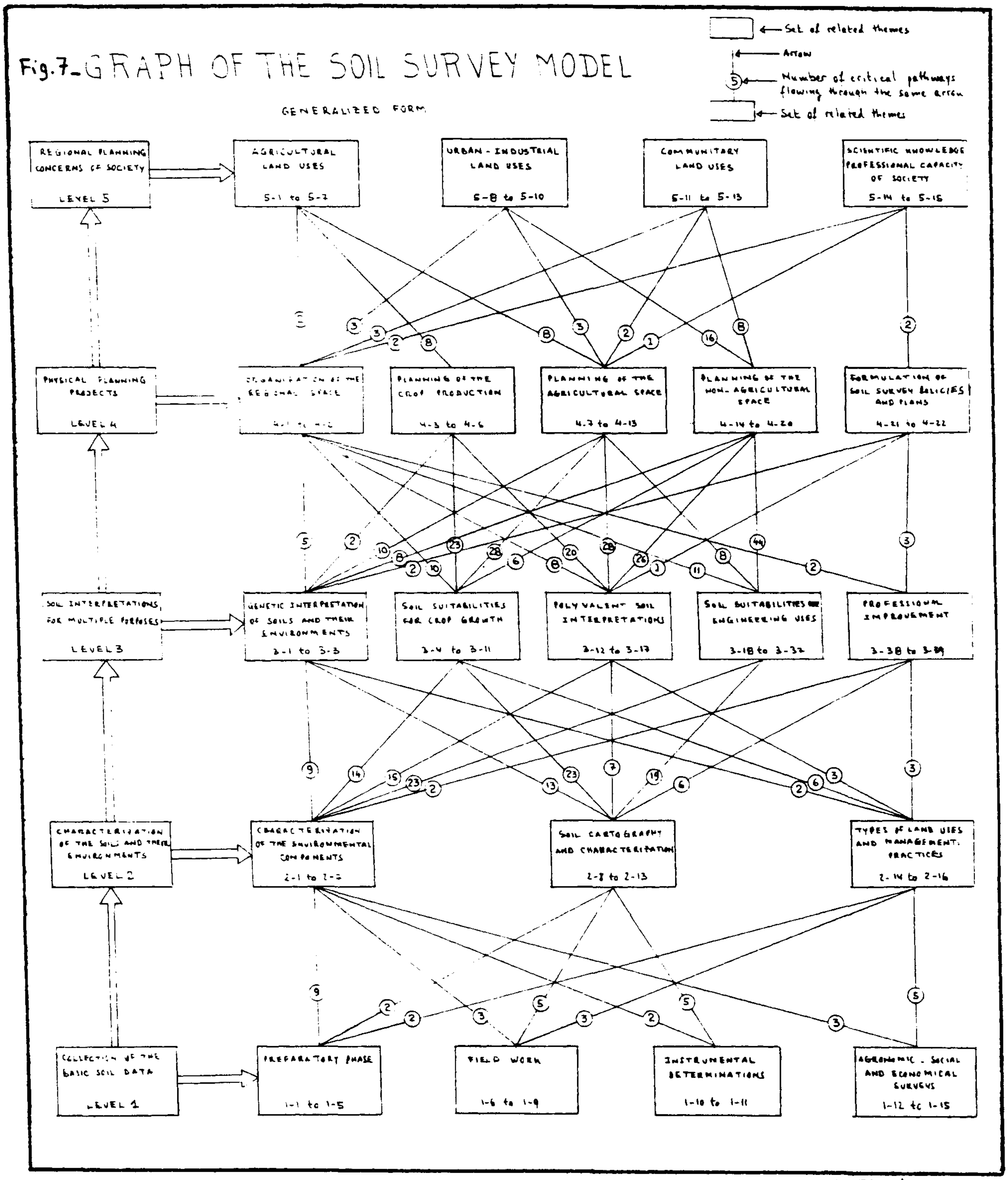


Fig.7_GRAPH OF THE SOIL SURVEY MODEL

A. Zinck, 1977.

II. MODES OF IMPLEMENTING GEOMORPHOLOGY IN SOIL SURVEY

This is an atempt of presenting in a structured way the many approaches of using geomorphlogy for soil survey purposes either in combination with other disciplines or alone. This leads to a sort of epistemology of the application of geomorphology to soil survey.

A. GEOMORPHOLOGY APPLIED IN COMBINATION WITH OTHER DISCIPLINES

1. PHYSICAL ASSOCIATION

Concerns essentially a flexible combination of geology and geomorphology referred to as physiography.

a) Landtype approach

- Traditionally used by the Soils Group of ITC.
- Based on two hierarchical levels: landtype and sub-landtype.
- Uses indistinctly geological or geomorphic concepts at both levels depending on what factor(s) seem(s) to determine the main features of each landtype. For instance, concepts as varied as the following ones may be used at the landtype level:
  . Age : T (= Tertiary)
  . Lithology: S (= Sandstone)
  . Landscape: P (=Piedmont)
  . Process : A (= Alluvial deposition)

b) SOTER legend

- Refers to the so-called "Universal legend for a world soils and terrain digital database" to be used at the scale of 1:1.000.000, as part of the SOTER Project (Global Soils and Terrain Digital Database).
- Based on two levels consisting of:
  . Origin of the forms: alluvial, etc., or of specific origin
  . Lithology.

c) ILWIS terrain/soil module

- Refers to the legend used in the ILWIS Project of ITC (Integrated Land and Watershed Management Information System).
- Based on three levels consisting of:
  . Origin of the landforms
  . Lithology of the substratum
  . Morphometric attributes of landforms.

2. BIOPHYSICAL ASSOCIATION

Two main streams may be distinguished according to whether emphasis is given to the physical component (= physiographic approach) or to the biological component (= land-ecological approach).

a) Physiographic approach

* CIAF approach (Centro Interamericano de Fotointerpretación, Colombia)
  - Legend based on six levels:
    . Physiographic province (including climatic zones)
    . Gran landscape
    . Landscape
    . Sub-landscape
    . Element of landscape
    . Division of element.
  - Combines climate, vegetation, geology, geomorphology and soils into mapping units according to varied and open associations of concepts and criteria at each level of the legend.
  - Soil is already a component of the legend.

* CSIRO approach (Commonwealth Scientific and Industrial Research Organization, Australia)
  - Legend based on three levels
    . Land facet (or site): homogeneous unit in terms of landform, soil and vegetation
    . Land unit: a given landform
    . Land system: based on broad geomorphic and/or geologic features.

b) Land-ecological approach

- Used by the Rural Survey and Land Ecology Group of ITC.
- Implements the concept of land unit, based essentially on vegetation mapping with some additional information on soils and landforms.

3. COMMON CHARACTERISTICS

- The various approaches aim mainly at the establishment of mapping legends adapted to local or regional conditions.
- There is no thorough system analysis supporting the structure of the legends.
- Legends may have from 2 to 6 categorical levels of open or flexible (sometimes ambiguous) generic definitions.

B. GEOMORPHOLOGY APPLIED ALONE

Two main streams may be considered depending on whether emphasis is on geoform mapping or on soil mapping.

1. EMPHASIS ON GEOMORPHOLOGY (INDEPENDENT SURVEYS)

- The geomorphic survey is operated on its own with general application purposes; application to soil survey may be one of them.
- The geomorphic survey is executed before the soil survey: its application is therefore delayed.
- The main objective is the mapping of geoforms not of soils. Soils are sometimes mentioned as an additional element of the system, often as a component part of the weathering cover.
- Several modes have been developed.

a) Cartography of cover formations

- Systematic cartography of cover formations("formations superficielles") for soil survey has been developed by A. Journeaux of the Centre National de Géomorphologie de Caen, France.

- Broad detritic cover units are distinguished on the basis of their origin (alluvial, aeolian, etc.) and in relation to in-situ developed weathering materials.
- Some descriptive or analytical soil information is mentioned for each geomorphic unit.

b) <u>Legend of the geomorphic map of France (RCP77)</u>

- Based on a teamwork of French geomorphologists under the lead of J. Tricart (University of Strasbourg).
- Legend consisting of 5 levels, called terms for coding purposes:
  . Location
  . Structural context (essentially lithology)
  . Morphogenetic context (general environment, climatic zones, age)
  . Cover formations (essentially granulometry)
  . Landforms.

c) <u>Terrain analysis</u>

Terrain analysis covers many different acceptations, out of which three are mentioned here.

* <u>ITC's approach</u> (R. van Zuidam)
  - Distinguishes 4 hierarchical terrain classification levels:
    . Terrain province
    . Terrain system (pattern)
    . Terrain unit
    . Terrain component.
  - But taxonomy is essentially a lineal one operating at the level of terrain unit. The denomination of each terrain unit is accompanied by a set of terrain characteristics such as relief morphology, processes, rock type, soil, hydrologic situation and vegetation/land use.

* <u>Landscape architecture approach (USA)</u>
  Developed in Schools of Architecture and Environmental Design (USA).
  - Refers essentially to topographic features important to urbanism such as aspect (exposure) and relative height (sight).

* Military approach

Refers to the analysis of terrain stability.

2. EMPHASIS ON SOILS (INTEGRATED GEOMORPHOLOGY - SOIL SURVEY)

- The geomorphic survey is integrated with the soil survey.
- The main objective is soil mapping; geomorphology is used as a tool for that purpose.
- Geomorphology contributes to soil delineation and genetic interpretation.

a) Morphopedology (Kilian-Tricart, IRAT, France)

- Based on the concept of morphogenesis-pedogenesis balance (Fig.8).
- The resulting map shows stability degrees of the natural environments (stable, almost stable, unstable mediums), highlighting where pedogenesis can proceed without impediments and where not.
- Such a map is more an interpretative type of document, derived from original geomorphic and soil maps.

b) Catena models approach (ORSTOM, France)

- Based on the concept of soil volume as a criterion for soil mapping.
- System consisting of 4 levels used as mapping levels: (Fig.9)
  . Horizons
  . Soils
  . Cartographic units
  . Soil landscapes.
- At the 3rd level, relief morphology (modelé), parent material, vegetation, climate and topography are used for establishing the mapping units.
- At the 4th level, geomorphic provinces are used.
- Aims at dissecting the landscape into and representing it cartographically by unique soil associations along regional catena models.

c) Geopedology (approach used in this course)

- Based on a strong integration of geomorphology and pedology using geomorphology as a tool to improve and speed up the soil survey.

Fig. 8 – MORPHOPEDOLOGY APPROACH

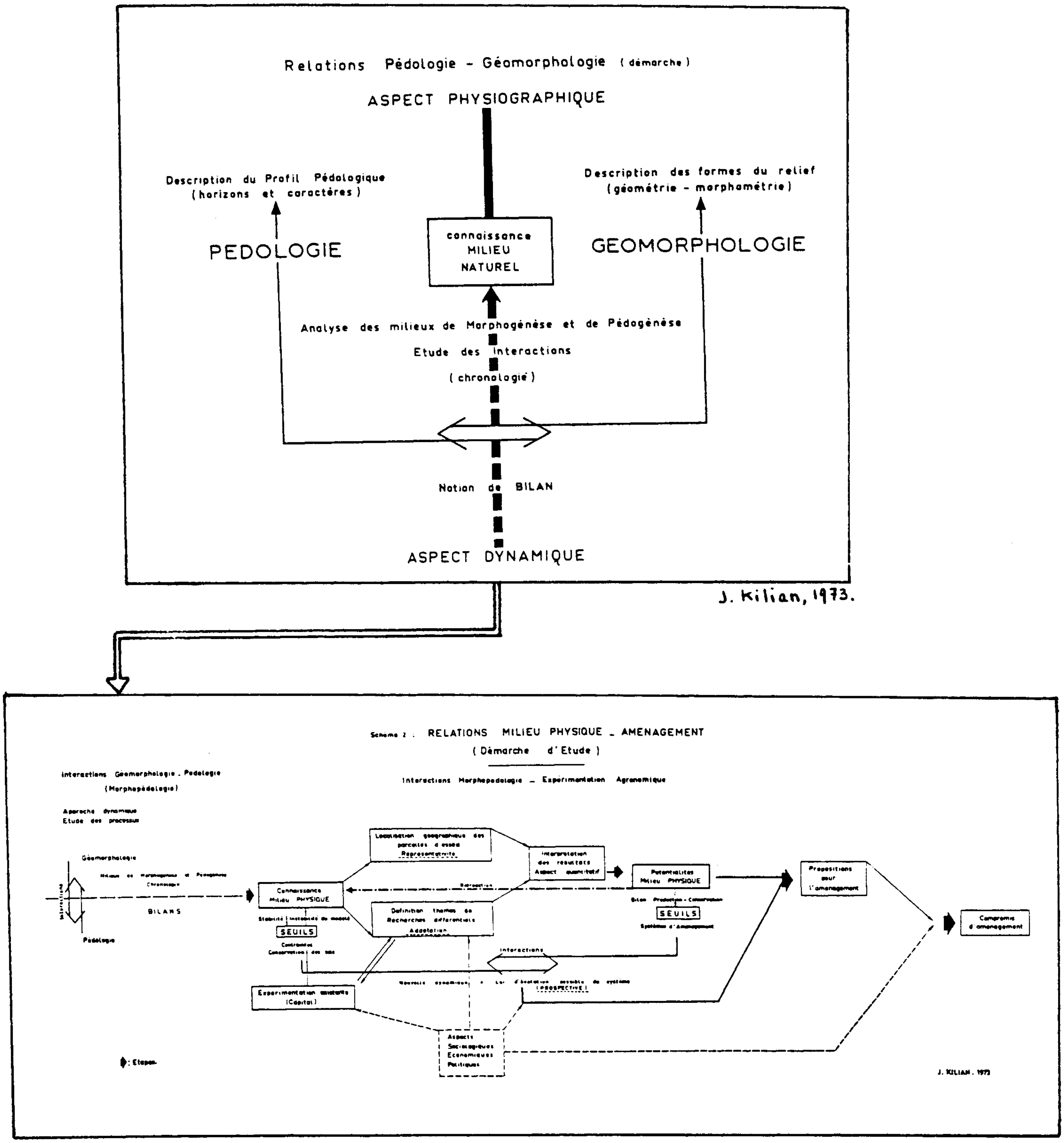
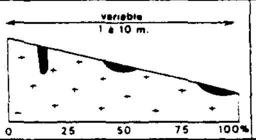
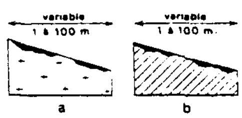
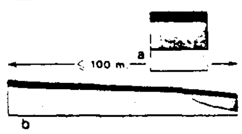
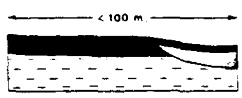
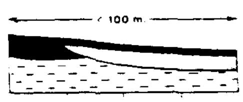
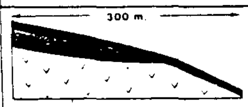
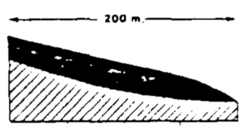
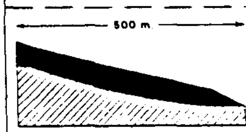


Fig. 9 - CATENA MODELS APPROACH

Le terme figurant en caractères gras représente, soit le sol d'une unité simple, soit le sol dominant par sa superficie dans une association. Dans une association de sols ordonnés le premier sol cité se trouve à l'amont, le second à l'aval des versants.

	Paysages pédologiques	Matériaux originels	SOLS		
			Organisation des principaux horizons	Unités taxonomiques (références C. P. C. S.)	Unités cartographiques
1	mosaïque lithosolique des montagnes à *Boswellia*	roches acides diverses		**SOLS MINÉRAUX BRUTS** **lithosols** SOLS PEU ÉVOLUÉS D'ÉROSION lithiques	1
2	mosaïque régosolique des pentes très érodées à *Boswellia*	a. granite ou gneiss b. micaschistes à séricite		**SOLS PEU ÉVOLUÉS D'ÉROSION** **régosoliques ou lithiques** SOLS MINÉRAUX BRUTS lithosols	2
3	mosaïque ou combinaison a. des bas-fonds inondables b. des bourrelets alluviaux à galeries forestières	sediments sablo-limoneux sablo-argileux ou sableux		**SOLS PEU ÉVOLUÉS D'APPORT** **alluviaux et colluviaux**	3
4	combinaison hydromorphe et vertique des plaines alluviales inondables à *Echinochloa* et *Mimosa*	sédiments argileux et argilo-sableux		**VERTISOLS** **à pédoclimat humide** SOLS HYDROMORPHES À GLEY peu profond	4
				VERTISOLS à pédoclimat humide **SOLS HYDROMORPHES À GLEY** **peu profond**	5
5	mosaïque fersiallitique et vertique des pédiments érodés à *Anogeissus* et *Acacia*	micaschistes à amphibole, et amphibolites		**SOLS FERSIALLITIQUES** **rubéfiés, parfois brunifiés** *phase érodée fréquente*	6
		conglomérats volcaniques		**SOLS FERSIALLITIQUES** **brunifiés** *et leur phase érodée*	7
		micaschistes à amphibole, et amphibolites		**SOLS FERSIALLITIQUES** **rubéfiés, parfois brunifiés** VERTISOLS à pédoclimat sec *et leur phase érodée ou dégradée*	8
				SOLS FERSIALLITIQUES rubéfiés, parfois brunifiés **VERTISOLS** **à pédoclimat sec**	9

Brabant - Gavaud, 1985.

- The implementation of geomorphology operates through a taxonomic system comprising 6 categorical levels (see next chapter).

3. COMMON CHARACTERISTICS

- In this second category of approaches, geomorphology is used as a discipline: more exhaustive use of geomorphic concepts, less mixing up of concepts derived from many disciplines.
- The integration geomorphology-pedology is based on preferential relationships (conceptual, methodological, operational).
- System analysis supports geomorphic taxonomy, the implementation of which leads to a more strongly structured legend.

C. NEW TRENDS AND CONTINGENCIES

1. GIS DATA REQUIREMENTS

The implementation of databases and geographical information systems imposes new conditions and constraints for data collection, organization and handling.

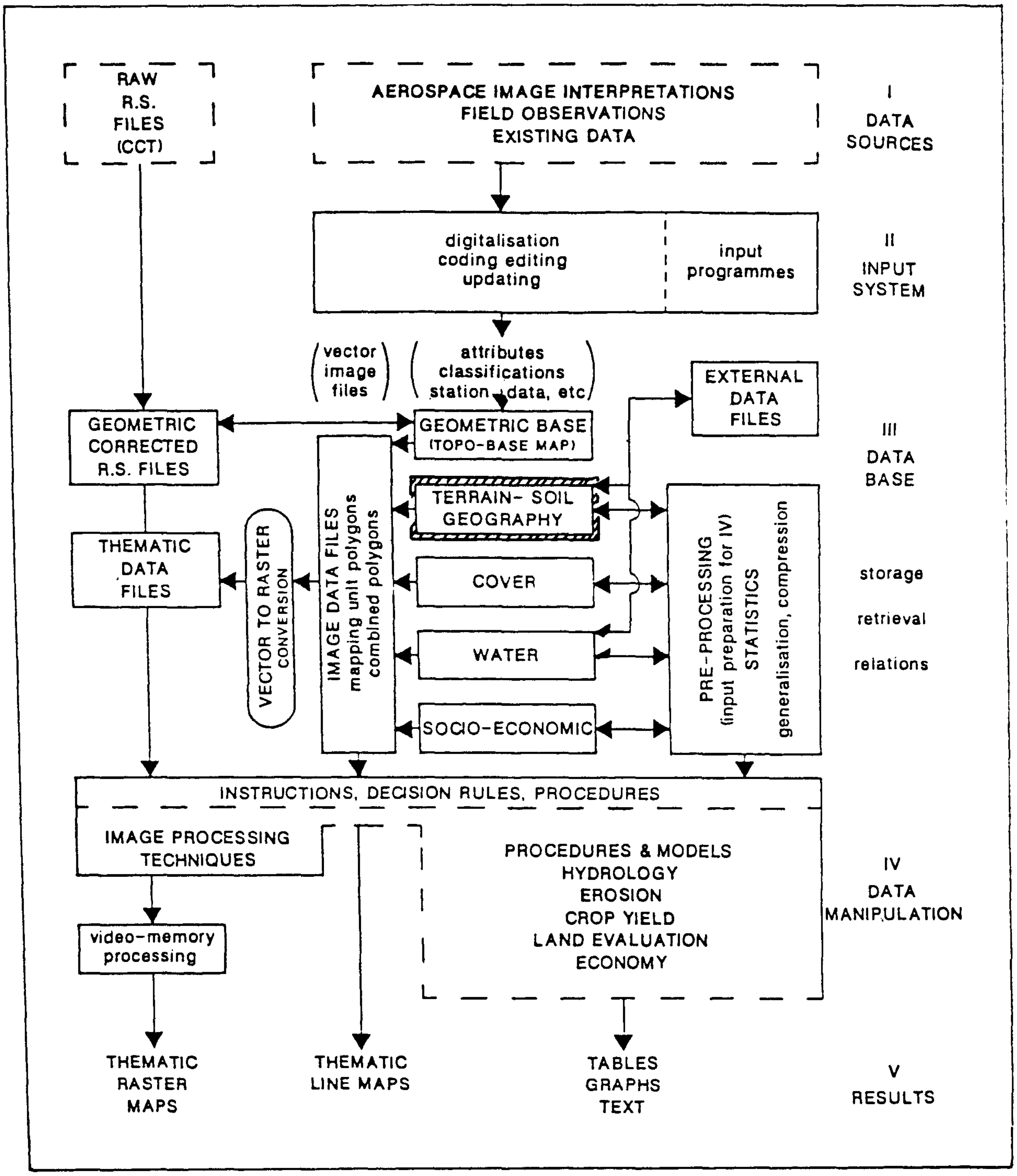
- The most efficient database for natural resources is a modular one, including one module per type of natural resource. Therefore data introduced in the system should be primary (disaggregated) data.
- The system should allow for easy updating of data. Therefore information exposed to changes over short periods of time (vegetation, land use) should be separated from more stable information (geomorphology, soils).
- One type of theme (= type of resource) must be given the lead for determining the master-lines in order to facilitate the superimposition of thematic maps. Geomorphology best meets this function.

2. APPLICATION EXAMPLES

a) ILWIS (Fig. 10).

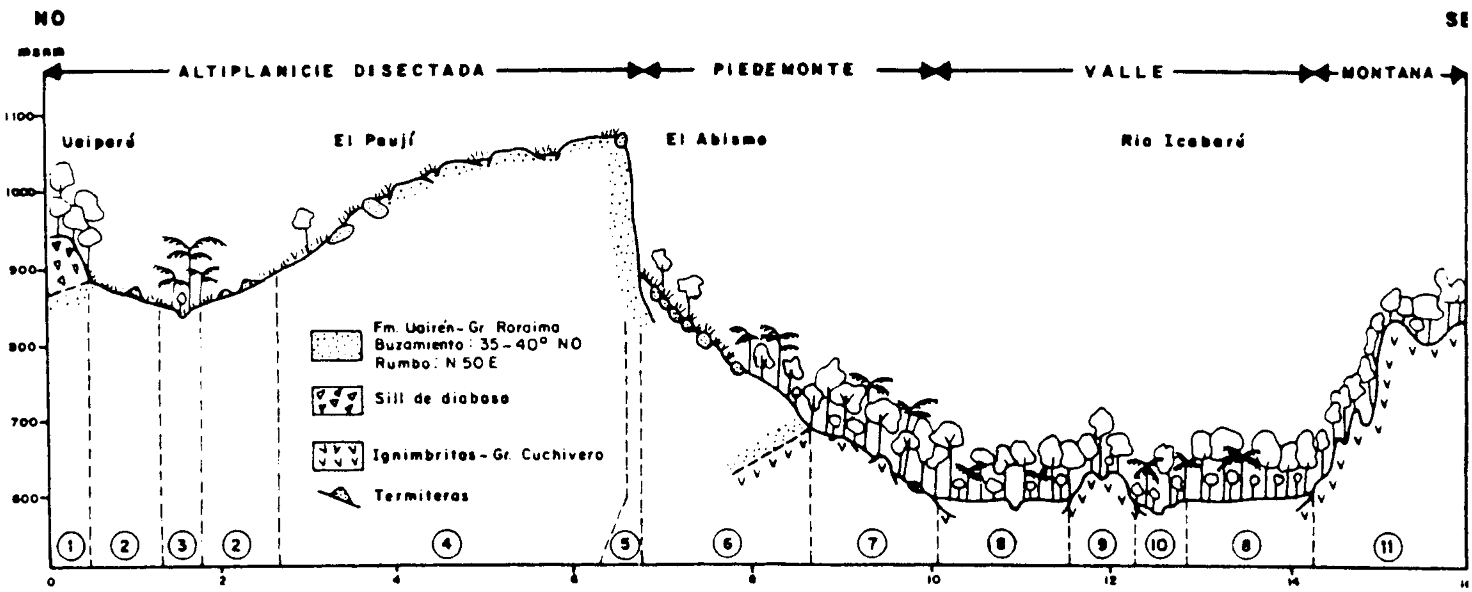
b) Inventory of natural resources of Guayana, Venezuela
  - Multidisplinary inventory (thematic teams)(Fig. 13).
  - Thematic cartography based on geomorphic photo-interpretation (Fig. 12).
  - Example of multi-thematic transect(Fig. 11).

Fig.10 - POSITION OF THE TERRAIN-SOIL GEOGRAPHY MODULE IN THE ILWIS SYSTEM



Valenzuela et al., 1986.

Fig. 11 _ EXAMPLE OF MULTI-THEMATIC TRANSECT USING GEOMORPHIC ENTRIES



①	②	③	④	⑤	⑥
LOMA DISIMETRICA CON DOMO TABULAR (30-70% PENDTE.)	GLACIS COLUVIAL (3-5% PENDTE) TERMITERAS	VEGA COLUVIO-ALUVIAL	REVERSO DE CUESTA (MESA INCLINADA) SUPERF. DE ABLACION	FRENTE DE CUESTA (CORNIZA SUBVERTICAL)	TALUD DE DERRUBIOS DE GRAVEDAD (80-90% PENDTE)
DIABASA (SILL)	MATERIAL SUELTO TRANSPORTADO SOBRE SUBSTR. DE ARENISCA	MATERIAL SUELTO TRANSPORTADO SOBRE SUBSTR. DE ARENISCA	ARENISCAS CONGLOMERATICAS ESTR. MONOCLINAL	ARENISCAS CONGLOMERATICAS ESTR. MONOCLINAL	FRAGMENTOS DE ARENISCAS CONGLOMERATICAS
TROPUDULTS DYSTROPEPTS	TROPOPSAMMENTS TROPORTHODS QUARTZIPSAMMENTS	TROPAQUENTS (INUNDABLES)	TROPORTHENTS (LITHIC) AFLORAM. ROCOSOS	AFLORAMIENTO ROCOSO	TROPORTHENTS HUMITROPEPTS (AMBOS LITHIC)
BOSQUE OMBROFILO MESOTERMICO MEDIO DENSO	SABANA RALA CON PASPALUM CONTRACTUM AXONOPUS PRUINOSUS	MORICHAL CON MAURITIA MINOR CARAIPA SP	SABANA COMO ② ARBUSTAL CON HUMIRIA BALSAMIFERA VANTANEA MINOR	SIN VEGETACION SALVO NUT LOCALMENTE	SABANA COMO ② ARBUSTAL COMO ④ BOSQUE RALO

⑦	⑧	⑨	⑩	⑪
GLACIS DE EROSION (40-60% PENDTE)	LLANURA ALUVIAL DE INUNDACION (0-2% PENDTE)	COLINA (70-80% PENDTE)	VEGA ALUVIAL (0-1% PENDTE)	FILA Y LOMA (>80% PENDTE)
IGNIMBRITAS	MATERIAL SUELTO TRANSPORTADO SOBRE SUBSTR. IGNIMBRITAS	IGNIMBRITAS	MATERIAL SUELTO TRANSPORTADO SOBRE SUBSTR. IGNIMBRITAS	IGNIMBRITAS
TROPUDULTS AFLORAM. ROCOSOS	TROPUDULTS TROPAQUULTS	TROPUDULTS	TROPAQUEPTS (INUNDABLES)	TROPUDULTS PALEUDULTS
BOSQUE OMBROFILO SUBMACROTERMICO MEDIO DENSO	BOSQUE OMBROFILO SUBMACROTERMICO MEDIO DENSO CONUCOS	BOSQUE OMBROFILO SUBMACROTERMICO MEDIO DENSO	BOSQUE DE GALERIA	BOSQUE OMBROFILO SUBMACROTERMICO MEDIO A BAJO DENSO

A. Zinck, 1986

Fig. 12 THEMATIC CLASSIFICATION SYSTEMS USED IN MULTI-DISCIPLINARY INVENTORIES

CUADRO. 1 SISTEMAS DE CLASIFICACION IMPLEMENTADOS POR LAS DIVERSAS DISCIPLINAS

GEOLOGIA (1)	GEOMORFOLOGIA (2)	VEGETACION (3)	SUELOS (4)
PROVINCIA GEOLOGICA	PROVINCIA FISIOG	CLASE DE FORMACION	ORDEN
SUPERGRUPO	REGION NATURAL	SUBCLASE DE FORMAC	SUBORDEN
GRUPO	TIPO DE PAISAJE	GRUPO DE FORMACION	GRAN GRUPO
FORMACION	TIPO DE RELIEVE	FORMACION	SUBGRUPO
MIEMBRO	FORMA DE TERRENO	SUBFORMACION	FAMILIA
CAPA	OTRAS SUBDIVISIONES	OTRAS SUBDIVISIONES	SERIE

(1) H. Hedberg et al. - Guía estratigráfica internacional. Editorial Reverté, Barcelona (1980).

(2) Alfred Zinck - Definición del ambiente geomorfológico con fines de descripción de suelos. MOP,- Cagua. (1974) y CIDIAT, Mérida (1980).

(3) UNESCO - Clasificación internacional y Cartografía de la vegetación. París (1973).

(4) USDA - Soil taxonomy. A basic system of soil classification for making and interpreting soil survey. Agriculture Handbook 436. SCS (1975).

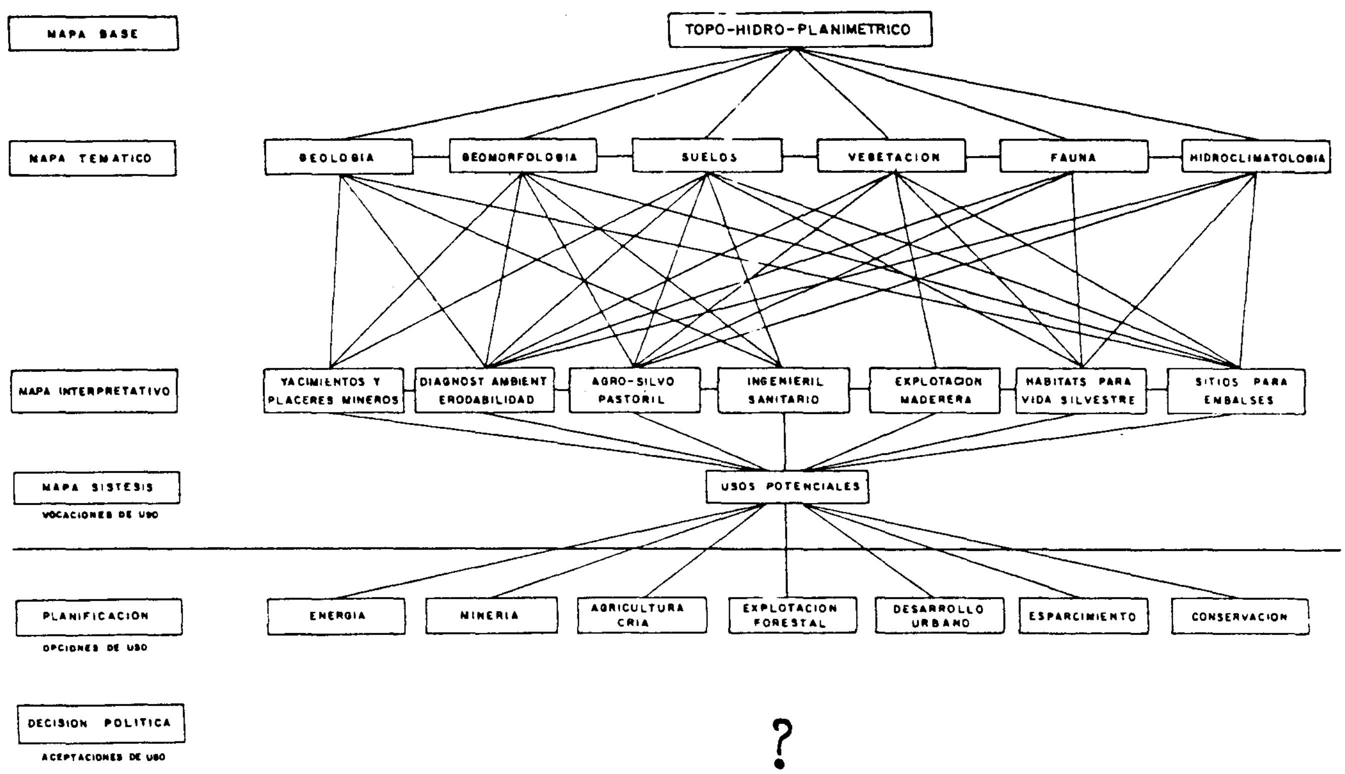
MIEMBRO Nivel categórico implementado en el correspondiente mapa temático.

NOTA: La disposición de los niveles categóricos en el cuadro no implica ningún intento de correlación horizontal entre las diversas disciplinas.

A. Zinck, 1986.

Fig. 13 - THEMATIC INFORMATION FLOWS IN MULTIDISCIPLINARY INVENTORIES

Fig. 5 FLUJOS DE INFORMACION — INVENTARIC DE RECURSOS NATURALES DE GUAYANA



A. Zinck, 1986.

III. STRUCTURE OF THE TAXONOMIC SYSTEM

Geomorphologists have always been concerned by classification, but the criteria used for it have changed over time and remain still very diverse. After discussing some main approaches to geomorphic classification, an attempt is made to present the structure of a proposed taxonomic system for classifying geoforms.

A. EXAMPLES OF GEOMORPHIC CLASSIFICATIONS

1. MORPHOMETRIC CLASSIFICATION (Tricart-Cailleux)

- Geoforms are classified according to their size (Table 1).
- The classification is hierarchical but essentially dimension-based and with major emphasis on structural geomorphology.

Table 1 - MORPHOMETRIC CLASSIFICATION

ORDERS	EXAMPLES	LENGTH OF MAIN AXIS
1	Continents, oceanic basins	-
2	Shields, geosynclines	Thousands of km
3	Mountain chains	Hundreds of km
4	Mountain ridges	Tens of km
5	Anticlines, synclines	km
6	Sliding	Hundreds of m
7	Solifluction lobe	m

2. GENETIC CLASSIFICATION

This is a classification based on the conventional subdivision of geomorphology as a scientific discipline into specialized fields concerned with the study of different types of geoforms.

Study fields of geomorphology	Types of geoforms
a) Structural geomorphology (types of relief)	{ Cuesta relief { Folded relief { Shield relief, etc.
b) Climatic geomorphlogy (types of "modelé" = molding)	{ Glacial molding { Periglaçial molding { Eolian molding, etc.
b) Azonal geomorphology (types of form)	{ Alluvial forms { Lacustrine forms { Coastal forms, etc.

3. GENETIC-CHOROLOGIC CLASSIFICATION

This type of classification is based on the concept of morphogenetic zones whose latitudinal and altitudinal distribution parallels the subdivision of the earth's surface into broad climatic zones, resulting in a set of morphoclimatic domains and associated geoforms:
- glacial
- periglacial
- temperate (dry, wet)
- mediterranean
- subtropical and tropical (dry, wet).

The classification combines origin and geographical distribution of geoforms. It is typically used for the presentation of geomorphology in textbooks.

4. CONCLUSION

a) Common characteristics

- Some hierarchical structure
- A typology (types as reference patterns).

b) Limitations

- Lack of clear definition of the criteria used for hierarchization and typology
- Tendency of over-emphasizing one or other attribute of geoforms: either dimension, or genesis or geographical distribution.

B. PRINCIPLES AND CONCEPTS FOR SYSTEM STRUCTURING

1. BASIC ASSUMPTIONS AND DEFINITIONS

a) Assumptions

The above-mentioned limitations of the traditional classification systems of geoforms led to an attempt based on the following assumptions.
- The dimension of geoforms is a subordinate, no-diagnostic characteristic. A geoform belongs to a given class independently of its

size (whether small or extensive) as long as it meets the attribute requirements of that class.

- The geographical distribution of geoforms is not a taxonomic criterion. Chorology of geoforms is taken care of by means of mapping and legend structure.
- The genesis of geoforms should be considered only at lower levels of the system since this aspect may be unclear or controversial, or a large set of data may be needed to determine it.

b) System development conditions

The development of the system makes intensive use of existing concepts, methods, information and experience.

- Typology of geoforms: definition and description attributes are partly taken from existing literature. The classification attempt does not pretend to "reinvent the wheels", but to organize the available knowledge into a hierarchical taxonomic system.
  Fundamental documents used for this purpose are:
  . Geomorphology manuals (M. Derruau, A. Strahler, W. Thornbury, J. Tricart, G. Viers, etc.)
  . Legend for the geomorphic map of France (RCP 77)
  . Informatique et Biosphère Association
  . ITC manuals (H. Verstappen, R. van Zuidam, etc.).
- Structure of the system: deep inspiration has been taken from the conceptual framework of the USDA-SCS Soil Taxonomy concerning the concepts of category, class and attribute.
- Development and validation of the system have been done mainly in Venezuela and partly in Colombia through numerous soil survey projects using geomorphology as a tool for soil mapping. The development and gradual improvement of the system are the result of an applied geomorphology approach.

c) Definitions

* Objective and object of classification
  - A taxonomic system has normally one objective (and only one): to classify taxonomically a set of objects belonging to the same universe. Objects in this case are geoforms or geomorphic units.

- A taxonomic system should aim at classifying the object by itself, through its characteristics, and not through its forming factors. The latter can be highlighted in a legend.
- A taxonomic system cannot classify simultaneously objects of different nature (e.g. soils, climate, geoforms, etc.).

* Taxonomic system and legend

Unique combinations of different universe of objects such as climate, vegetation, soils and geoforms can be showed in a legend. There is therefore a fundamental difference between a taxonomic system and a legend:

- A taxonomic system intends to classify objects.
- A legend implements the results generated by one or more taxonomic classifications for cartographic purposes.

  As a consequence, a legend is more flexible, a taxonomic system is more rigid.

Examples of legend using results of taxonomic classification

(1) Soil groupings according to drainage classes:
  - (a) Well drained to moderately well drained soils:
    - Typic and Aquic Haplustolls
    - Fluventic and Fluvaquentic Ustropepts
  - (b) Poorly to very poorly drained soils:
    - Aeric Tropaquepts and Typic Tropaqualfs
      (One mapping unit composed of two taxonomic units)

(2) Soil groupings according to their position on the landscape:
  - (a) Floodplain soils : Fluvents and Tropepts
  - (b) Middle terrace soils: Tropustalfs and Argiustolls

Conclusion: A soil legend arranges and displays a population of taxa according to a given purpose, highlighting in general the influence of one or more prominent soil forming factors (as summarized for example by a geomorphic unit = parent material + topography + time).

* Natural and technical classification systems

- Natural system = taxonomic system

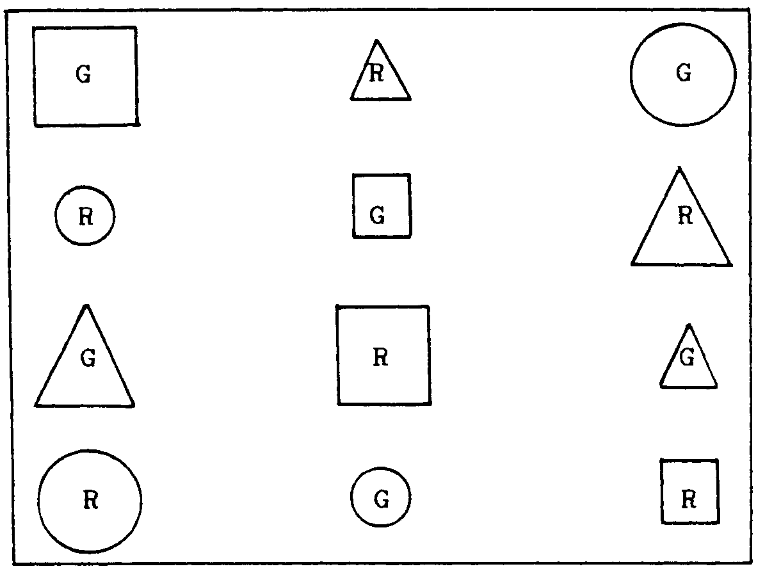
e.g. USDA Soil Taxonomy
Plant classification
Geoform classification

- Technical system = interpretative system for practical purposes
  e.g. USDA land capability classification
  FAO land suitability classification

2. CLASSIFICATION PRINCIPLES AND MECHANISM

a) Population of objects

Fig.14-



R = red
G = green

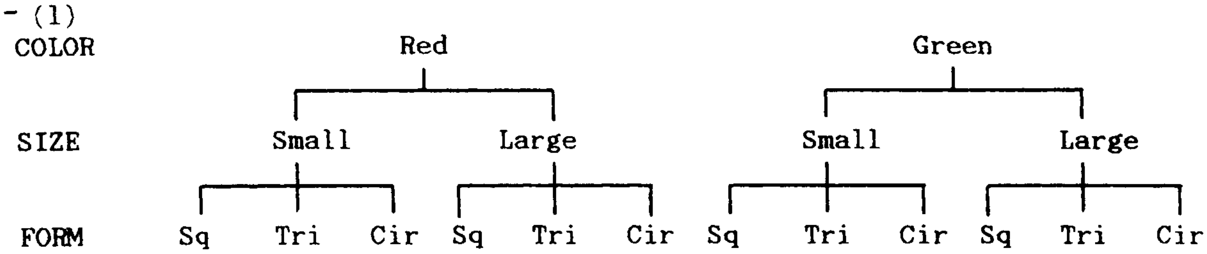
b) Contingency table (3 criteria, several varieties of each one)

Table 2-

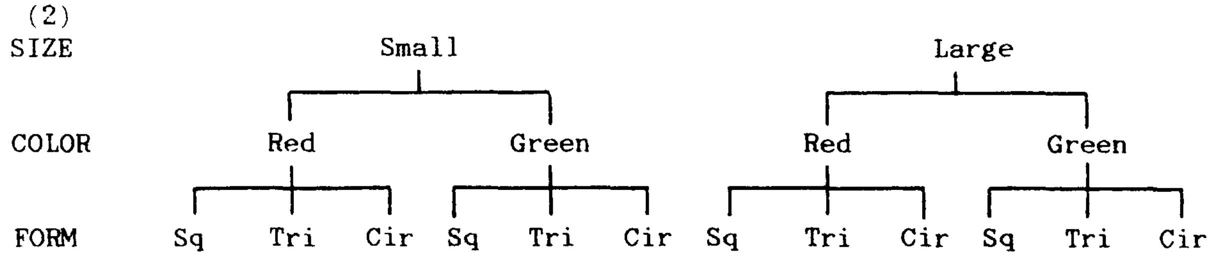
Attributes	Attribute states		
Color	Red	Green	-
Size	Large	Small	-
Form	Square	Triangle	Circle

c) Classification alternatives (6 possible combinations)

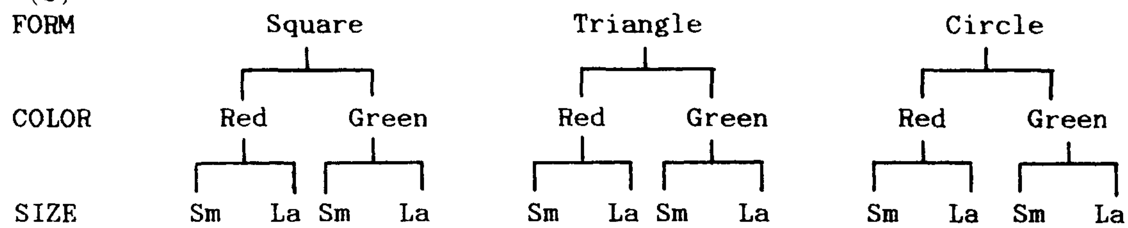
Fig.15- (1)



(2)



(3)



Remaining alternatives of hierarchization

(4)	(5)	(6)
Color	Size	Form
Form	Form	Size
Size	Color	Color

d) Classification elements

From the previously developed example, the three fundamental elements of any hierarchical classification system can be deduced, namely category, class and attribute.

- Hierarchical levels = categories supporting the hierarchy of the system
  Three categories are present
  Several (6) hierarchical arrangements are possible
- Groupings = classes
  All reds, all greens
  All smalls, all larges
  All squares, all triangles, all circles
- Characteristics = attributes
  Attribute nature: color, size, form
  Attribute state : red and green (for color)

e) Principles involved in the classification mechanism

- Knowledge : color, size, form
- Logic : hierarchical arrangement
- Decision making: for selecting the most appropriate hierarchical arrangement in relation to the objective of the classification system.

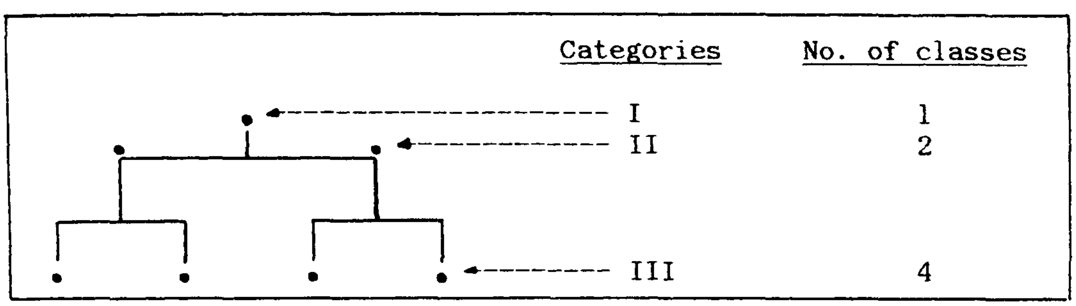
3. SYSTEM STRUCTURE AND ELEMENTS

A taxonomic system is characterized typically by:
- its structure (or configuration)
- its component elements.

a) System structure

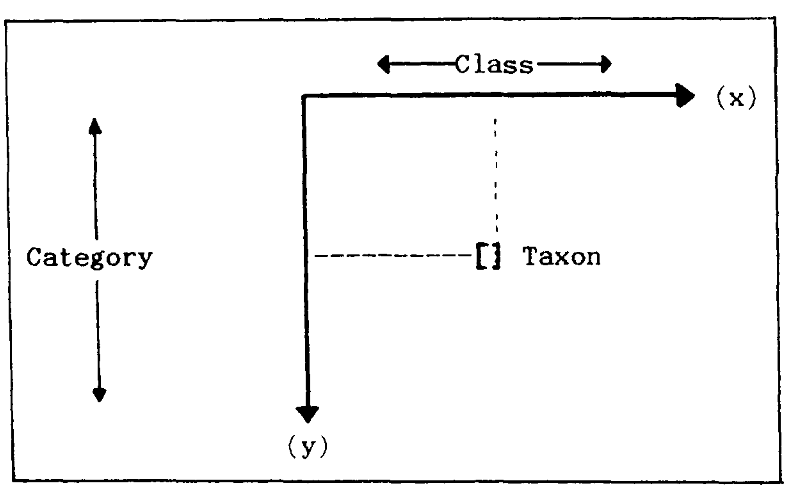
- Several configuration models are possible: hierarchical, relational, network, lineal, etc.
- The hierarchical structure is considered in general as the most appropriate for taxonomic purposes (= multi-categorical system).

Fig. 16



- Matrix configuration showing the 3 basic elements of a two-dimensional hierarchical system: category, class and taxon.

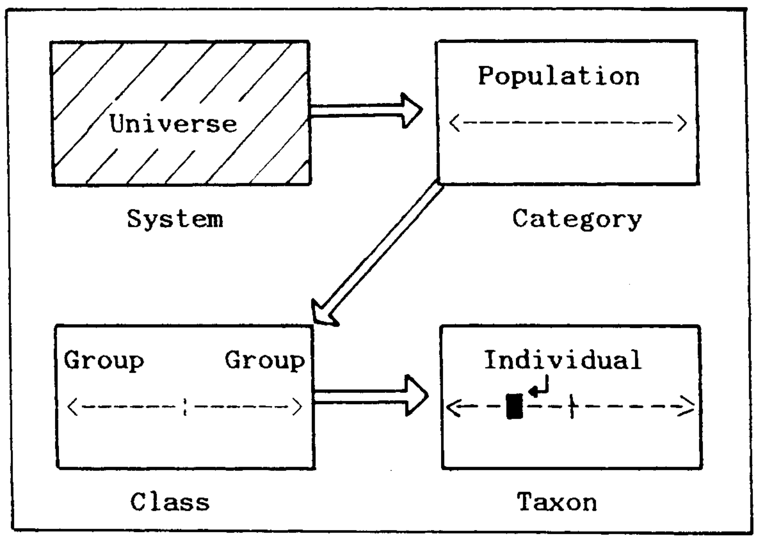
Fig. 17



b) <u>System elements</u> (Fig. 18)

Classification operates through and results in:
- segmentation of an universe (e.g. soil continuum) into populations, groups and individuals (= top-down mechanism, disaggregation),
- assembling of individuals into groups, populations and universe (bottom-up mechanism, aggregation).

Figure 18 _ SEGMENTATION OF AN UNIVERSE



* <u>Universe</u>

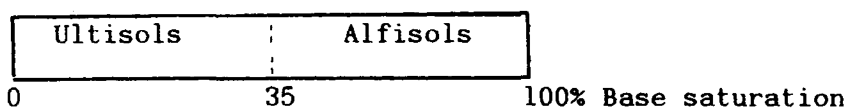
A system can be compared to a black box containing all individuals of the same object we want to classify: e.g. all soils, all geoforms. This collection of individuals constitutes the universe we want to dissect into classes.

* <u>Category</u>
- If we shake the black box, an arrangement of the contained individuals will occur according to their size, weight, form, etc. into strata = categories.
  - A category is:
    . a segment of an universe, represented by a population of individuals of a given homogeneity,
    . a set of classes showing a similar level of abstraction.
  - A category is identified by a generic concept applicable to all individuals present at that level (e.g. color, size, form in the former example).

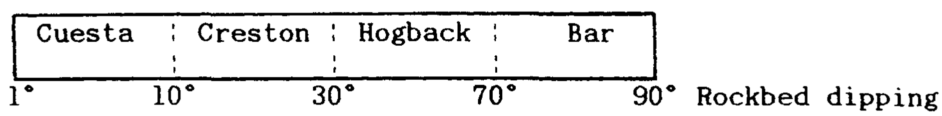
- A category is a level of abstraction (≃ generalization): the higher the level of the category, the higher the level of abstraction.

* Class

- Any formal subdivision of a population at a given categorical level. Therefore, a class is a member of a category.
- A class may be defined using different types of concepts:
  . Range of variation of selected attributes:
  e.g. Difference between Alfisols and Ultisols using the attribute % base saturation to determine the class limits.



e.g. Classes of monoclinal reliefs established on the basis of the dip slope of the rockbeds.



. Central typifying concept in relation to intergrades or extragrades:
e.g. Typic as used at the subgroup level in the USDA Soil Taxonomy.

* Taxon (taxons) or Taxum (taxa)

- A concrete taxonomic unit being a member of an established class at a given categorical level.
- A taxon may cover only part of the allowed range of variation concerning the attributes selected to define the class (Fig. 18).

* Attribute

- A characteristic (or variable) used for:
  . establishing limits of classes (constructing the system)
  . describing and classifying individuals (making the system operational).

- Types of attributes:
  . dichotomous: e.g. presence or absence of iron reduction mottles
  . multi-states without ranges: e.g. structure types
  . multi-states with ranges: e.g. size of structural peds
  . continuous variation: e.g. base saturation.
- Problems:
  . selection, categorization (diagnostic or not) and hierarchization of attributes
  . measurement of attributes.

4. CONCLUSION

To establish a taxonomic system, 5 main issues must be analyzed and solved:
a) Selection of the most appropriate system structure
b) Definition and number of categories (2 --> ?)
c) Definition and limits of classes
d) Selection and hierarchization of attributes
e) Nomenclature (vocabulary) for naming categories and classes.

There is more tan one way to solve these problems. Iteration is a good one, proceeding by trials and errors and combining the following approaches:
- system analysis
- existing knowledge implementation (knowledge base --> expert system)
- clear definition of the objective of the system.

C. CONFIGURATION OF THE PROPOSED SYSTEM

1. BASIC CONSIDERATIONS AND RULES

a) Taxonomy versus chorology

- Chorologic units, which are normally related to a given geographic setting, should not be introduced as classes in the system because they cannot be submitted to an abstraction process and therefore have no taxonomic meaning (see point 2).
- Toponymic designations can be used as phases of taxonomic units, e.g. Makuko Depression, Bamber Highlands.
- Cartography and legend can take care of showing chorologic relationships.

- The classes of the geomorphic taxonomy can be used as an input for national or supranational physiographic or landscape-ecological legends, based on biophysical geographic units, together with the contribution of other thematic classifications (geology, vegetation, etc.). A hierarchical approach can be used for that purpose (Table 3).

Table 3 - HIERARCHY AND DETERMINING FEATURES OF PHYSIOGRAPHIC LEVELS

LEVEL	GENERIC CONCEPT	MAIN FEATURES Topo.	Geol.	Geom.	Clim.	Veget.	Soils.	L.use
National	Physiographic province	x	x					
Regional	{ Natural region	x	x	x	x			
	{ "Land", "pays", "country"	x	x	x	x	x	x	
Local	?	x	x	x	x	x	x	x

Figure 19 shows an application to the Venezuelan territory.

b) Need for hierarchization of classes

Classes such as plateau, terrace and levee should be located at different categorical levels in the system, because they correspond to different levels of abstraction.

c) The place of geogenetical concepts in the system

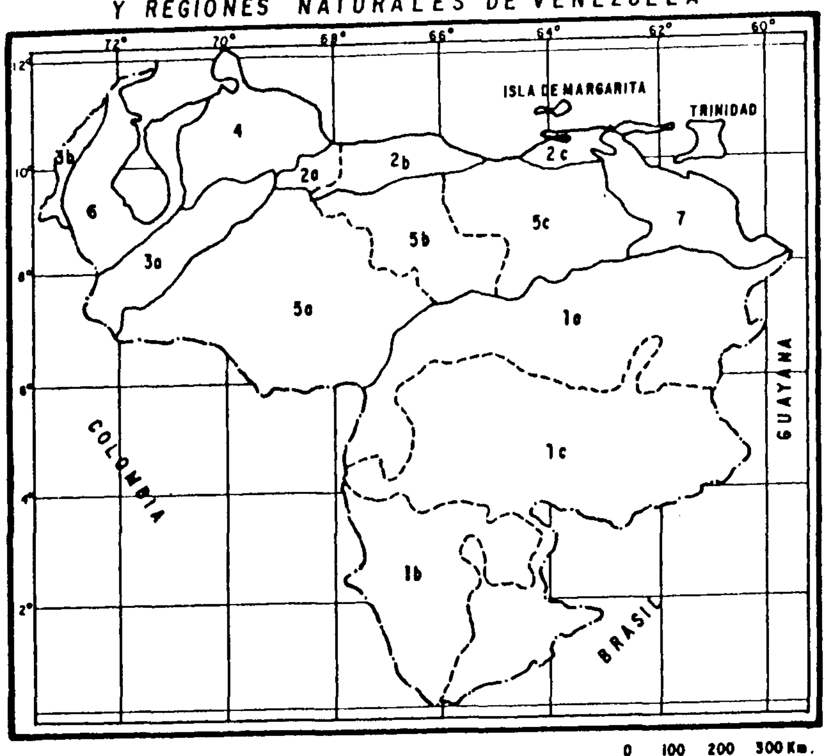
Genesis of geomorphic units is often not clearly known, and/or large, sometimes expensive sets of data are required for its determination. Therefore complex genetical considerations should be introduced only at the lower levels of the system. At the higher levels, more descriptive and objective attributes should be implemented. This premise parallels pattern recognition techniques used in aerial photo-interpretation.

d) Object properties versus forming factors

Emphasis should be on the properties of the object to be classified. Reference to forming factors should be restricted, especially where interferences between several forming factors may make it difficult to weigh out cause-effect relationships.

Fig. 19 - PHYSIOGRAPHIC - CHOROLOGIC DIVISION OF THE VENEZUELAN TERRITORY

PROVINCIAS FISIOGRAFICAS Y REGIONES NATURALES DE VENEZUELA



① ESCUDO GUAYANES
- 1a Penillanura del Norte
- 1b " del Casiquiare
- 1c Tepuis y Gran Sabana

② SISTEMA DE LA COSTA
- 2a Tramo Occidental
- 2b " Central
- 2c " Oriental

③ SISTEMA DE LOS ANDES
- 3a Cordillera de Mérida
- 3b " " Perijá

④ SISTEMA CORIANO Y SUS MARGENES

⑤ LLANOS
- 5a Llanos Occidentales
- 5b " Centrales
- 5c " Orientales

6 DEPRESION DEL LAGO DE MARACAIBO

7 DELTA DEL RIO ORINOCO

PROVINCIAS FISIOGRAFICAS Y REGIONES NATURALES DE VENEZUELA *

TIPO DE ESTRUCTURA GEOLOGICA	PROVINCIA FISIOGRAFICA **	REGION NATURAL **
Zócalo	Escudo Guayanés	a) Penillanura del Norte b) Penillanura del Casiquiare y tierras bajas del Ventuari. c) Tepuis y Gran Sabana
Cordilleras geosinclinales	Sistema de la Costa	a) Trazo occidental - Macizo de Nirgua - Depresiones intermontanas: Nirgua, Bejuma b) Trazo central - Serranía del Litoral - Serranía del Interior - Galeras - Depresiones intermontanas: Valencia, Caracas, Tuy - Barlovento c) Trazo oriental - Serranía del Litoral - Serranía del Interior - Depresiones intermontanas: Cumanacoa, Campona-Casanay d) Islas del Caribe
	Sistema de los Andes	a) Cordillera de Mérida b) Cordillera de Perijá c) Depresiones intermontanas: Táchira, Chama, Valera
	Sistema Coriano y sus márgenes	a) Sierras Corianas b) Depresiones intermontanas: Barquisimeto-Carora, Yaracuy c) Litoral falconiano d) Península de Paraguaná
Cuencas sedimentarias	Llanos	a) Llanos occidentales - Llanos Altos - Llanos Bajos b) Llanos centrales - Llanos Altos - Llanos Bajos c) Llanos orientales - Mesas - Depresión de Unare - Llanos Bajos
	Depresión del Lago de Maracaibo	a) Región Norte b) Región Sur (ciénagas)
	Delta del río Orinoco	

* Según A. Cárdenas modificado

** Región y Subregión, respectivamente, en el cuadro original.

A. Zinck, 1974.

Climate and vegetation for example should be rather used as phases of taxonomic units and implemented in legend structuring but not as determining concepts in the taxonomic system. Climate is, however, implicitely present in several places of the system (e.g. morphogenetic environment, material facies, etc.).

e) Nomenclature (vocabulary)

One of the main weaknesses of geomorphology is its (pre)scientific vocabulary for naming geoforms. Class names are frequently extracted from common language, making scientific description difficult and leading to many meaning discrepancies. It is attempted here to select the best fitting terms on the basis of etymology, universality, usage, etc.

2. PERCEPTION LEVELS AND SYSTEM STRUCTURING

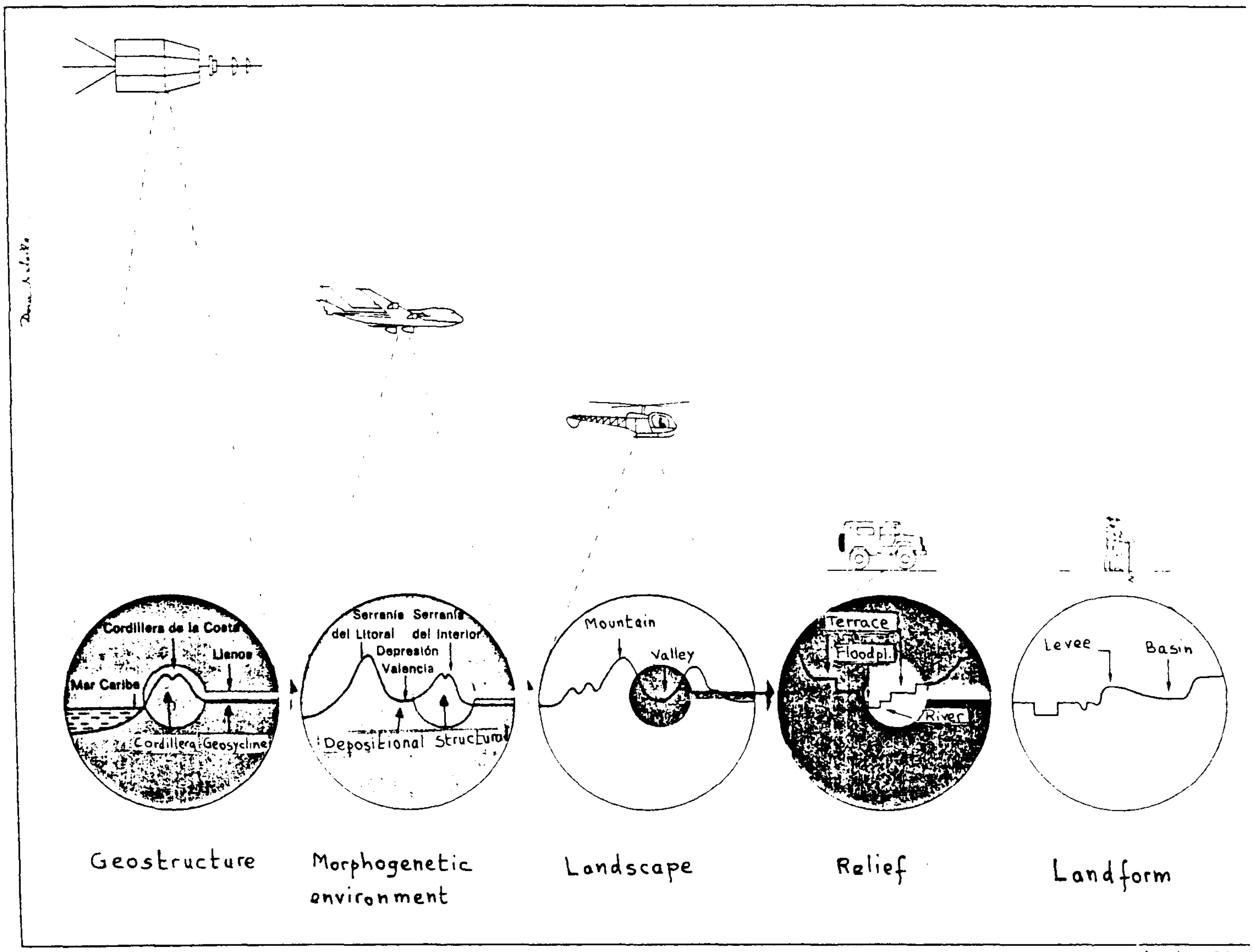
a) Introduction

Geomorphic units can be perceived (or remotely-sensed) by means of human sight faculty or artificial sensors, because they have a physionomic appearance on the landsurface. They are the formative elements of the landsurface.
Even a no-scientific observer is able to notice that any portion of the earth's crust has a given internal structure, allowing for further subdivision into composing elements.
How many times a landsurface can be subdivided depends on the level of perception used for it. Eventhough the concept of perception level is a subjective one when human eyes are used, it helps identify the hierarchical structure of a landsurface.

b) Development of an example

It refers to a contact zone between the Caribbean Sea and the northernmost area of the Southamerican continent. The use of successive perception levels of increasing accuracy, symbolized by observation platforms of decreasing height over the earth surface, allows for subdividing a portion of land into 5 hierarchical categories (Figs 20, 21 and Table 4).

Fig. 20 _ SEQUENTIAL LEVELS OF PERCEPTION OF GEOFORM TYPES AND THEIR COMPONENTS



A. Zinck, 1980

Fig. 21 - SEQUENTIAL IDENTIFICATION OF GEOFORMS

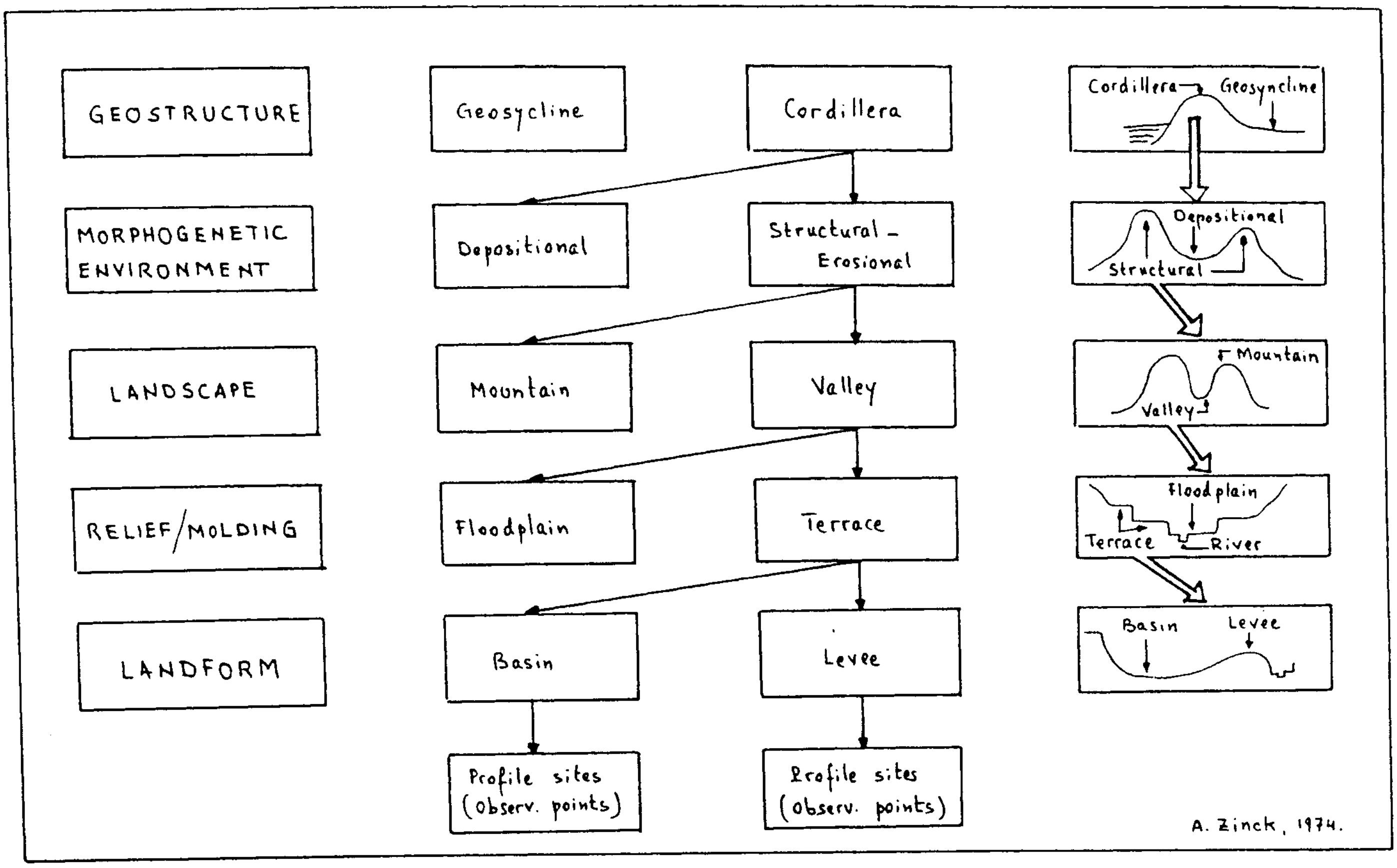


Table 4 - SEQUENTIAL IDENTIFICATION OF GEOFORMS (RELATED TO Fig. 21)

OBSERVATION PLATFORM	OBSERVATION AREA	OBSERVED FEATURES	CRITERIA USED INFERRED FACTORS	RESULTING GEOFORMS	DERIVED GENERIC CATEGORY CONCEPTS
Satellite	Large portion of a continent	Longitudinal, narrow, high relief mass; abrupt limits	Topography Int. geodynamics (orogenic area)	Cordillera (folded mountain chain)	Geostructure
		Large, flat, low-lying relief mass	Topography Int. geodynamics (subsiding area)	Geosyncline (sedimentary basin)	
Airplane	Cordillera	Longitudinal highlands formed of parallel mountainous chains; strongly dissected	Topography Ext. geodynamics (erosion)	Structural/ erosional environment	Morphogenetic environment
		Sequence of flat lowland areas between chains; concave rims	Topography Tectonics Ext. geodynamics (deposition of sed.)	Depositional environment	
Helicopter	Structural/ erosional environment	Parallel mountainous ridges	Topography Tectonics Hydrography	Mountain	Landscape
		Longitudinal, narrow depressions parallel or perpendicular to ridges	Topography Tectonics Hydrography	Valley	
Earth surface	Valley	Staircase configuration, parallel topographic levels separated by scarps	Topography	Terrace	Relief
		Valley bottom, river system, riparian forest	Topography Drainage Vegetation	Floodplain	
Above and beneath the earth surface (upper earth crust)	Terrace	Longitudinal, narrow, convex bench; well drained; coarse-textured	Topography Drainage Morphogenesis	Levee	Landform
		Large, ample, concave depression; poorly drained; fine-textured	Topography Drainage Morphogenesis	Basin	

3. SYSTEM CATEGORIES AND MAIN TAXA

The system comprises six categorical levels such as:
- geostructure
- morphogenetic environment
- landscape
- relief/molding
- lithology/facies
- landform

a) Geostructure

* Definition

Large continental portion characterized by a specific geological structure (age and nature of rocks, tectonic style). Relationship with plate tectonics.

* Taxa

- **Cordillera:** system of young mountain ranges including plains and valleys, which has been strongly folded (and faulted) by relatively recent orogenesis. Its component chains may have various trends, but the cordillera has one general direction.

- **Shield:** continental block that has been relatively stable over a long period of time and has undergone only gentle warping in contrast to the cordillera belts; mostly composed of Precambrian rocks.

- **Geosyncline (or sedimentary basin):** large, generally linear trough that subsided deeply throughout a long period of time, in which a thick succession of stratified sediments and possibly extensive volcanic rocks commonly accumulated. By orogenesis and folding, geosynclines are transformed into cordilleras.

b) Morphogenetic environment

* Definition

Broad type of biophysical medium, fundamentally originated and controlled by a given style of geodynamics, either internal or external or a combination of them.

Table 5 - SYNOPSIS OF THE GEOFORM CLASSIFICATION SYSTEM

LEVEL	CATEGORY	GENERIC CONCEPT	SHORT DEFINITION
6	Order	Geostructure	Large continental portion characterized by a broad geologic structure (e.g. cordillera, geosyncline, shield)
5	Suborder	Morphogenetic environment	Broad type of biophysical medium originated and controlled by a style of internal and/or external geodynamics (e.g. structural, depositional, erosional, etc.)
4	Group	Landscape	Large portion of land characterized by a repetition of similar relief types or an association of dissimilar relief types (e.g. valley, plateau, mountain, etc.)
3	Subgroup	Relief/molding	Relief as determined by a given combination of topography and geologic structure (e.g. cuesta, horst, etc.). Molding as determined by specific morphoclimatic conditions or morphogenetic processes (e.g. glacis, terrace, delta, etc.)
2	Family	Lithology/ facies	Petrographic nature of hard rocks (e.g. gneiss, limestone, etc.) or origin/nature of soft cover formations (e.g. periglacial, lacustrine, alluvial, etc.)
1	Subfamily	Landform	Conspicuous basic geoform type, characterized by an unique combination of geometry, dynamics and history.

* Taxa

- **Structural environment:** controlled by internal geodynamics through tilting, folding, overthrusting and faulting of bedrocks, or volcanism.
- **Depositional environment:** controlled by the deposition of detritic, soluble and/or biogenic materials carried by water, wind or ice.
- **Erosional (or denudational) environment:** controlled by processes of dissection and removal of materials transported by water, wind or ice.
- **Dissolutional environment:** controlled by processes of rock dissolution generating chemical erosion (karst, pseudo-karst).
- **Residual environment:** characterized by the presence of surviving relief features (inselberg).
- **Mixed environment:** e.g. structural environment dissected by erosion.

c) Landscape

* Definition

Complex concept covering many acceptations:

- **In common language:** a view of land scenery or its pictorial representation.
- **In scientific language:** differently used in landscape ecology, soil science, biogeography and geomorphology.
- **Adopted definition:** large portion of land characterized either by a repetition of similar relief types or an association of dissimilar relief types. For instance, an active alluvial plain may be constituted by a systematic repetition of the same relief type, namely floodplains. A valley shows normally an association of various relief types such as floodplains, terraces, fans and glacis.

- **Ambiguity of the concept of landscape:** e.g. valley may cover three different types of spaces (Fig.22):
  . Area of longitudinal transport and deposition of sediments, corresponding to the floodplain and terraces of the valley bottom.
  . Area similar to the former plus the lateral depositional sectors corresponding to piedmont fans and glacis.
  . Area controlled by human settlements, including the lower parts of the surrounding mountainous slopes.

* <u>Taxa</u> (Fig.23)
  - **Valley:** elongated, flat land portion intercalated between two bordering, higher relief zones (piedmont, plateau, hill or mountain). Generally drained by a river. Stream confluences are frequent.

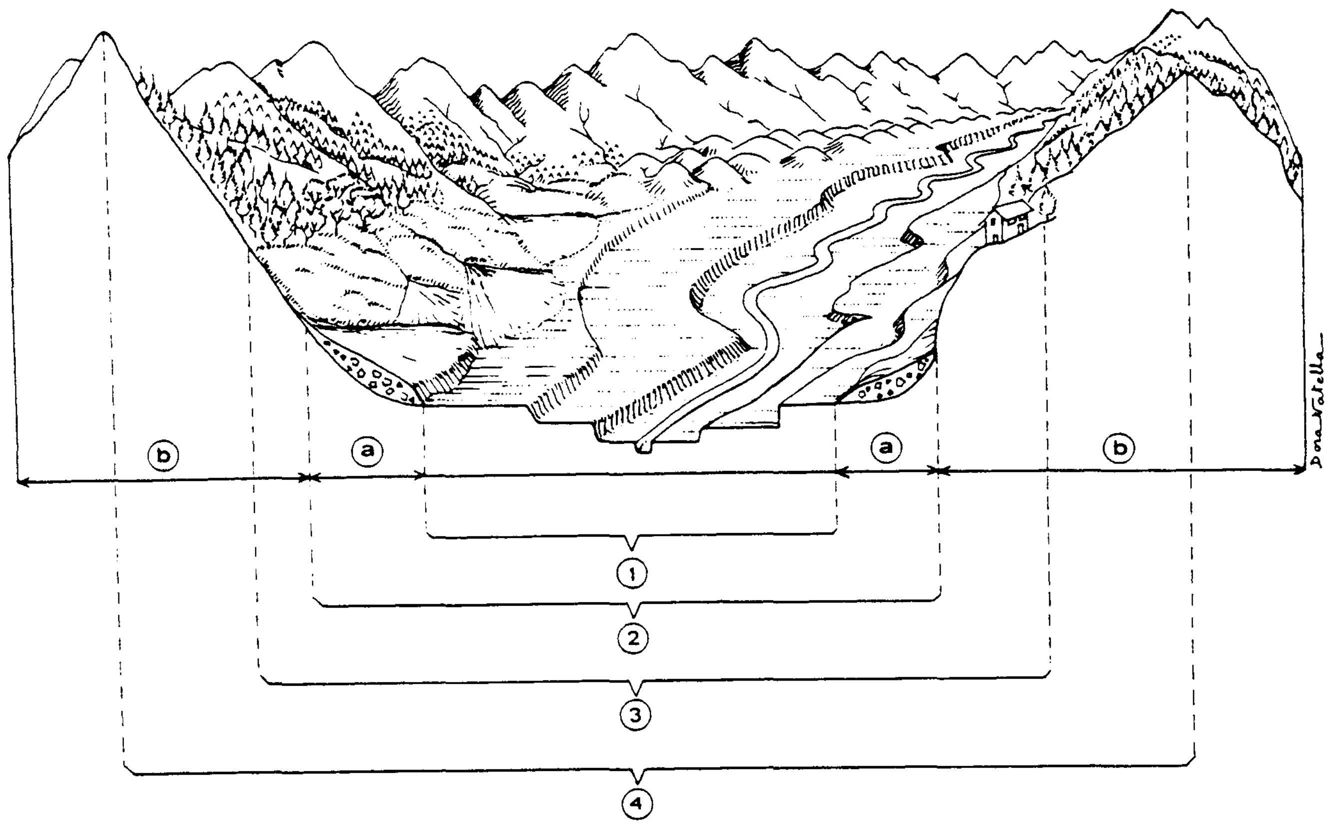
  - **Plain:** large, flat, unconfined, low-lying land portion with low relief energy (1-10 m of altitude differences) and gentle slopes (generally less than 3%). Several rivers contribute to form a complex fluvial system. Stream diffluences are frequent.

  - **Peneplain:** gently undulating land portion, characterized by a pervasive repetition of low hills, rounded or elongated, with summits of similar height, separated by a dense, reticular hydrographic network. They form either by dissection of a former plain or plateau, or by downwasting and flattening of an originally rugged landsurface.

  - **Plateau:** large, flat, unconfined, relatively elevated land portion which is commonly limited on at least one side by an abrupt descent (escarpment) to lower land. It forms frequently by tectonic uprising of a former plain, subsequently subdivided by the incision of deep gorges or valleys. The surface topography remains table-shaped or gently undulated because erosion is fundamentally lineal.

  - **Piedmont:** sloping land portion lying at the foot of more elevated landscape units (plateau, mountain). Its internal composition is generally heterogeneous, including:

Figure 22 - VARIOUS DEFINITIONS OF THE "VALLEY" CONCEPT AND CORRESPONDING SPATIAL EXPRESSIONS



(1) Valley as an area where sediments of longitudinal origin, carried from upper watershed (catchment area), are deposited in floodplain and terrace units occupying the valley bottom.

(2) Valley as an area covered by longitudinal as well as lateral sediments, including therefore piedmont fans and glacis.

(3) Valley as an area directly influenced by human activities, including therefore the lower stretches of the surrounding slopes.

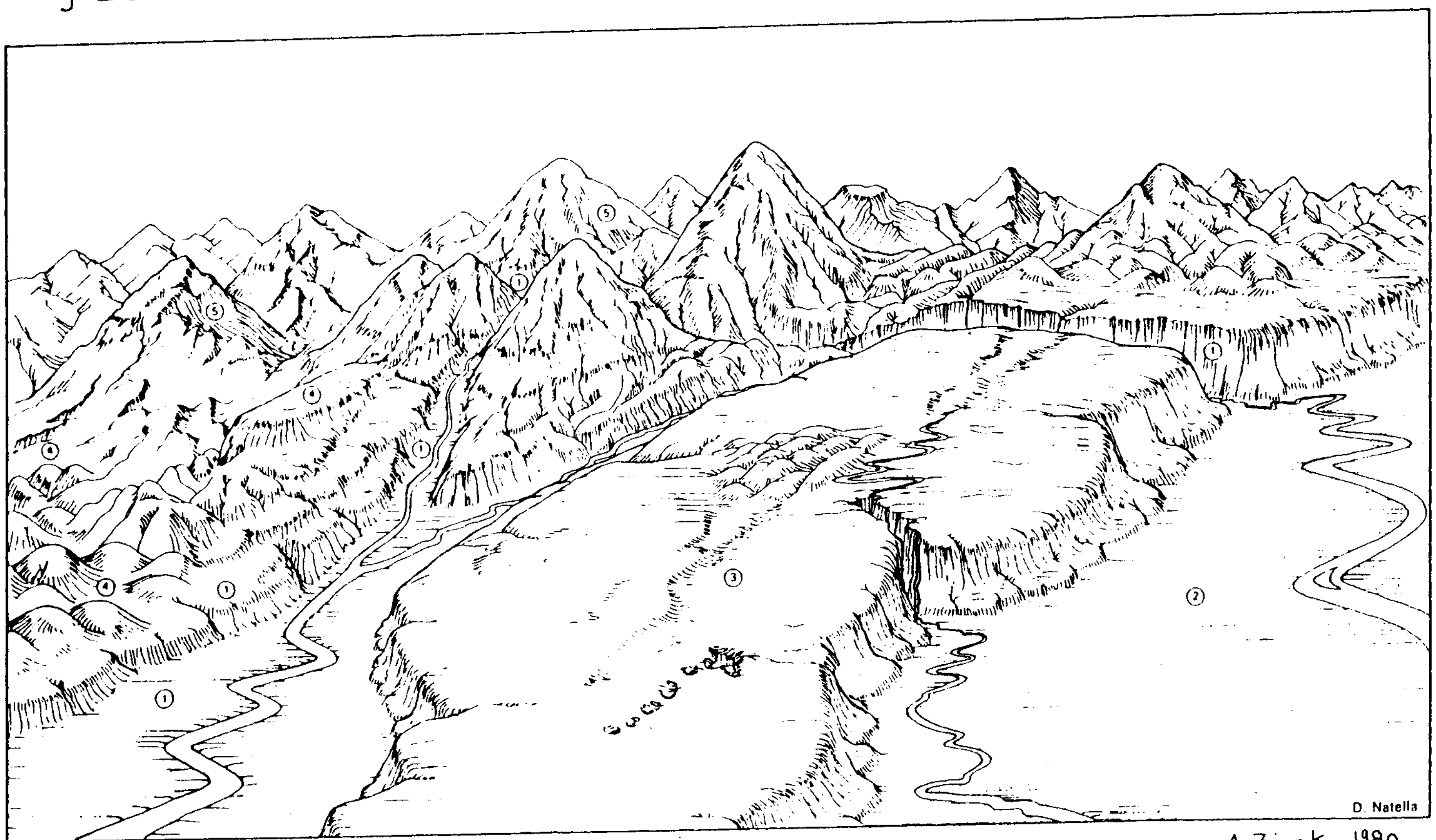
(4) Watershed or hydrographic basin as delineated by water divides.

(a) Piedmont

(b) Mountain

A. Zinck, 1980.

Fig. 23 – MAIN LANDSCAPE TYPES



① Valley ② Plain ③ Plateau ④ Piedmont ⑤ Mountain

A. Zinck, 1980.

. hills formed from pre-Quaternary substratum, frequently exposed after removal by erosion of the original alluvial cover mantle;
. fans and glacis, often in terrace position (fan-terrace, glacis-terrace), composed of Quaternary detritic material carried by torrents from the surrounding highlands.

- **Hilland:** rugged land portion characterized by the repetition of high hills, generally elongated, with uneven summit heights, separated by a moderately dense hydrographic network.

- **Mountain:** elevated, rugged, deeply dissected land portion, characterized by:
  . important relative height in relation to lower-lying, surrounding (external) landscape units;
  . important internal dissection, generating high relief energy between the mountainous areas and the intercalated (intra-mountainous) valleys.

d) Relief/molding ("modelé")

* Definition

Based on the commonly accepted definition of both terms in the French geomorphic literature:
- Relief: geoform determined by a given combination of topography and geological structure (e.g. cuesta relief)
- Molding: geoform determined by specific morphoclimatic conditions or morphogenetic processes (e.g. glacis, fan, terrace, delta).

* Taxa

See collection of taxa in Table 6 and consult geomorphology manuals for corresponding definitions.

Table 6 _ RELIEF/MOLDING TYPES

Structural	Erosional	Depositional	Dissolutional (karstic)	Residual
Depression Mesa Cuesta Creston Hogback Bar Flatiron Escarpment Graben Horst Anticline Syncline Excavated anticline Hanging syncline Combe Cluse Ridge Cone (volcano) Dike	Depression Vale Canyon Glacis Mesa Hill Crest Chevron (rafter) Ridge Dike	Depression Swale Floodplain Flat Terrace Mesa Fan Glacis Delta Estuary Coral reef Atoll	Depression Dome Tower Hill (hum) Poljè Blind vale Dry vale Canyon (=collapse vale)	Planation surface Dome Inselberg Monadnock Tors (=boulders field) ....

e) Lithology/facies

* Definition

Refers to the petrographic nature of the hard rocks and the facies of the soft cover formations.

* Justification

- Why is this categorical level needed?

  If the taxonomic system were restricted to geoforms occurring in depositional areas, the present level could be skipped since lithology would be conveniently covered by the facies of the geomorphic material (= soil parent material) at the lowest level of the system (landform level). In the case of sloping areas, however, where soils form directly or indirectly from consolidated geological material, the system should allow for introducing information on lithology.

- What is the most appropriate place for it in the hierarchy of the system?

In some geomorphic legends or systems in use, lithology is mentioned at the highest categorical levels. For instance, in the legend of the geomorphic map of France, lithology occupies the second highest term of the structure (the first being just location).
Analyzing the portion of land represented in Fig. 24 , a observer would, by reasoning on the field or through aerial photo-interpretation, recognize successively (hierarchically) the patterns identified in Table 7 .

Figure 24_ SEQUENTIAL PARTITION OF A LANDSCAPE

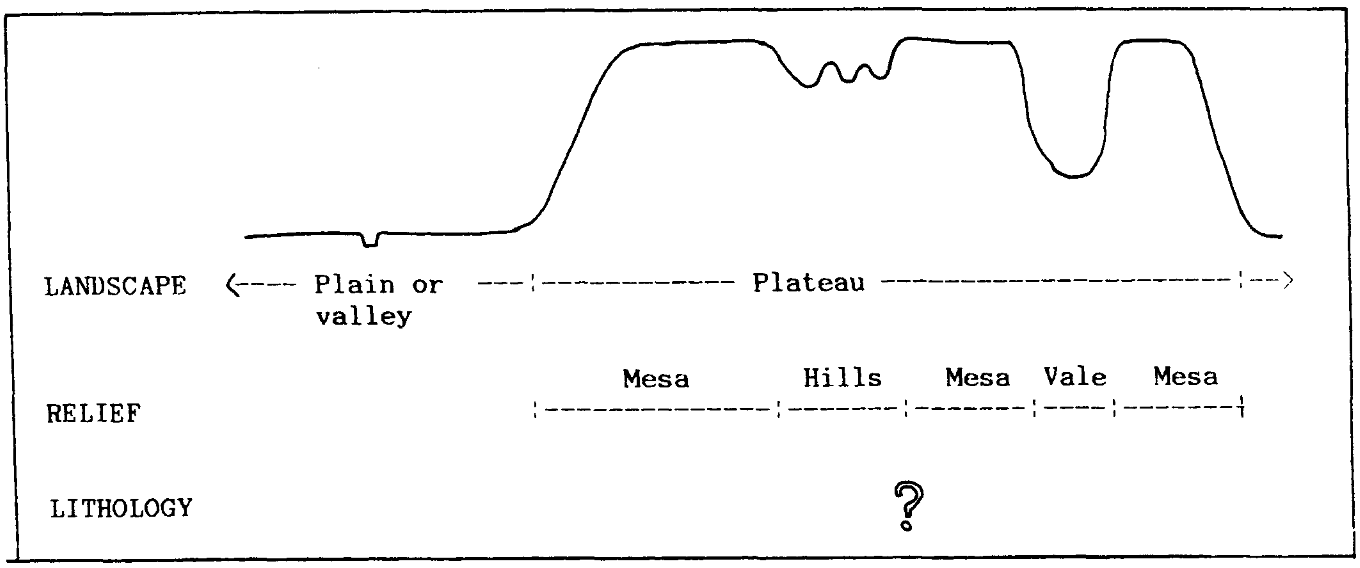


Table 7 _ SEQUENTIAL PARTITION OF A LANDSCAPE (RELATED TO Fig. 24)

CATEGORICAL LEVEL	IDENTIFICATION FEATURES	INFERRED GEOFORM OR MATERIAL	GENERIC CONCEPT	RESOLUTION	
				API	Field
Higher	- Relatively flat summit topography - Elevated position in relation to surroundings - Abrupt edges (scarps) - Deep river incision	Plateau	Landscape	+	-
Intermediate	Summit topography subdivided into: (1) level areas (2) undulated areas	(1) Mesas (2) Hills	Relief/molding	±	±
Lower	(1) If concordance between topography and rockbed dipping, then structural surface supported by horizontally-lying, stratified rocks (2) If no-concordance between topography and rockbed dipping, then erosion surface truncating no-horizontally-lying rocks	(1a) Resistent sedimentary rocks (e.g. sandstone, limestone), or (1b) Resistent igneous extrusive (volcanic) rocks (e.g. basalt lava flow) (2a) Tectonized stratified rocks (sedimentary or volcanic), or (2b) Igneous intrusive rocks	Lithology	-	+

As a consequence, lithology should be placed at a lower categorical level than the concepts of landscape and relief/molding respectively (hierarchical subdivision mechanism, level of perception and degree of resolution from API, need of field and laboratory data).

* Taxa
  - Rock classes: see Fig. 54 (p. 53, Chapter 1) or other convenient rock classification schemes.
  - Material facies:
    . nival (snow)
    . glacial (ice, glaciers)
    . periglacial (ice, cryoclastism, thermoclastism)
    . alluvial (concentrated waterflow; ≃ fluvial = river)
    . colluvial (diffuse waterflow)
    . diluvial (torrential waterflow)
    . lacustrine (lake deposits)
    . litoral or coastal (actions and deposits along the fringe between continents and oceans; ≃ tidal)
    . mass movement (plastic and liquid debris flows; sliding)
    . gravity (rock fall)
    . volcanic (surface flow or aerial shower of extrusive igneous materials)
    . biogenic (coral reef)
    . mixed (fluvio-glacial, colluvio-alluvial, fluvio-volcanic)
    . anthropic (kitchen middens, sambaquis, tumuli, etc.).

f) Landform

* Definition
  - Frequently used as a very general term covering any type of geomorphic unit from landscape level downwards, without distinction of hierarchy (or level of abstraction). Synonymous of geoform.
  - Adopted acceptation:
    . Landform is considered here as the generic concept for the lowest level of the proposed hierarchical system. It is the elementary geomorphic unit, which can be subdivided only by means of phases.
    . Is is characterized by a geometry, dynamics and history.

* <u>Taxa</u>

Defined in Part V.

Table 8 - LANDFORM DEFINITION

MORPHOGRAPHY MORPHOMETRY	MORPHOGENESIS	MORPHOCHRONOLOGY
=Topographic form	=Geomorphic position	= Geochronologic unit
Bench	Overflow mantle	Holocene
		Upper Pleistocene
		Lower Pleistocene
	Splay mantle	Holocene
		Upper Pleistocene
		Lower Pleistocene
LANDFORM = topographic form + geomorphic position + geochronologic unit = soil formation frame		

4. CONCLUSION

Since many of the concepts implemented for structuring and operating this geomorphic taxonomy, such as landscape, relief and landform, are used in the literature with different acceptations, an attempt is made here to define them clearly for the present purpose.

The taxonomic scheme analyzed here is based on a multi-categorical (hierarchical) system, presenting the following general characteristics:

- It is composed of 6 levels of abstraction; abstraction increases towards the higher levels and, conversely, concretization increases in the opposite direction.
- Similarly, generalization increases towards the higher levels as the number of attributes used for identifying and classifying geoforms decreases (see next chapter).

- The system is used downwards for classification and upwards for identification.
- The scheme is a category-closed system: there are only 6 categories in the present set-up. But it is a class-open-ended system allowing the incorporation of new classes at any desired category according to their level of abstraction.
- The hierarchical structure parallels the procedure used for information extraction and pattern recognition from aerial photographs and satellite images (preferentially downward stream).

Table 9 - SYSTEM OVERVIEW

LEVEL	CATEGORY	GENERIC CONCEPT
6	Order	Geostructure
5	Suborder	Morphogenetic environment
4	Group	Landscape
3	Subgroup	Relief/molding
2	Family	Lithology/facies
1	Subfamily	Landform

↑ Abstraction Generalization (less attributes)

↓ Concretization Detailing (more attributes)

↓ Classification

↑ Identification

The essay intends to make use of conventional concepts of broad acceptance in geomorphology and to ordely incorporate them in a hierarchical system:

- Geostructure: broad concepts of internal geodynamics related to plate tectonics.
- Morphogenetic environment: parallel to the concept of morphogenetic system but with less genetic implications.
- Landscape: concept of levels of perception, fundamental in geography.
- Relief/molding: traditional split between structural and climatic geomorphology.
- Lithology/facies: geological substratum and cover formation.
- Landform: implementation of the available geomorphic knowledge-base as to morphogenesis and morphochronology.

Categorical levels can be grouped on the basis of generic commonality such as follows:

- Order and suborder: geostructure and its control exerted on broad morphogenetic environments.
- Group and subgroup: main physionomic and topographic features as expressed by landscape and relief/molding types.
- Family and subfamily: origin and nature of materials (= soil parent materials) as expressed by landform types and families.

IV. ATTRIBUTES FOR DETERMINING GEOMORPHIC TAXA

Attributes are characteristics used for description, identification and classification of geoforms. They make the system operational.
Two main questions have to be solved:
- What are the attributes to be used for describing and classifying geoforms?
- What attributes should be used at a given categorical level?

A. CLASSES OF ATTRIBUTES

The proper naming of a geoform requires a stepwise approach including:
- description and measuring = characterization of properties and constituents;
- identification = comparison with an established reference type;
- classification = placing in the taxonomic system.

For that purpose, four classes of attributes may be used:

1. Morphographic attributes, describing the geometry of geoforms.
2. Morphometric attributes, measuring the geoforms.
3. Morphogenetic attributes, determing the origin and evolution of geoforms.
4. Morphochronologic attributes, circumscribing the time context.

1. MORPHOGRAPHIC ATTRIBUTES - GEOMETRY OF GEOFORMS

Morphographic attributes are essentially descriptive ones. They refer to topography and planimetry.

a) Topography (Fig.25)

Topography refers to the transverse section of a portion of land. It can be visualized two-dimensionally (cross-section) or three-dimensionally (block-diagram). It is of fundamental importance in sloping areas. Shape and profile of the topography are described according to the categorical level considered (from landscape to landform).

* Shape of the topography (applicable to landscape)

Table 10.

Shape class	Slope % class	Range of elevation (relief amplitude)
Flat or almost flat	0 - 2	Very low
Undulating	2 - 8	Low
Rolling	8 - 16	Low
Hilly	16 - 30	Moderate
Steeply dissected	> 30	Moderate
Mountainous	> 30	High

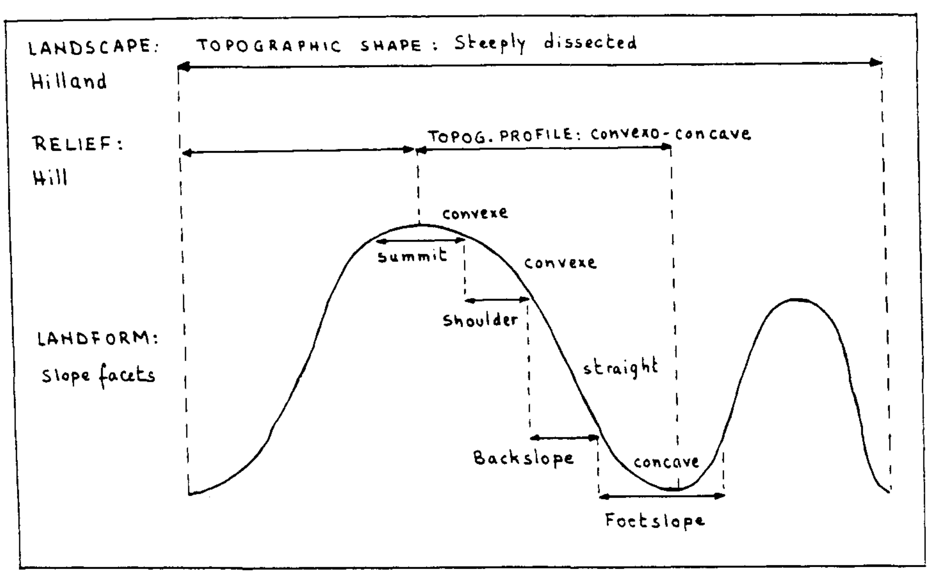
* Profile of the topography (applicable to relief and landform) (Fig.25)

Classes	Examples
Level	Mesa, terrace
Concave	Basin, footslope facet
Convexe	Levee, shoulder facet
Convexo-concave	Slope facet complex
Convexe-straight-concave	Slope facet complex
Rectilinear	Backslope
With intermediate flat step(s)	Slope facet complex
With rocky embossment(s)	Slope facet complex
With rocky scarp(s)	Slope facet complex, cuesta
Dissymmetrical	Hill, hogback
Irregular	--

* Exposure (or aspect)

Conventional classes: N, S, E, W and their subdivisions.

Fig.25- MORPHOGRAPHIC ATTRIBUTES



b) Planimetry

Planimetry refers to the vertical projection of geoform boundaries on a horizontal plane. It is a two-dimensional representation of given topographic features, which strongly control soil patterns (Friedland; Hole and Campbell). Configuration and contour design of geoforms, drainage pattern and surrounding conditions are main attributes described for this purpose.

* Configuration of geoforms (applicable to relief and landform)

Idea of massivity or narrowness of a geoform.

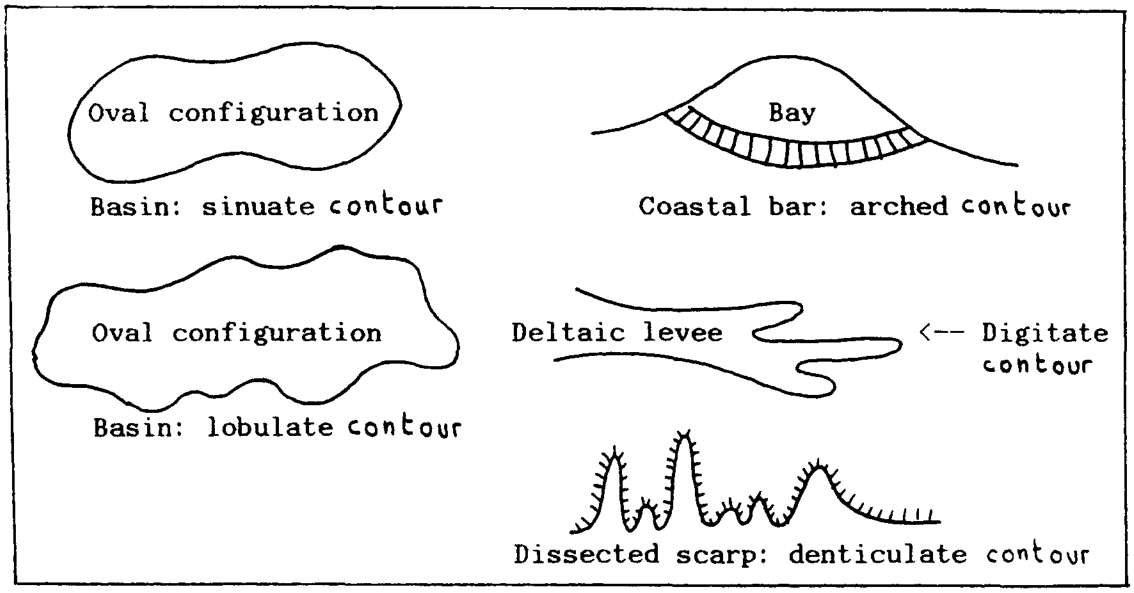
Classes	Examples
Narrow	Levee
Large	Overflow mantle
Elongated	Dike
Massive	Basin
Annular	Ring-dike
Oval/elliptic	Doline
Rounded	Hill
Triangular	Fan
Irregular	--

Combinations:
- levee: narrow and elongated
- basin: large and massive.

* Contour design of geoforms (applicable to relief and landform)

Classes	Examples
Rectilinear	Escarpment
Arched (lunate)	Coastal bar
Sinuate (sinuous)	Deltaic levee
Lobulate	Basin
Denticulate	Dissected scarp
Digitate	Deltaic levee (distal part)
Irregular	--

Fig. 26 - EXAMPLES OF CONTOUR DESIGN



* Drainage pattern

It refers to a frame of waterways which contribute to highlight the configuration and contour design of geoforms. It is mainly controlled by the geologic structure (tectonics, lithology, volcanism). Patterns are represented in Fig. 27 , taken from Manual of Photographic Interpretation (p. 348).

* Surrounding conditions (applicable to landscape, relief, landform)
  - Overtopped by ....
  - Overtopping ....
  - Bordering ....

* Bordering unit

The neighboring unit, taken at the same categorical level, is mentioned together with the surrounding conditions (e.g. plain overtopped by a plateau).

2. MORPHOMETRIC ATTRIBUTES - DIMENSIONS OF GEOFORMS

Morphometry refers to quantitative features of geoforms. Three types of attributes are able to be submitted to some kind of measurement: relative altitude, valley density and slope steepness. These are subordinate (no-diagnostic) attributes, which can be used at any categorical level with variable weight. They can be generated by digital procedures through digital elevation models DEM (Fig. 28).

Fig. 27 _ BASIC DRAINAGE PATTERNS

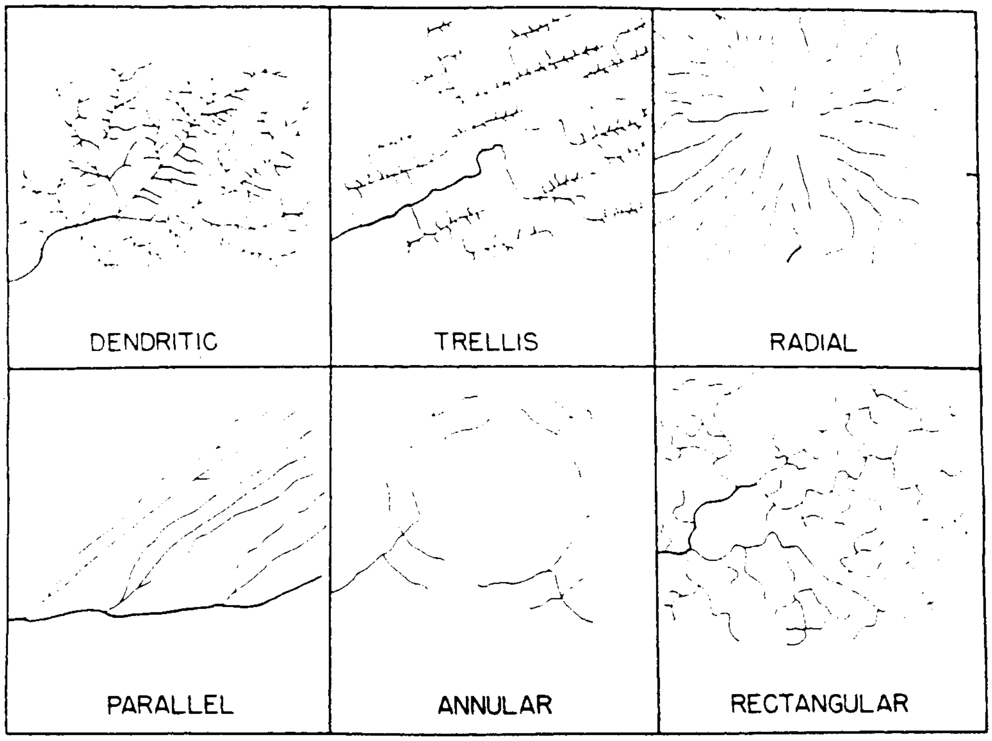


FIG. 1. Representations of the six basic drainage patterns shown in Figure 2.

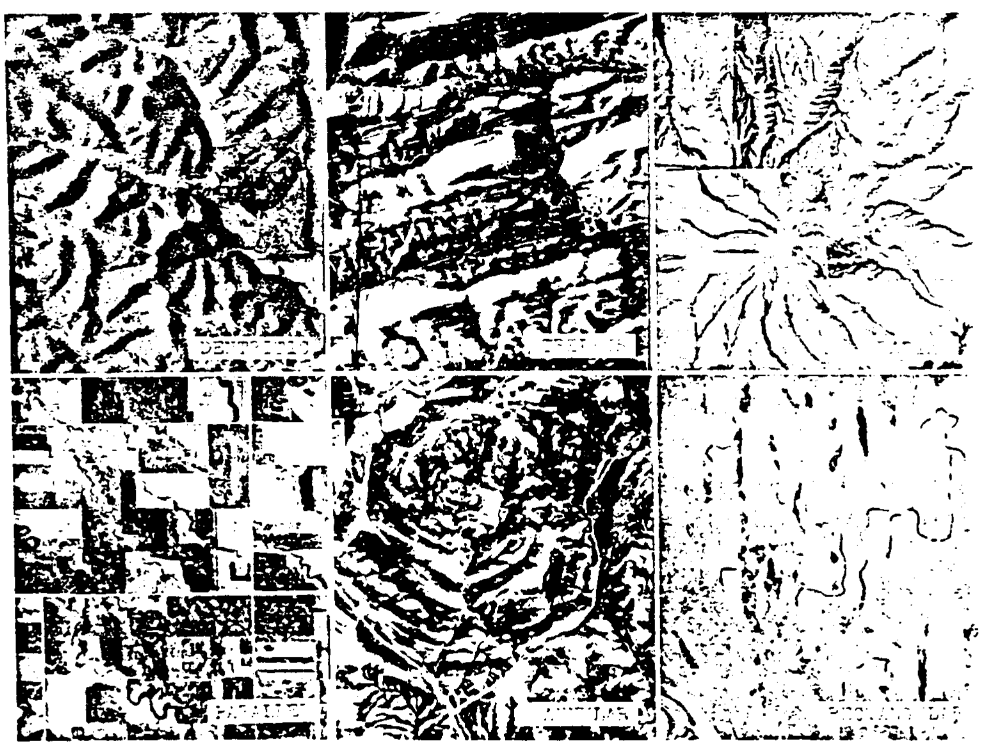
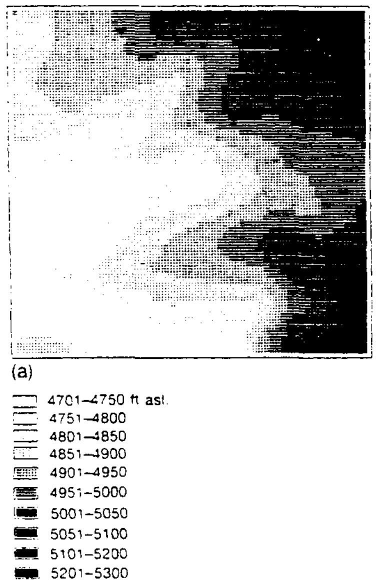
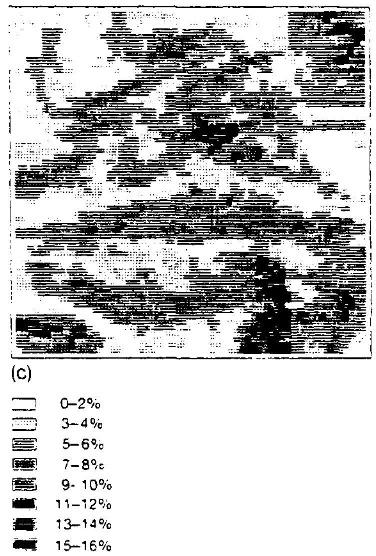


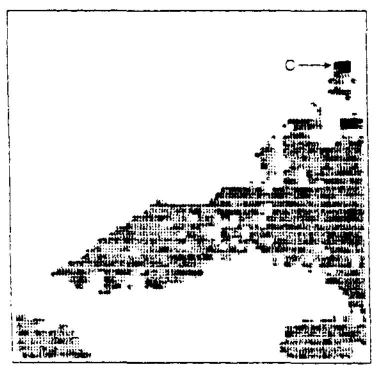
FIG. 2. Vertical aerial photos showing the six basic drainage patterns.

Am. Soc. Photogrammetry, 1960.

Fig. 28 - THE USE OF DIGITAL ELEVATION MODELS FOR DETERMINING MORPHOMETRIC ATTRIBUTES







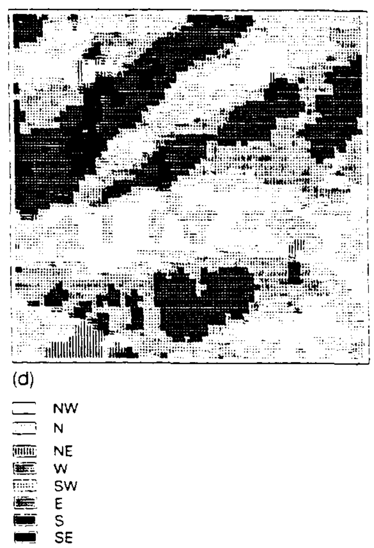


Fig. 3.10 Derivatives of an altitude matrix from the Kisii area (Fig. 3.8) displayed as simple cell maps. (a) Relief contours. (b) The viewshed (the area that can be seen) from the coffee factory located at point C. (c) Slope classes (NB slope classes are those used by the soil survey of the area). (d) Aspect classes.

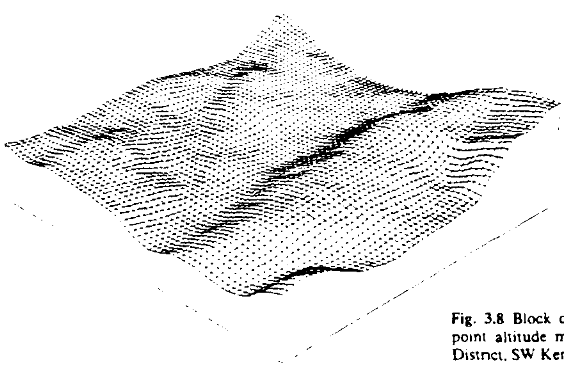


Fig. 3.8 Block diagram of DEM computed from a 60 × 60 point altitude matrix of a 3750 × 3750 m area of the Kisii District, SW Kenya.

P. Burrough, 1986.

a) Relative altitude (or relief amplitude, or internal relief) Fig.
- High
- Medium
- Low

The range of values for each class may be determined for a whole region or a project area. There are no universal rules.

b) Valley density (≃ drainage density)
Valley density measures the degree of dissection or incision of a landsurface. Density classes are established empirically for a whole region or a project area (Fig.29).

c) Slope steepness
Expressed in % or degrees.

3. MORPHOGENETIC ATTRIBUTES - DYNAMICS OF GEOFORMS

Some attributes reflect processes, especially depositional ones, and may therefore be used to reconstruct past morphogenetic evolution or environmental conditions. Only some of them are mentioned here as examples.

a) Particle size distribution

It is the most important property of a geomorphic material as well as a soil material. Two main reasons for it:
- It allows to infer other material properties which strongly depend on the particle size distribution (often in combination with the structure of the material) such as bulk density, permeability, hydraulic conductivity, infiltration rate, consistence, erodibility, CEC, etc.
- It reflects geo- and pedodynamic features such as:
  . Transport agents (water, wind, ice)
  . Depositional processes and environments
  . Weathering processes (physical and chemical)
  . Soil forming processes.

Please refer to Chapter 1, pp. 12-18 (diagnostic importance of granulometric curves).

Fig. 29 _ MORPHOMETRIC ATTRIBUTES

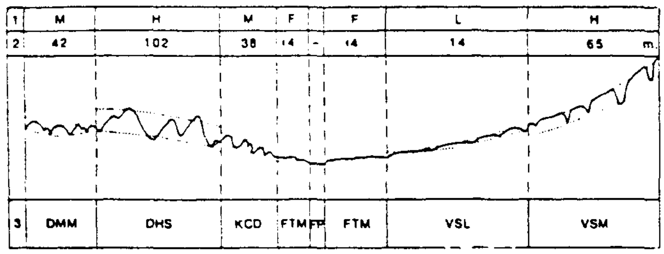


FIGURE 6 Sketch illustrating the relief amplitude or local relief per geomorphologically-based TMU
1 = class symbol for internal relief (F: very low; L: low; M: medium; H: high). 2 = internal relief, average amplitude, determined per mapping unit. 3 = geomorphologically based TMUs (hypothetical); DMM: denudational, highly dissected unit on marls; DHS: denudational hills, steep straight slopes on granites; KCD: karst, complex of conical hills and dolines; FTM: medium and low fluvial terraces; FP: floodplain and river; VSL: volcanic, lower slopes of strato-volcano; VSM: volcanic, upper deeply dissected part of strato-volcano.

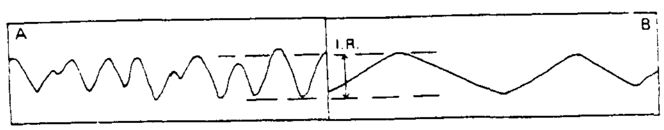


FIGURE 9 Two units having similar internal relief but different valley densities and slope steepness

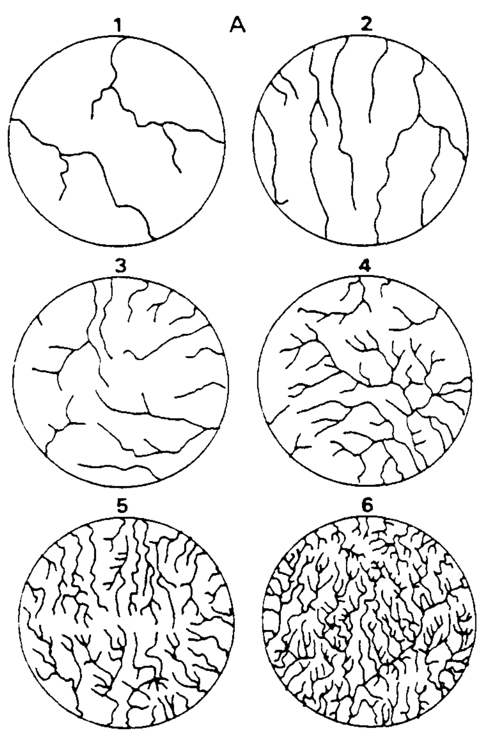


FIGURE 10 Classes of valley (drainage) density
Valley density or density of drainage lines in large and small valleys (VD) is defined as $VD = \Sigma L/A$, where ΣL = accumulated length of drainage lines (in km), and A = area (in km²). Note that scale affects numerical values of VD.

A.M.J. Meijerink, 1988.

b) Structure

* Geogenetic structure

It refers to the structure of the geologic or geomorphic material, and allows to identify:

- degree of rock weathering
- nature of depositional processes.

* Pedogenetic structure

It refers to soil structure, and allows to identify:

- soil forming environments (= geomorphic positions)
- soil development degrees as reflecting time factor.

Please refer to Chapter 1, pp. 21-24.

c) Consistence (Atterberg limits)

It refers to the mechanical behaviour (actual or potential) of soft soil or geomorphic materials. It allows to determine:

- material workability
- shrink-swell potential
- material stability in sloping areas (mass wasting hazard)
- nature of mass movement processes.

Please refer to Chapter 1, pp. 19-20.
Example developed: Rancho Grande (Venezuela).

d) Mineralogy

It refers to the mineralogical composition of sand, silt and clay fractions of soft materials (cover formations). It allows to determine the geochemical dynamics of the environment as related to or controlled by morphogenetic processes, and to follow transport pathways of diagnostic minerals.

* Origin of depositional materials
  - Mineral associations of cover formations as reflecting prevailing lithologies in sediment production watersheds.
  - Distinction between fresh and reworked materials (mixing of materials during the sediment transport phase).

    Example: Santo Domingo, Venezuela (Table 11).

Table 11 - MINERALOGIC AND MORPHOSCOPIC ANALYSIS OF SILT AND SAND FRACTIONS (%)
Eastern piedmont of the Andes Mountains, Venezuela (Barinas)

Samples	Clean quartz + feldspars	Ferruginized quartz	Soil aggregates	Rock fragments	Micas	Total	Angular grains
A	40	5	55	0	0	100	93
B	21	14	22	42	1	100	100
C	22	0	0	0	78	100	100

COMMENTS:

A - Colluvial deposit (reworked material). Rubified colluvium, originated from truncating of a strongly developed red soil lying on an older , higher terrace (Q3). The reworking effect can be inferred from high contents of clean quartz grains, washed during the colluvial translocation by diffuse overland flow, and soil aggregates respectively. The absence of rock fragments and micas indicates that colluviation removed material completely pedogenized. The morphoscopic analysis reveals the presence of a small amount of rounded grains (7%), which may be related to Tertiary marine sediments outcropping along the pre-Andean zone (Pagüey and Paràngula Formations).

B - Mixed deposit, colluvial (reworked material) and alluvial (fresh material). Mixture of red colluvium (presence of aggregates), reworked from an older soil mantle lying on a middle terrace (Q2), and recent alluvium (presence of rock fragments) carried in by the Santo Domingo river.

C - Alluvial deposit. Holocene alluvial sediments, exclusively composed of clean quartz and fresh micas. The high proportion of micas results from biotic trapping of silt particles by dense grass cover.

Source: A. Zinck and P. Stagno - Soil survey report, Santo Domingo-Pagüey area, Barinas, Venezuela, 1966.

A. Zinck, 1970.

* Morphoclimatic conditions (examples)
  - dry hot environment: halites
  - wet hot environment: kandites.

* Topographic influence on spatial redistribution of clay minerals
  Catena model (see Fig. 28, p. 33, Chapter 1).

e) Morphoscopy (Exoscopy)

Morphoscopy deals with the examination of coarse grains (sand and coarse silt) in order to determine their degree of roundness and their surface aspect.

- Degrees of roundness: from very irregular to well rounded.
  . Well rounded grains reflect a continuous action by (sea)water or wind.
  . Irregular grains indicate either torrential transport or short transport distance.
- Surface shinniness and markings such as striations, frosting, polishing, chattermarks, gouges, indicate special transport modes or environmental conditions.
  . Shinny grains : sea water action
  . Frosting surface: eolian action
  . Speckled grains : effect of eolian chattering or chemical corrosion.

4. MORPHOCHRONOLOGIC ATTRIBUTES - HISTORY OF GEOFORMS

a) Properties concerned

* Degree of activity of geoforms
  - active (e.g. moving sand dune)
  - inherited in survival state (e.g. slope facet complex, locally affected by solifluction)
  - stabilized (e.g. coastal bar colonized by vegetation).

* Age of the geoforms
  Mainly determined in relative terms as developed hereafter.

b) Techniques of (absolute) dating

* Classes

- Radiometric techniques: based on the differential desintegration of pairs of radio-active isotopes such C14/C12, O18/O16, K/A, etc.
- Other techniques:
  . dendrochronolgy (counting of tree rings)
  . tephrochronology (counting of ash layers)
  . varve counting (pro-glacial lacustrine layers)
  . pollenanalysis (together with radiometric data)
  . analysis of historical and prehistorical events (earthquakes, etc.).

* Limitations

- Expensive (500-1000 US$ for one C14 determination)
- Applicable to a given type of materials:
  . K/A : volcanic material
  . C14 : C-rich materials (organic material, shells)
- Applicable to given spans of time:
  . C14 : periods shorter than 50.000-70.000 years B.P.
  (C14 half-time = 5.600 years)
  . K/A not applicable to recent periods (> 10^6 years)
- Possible interpretation errors due to:
  . contamination of samples
  . residence time of organic matter (in the case of C14).

c) Systems of relative geochronology

* Basic considerations

- The Quaternary period is fundamentally important. Main geoforms and soils have formed or have been strongly modified during this period. Pre-Quaternary relics exist but are of minor extension.
- The Quaternary has been a period of strong morphogenetic activity due to recurrent, worldwide climatic changes and volcano-tectonic paroxysms, contributing to the removal, burying or modification of Pre-Quaternary geoforms and soils.
- Quaternary stratigraphy is conventionally based on the recurrence of climatic periods assumed to have been alternatively of low and high morphogenetic activity. One commonly used criterion for structuring

Quaternary geochronological systems is based on the bio-rhexistasis theory of H. Erhart, distinguishing between (Fig.):

. Rhexistatic periods: environmentally unstable, colder and drier, favouring intense morphogenesis.

. Biostatic periods: more stable, warmer and wetter, favouring soil development.

* Some reference systems for Quaternary geochronology (Tables 12-13).

- Classical schemes (Penck and Brückner)
- Derived systems (t, K and Q systems)
- New trends (multiple glaciations approach).

d) Pedostratigraphy (soil stratigraphy)

* Definition

It consists of using soil properties to estimate the relative age (= stratigraphic position in an established geochronological scheme) of cover formations and geoforms from which soils have developed (see definition in Northamerican Stratigraphic Code).

* Criteria (e.g. Guarapiche river valley, Venezuela) Figs.30-39 and tables 14-20.

- Weathering degree of the parent materials (rocks and cover formations).
  . Color
  . Degree of desintegration of pebbles and stones
- Degree of soil morphological development
  . Color
  . Pedogenetic structure (development grades)
  . Solum thickness
- Leaching indices
  . Calcium carbonate
  . Clay particles
- Status of the adsorption complex
  . Soil reaction (pH)
  . Cation exchange capacity
  . Base saturation
- Clay mineralogy: time-controlled substitution of clay mineral associations.

Table 12 - QUATERNARY GEOCHRONOLOGICAL SYSTEMS

	(A)	(B)	(C)	(D)
HOLOCENE	Recent	Recent	$t_o a$	K_{0u}
	Lower Holocene	Lower Holocene	$t_o b$	K_{1s}
PLEISTOCENE	Würm	Wisconsin	t_I	K_{1u}
	Interglacial		$t_I - t_{II}$	K_{2s}
	Riss	Illinois	t_{II}	K_{2u}
	Interglacial		$t_{II} - t_{III}$	K_{3s}
	Mindel	Kansas	t_{III}	K_{3u}
	Interglacial		$t_{III} - t_{IV}$	K_{4s}
	Günz	Nebraska	t_{IV}	K_{4u}
				K_5

(A) European system (Chronology of Penck and Brückner). The first period of the lower Pleistocene is frequently referred to as Villafranchien, which is a more ample chrono-stratigraphic unit as Günz.

(B) American system.

(C) System used by the Center for Applied Geography of the Strasbourg University (France). The periods t_I, t_{II}, t_{III}, t_{IV} are periods of intense morphogenesis with predominance of mechanical processes. The intervals referred to as t_0, $t_I - t_{II}$, $t_{II} - t_{III}$, $t_{III} - t_{IV}$, are morphogenetically less active, favoring biologic and chemical evolution processes. The period $t_o a$ covers the historical morphogenetic phenomena in general and anthropogenic erosion in particular.

(D) Butler's system as presented in B.E. Butler - Periodic phenomena in landscapes as a basis for soil studies. CSIRO, Australia, 1959. The subscripts "s" and "u" correspond respectively to the stable and unstable phases of each K cycle. The designator K_5 applies to pre-Quaternary groundsurface remnants.

A. Zinck, 1970.

Table 13 _ PROPOSED NOMENCLATURE FOR QUATERNARY CHRONOSTRATIGRAPHY

		Rhexistatic periods	Biostatic periods
HOLOCENE		. . . .	Q0
	Upper	Q1	
		. . . .	Q1-2
	Late Middle	Q2	
PLEISTOCENE		. . . .	Q2-3
	Early Middle	Q3	
		. . . .	Q3-4
	Lower	Q4	

REMARKS:

1) The designators refer to the presumed relative age of parent materials, but not directly to the age of the derived soils. On denudational, structural and residual topographies, there is frequently a wide difference between the age of the geologic substratum and the age of the overlying soil mantle. In many cases, the underlying rocks may even not be the actual parent material of the soils when cover formations (e.g. slope formations) are intercalated in-between. On the contrary, in depositional environments, the initiation of soil development may coincide approximately with the end of the accumulation period. However, in large sedimentation areas, deposition stops neither abruptly nor in all sectors at the same time. In broad alluvial plains, for instance, the deposition of Q1 extends locally into Q0 without noticeable interruption.

2) Increasing subscripts refer to increasing relative age of the parent materials. Where necessary, the relative scale can be extended (e.g. Q5 and so on) to designate deposits overlapping with the end of the Pliocene.

3) Each period can be subdivided using additional alphabetic subscripts such as a, b, c, etc., according to increasing relative age (Q1a more recent than Q1b).

4) Some geoforms such as colluvial glacis have developed over several (successive) periods. A composite symbol can be used to reflect such a time-crossing genesis, indicating the presumed initiation and ending of the deposition (e.g. Q1-Q2; Q1-Q1-2).

A. Zinck, 1970.

FIG. 30 - LOCATION OF THE GUARAPICHE VALLEY - VENEZUELA

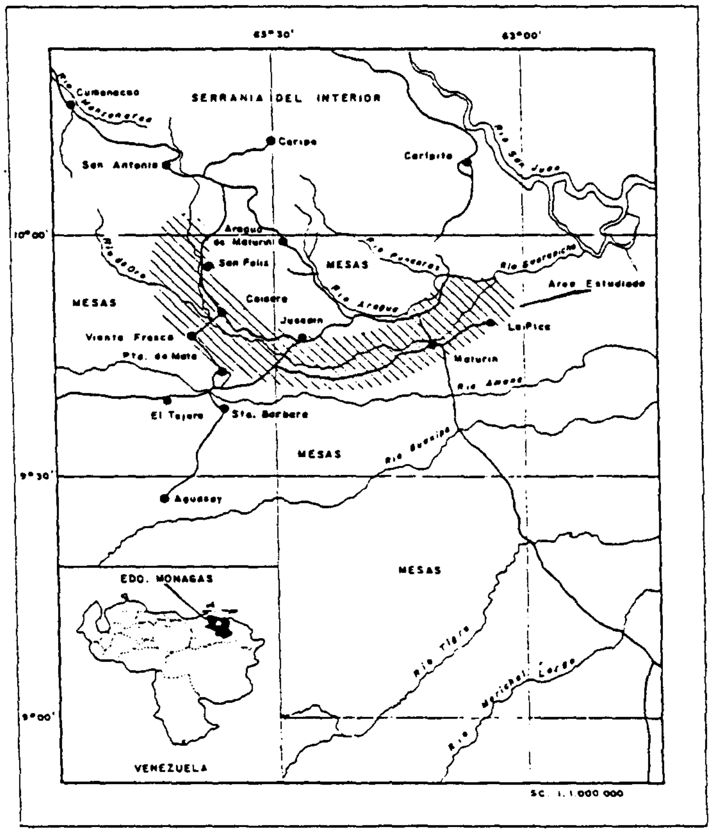
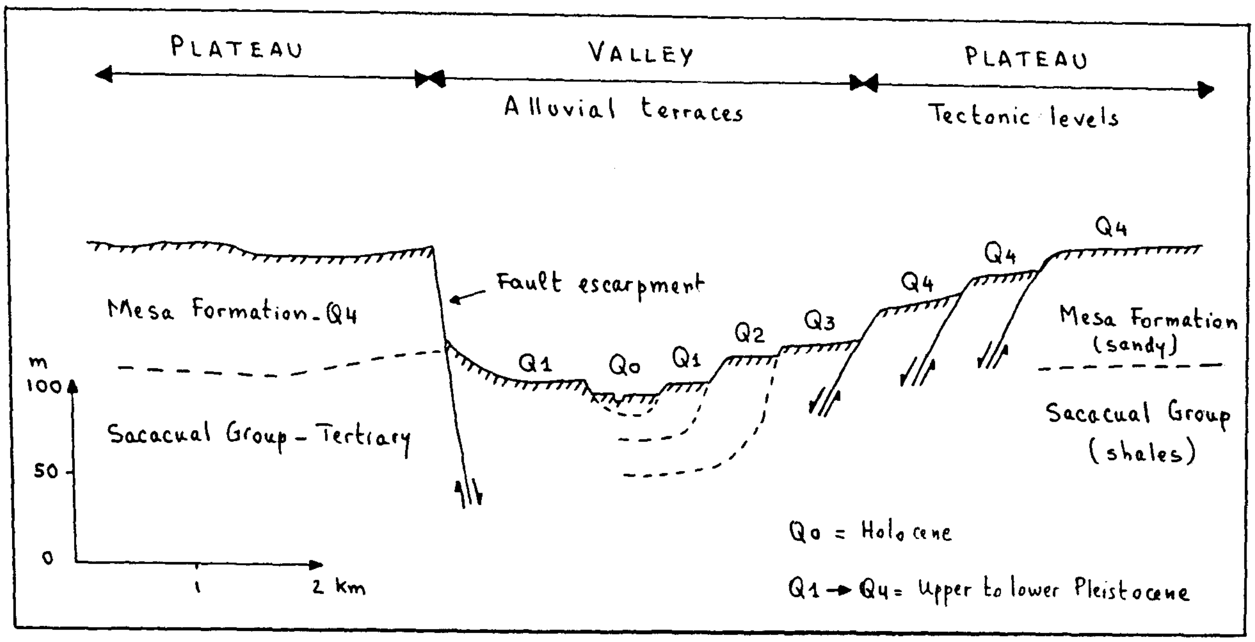


Fig. 31 - CROSS-SECTION OF GUARAPICHE RIVER VALLEY - VENEZUELA



A. Zinck and P.L. Urriola, 1970.

Table 14 - SOIL DEVELOPMENT ATTRIBUTES
Soils formed from levee and splay deposits (Guarapiche river, Venezuela)

	Relative age parent material	Q0	Q1	Q2	Q3	Q4	
	Soil series	Guatatal	San Fèlix	El Tomate	El Zamuro	Maturin	Sabaneta
CHARACTERISTICS OF MORPHOLOGICAL DEVELOPMENT	Dominant color subsurf. horizons	V.dark gray.brown	Dark brown	Yellowish red	Red.yellow Red, gray mottles	Red.yellow over red	Red.yellow Red, gray mottles
	Pedogenetic structure	Blocky sub. weak, med.	Blocky sub. mod. med.	Blocky ang. mod. med.	Blocky ang. mod. med.	Blocky ang. weak, med.	Blocky ang. mod. med.
	HCl effervescence	Strong	Absent over strong	Absent	Absent	Absent	Absent
	Solum thickness cm	30	80	200	250	300	300
	Texture of parent material	sl-ls	sl	sl	sl	sl	sl-scl
LEACHING INDICES	% Eq. CaCO3	3.1-4.5	0.9-3.0	No results	0.1-1.3	0	0.18-0.87
	Decarbonatation index	-	3.3	-	-	-	-
	Clay trans-location index	-	-	1.59	2.68	2.50	2.38
ADSORPTION COMPLEX	pH 1:1 water	7.7-8.0	6.2-7.8	5.1-6.8	4.0-4.4	4.7-5.2	4.1-4.7
	% Base saturation	100	88-100	17-39	25-46	3-14	13-22
	Exchangeable acidity me/100 gr soil	0	0-2.6	1.7-6.1	5.0-12.2	3.5-6.7	4.6-13.1
	CEC-Sum cations me/100 gr clay	92-106	91-94	32-52	43-44	20.7-27.5	23.7-24.9
	CEC in Bt horiz. me/100 gr clay	-	-	36-52	43-44	20.7-24.6	23.7-24.9
TAXONOMIC FEATURES	Diagnostic horizon	Ochric	Mollic Cambic	Argillic	Argillic Plinthite	Argillic —>oxic	Argillic —>oxic Plinthite
	Soil order	Entisol	Mollisol	Alfisol	Ultisol	Ultisol s/gr.Oxic	Ultisol s/gr.Oxic

A. Zinck - P.L. Urriola, 1970.

Table 15 - SOIL DEVELOPMENT ATTRIBUTES
Soils formed from overflow mantle deposits (Guarapiche river, Venezuela)

	Relative age parent material	Q0	Q2	Q3
	Soil series	Guarapiche	El Viboral	Plantaciones
CHARACTERISTICS OF MORPHOLOGICAL DEVELOPMENT	Dominant color subsurf. horizons	Grayish brown to brown	Light gray Yellowish red mottles	Grayish brown Red, gray mottles
	Pedogenetic structure	Blocky sub. mod. med.	Blocky ang. to prismatic	Blocky ang. to prismatic
	HCl effervescence	Strong	Absent	Absent
	Solum thickness cm	50	190	225
	Texture of parent material	sicl	sicl	cl-sicl
LEACHING INDICES	% Eq. $CaCO_3$	2.2-6.7	0.2-1.8	0.1-1.2
	Decarbonatation index	-	9.0	-
	Clay translocation index	-	1.21	2.08
ADSORPTION COMPLEX	pH 1:1 water	7.4-8.0	4.7-5.2	4.5-4.7
	% Base saturation	100	41-64	5-42
	Exchangeable acidity me/100 gr soil	0	2.0-7.0	10.9-20.0
	CEC-Sum cations me/100 gr clay	79-117	45-54	49-54
	CEC in Bt horizon me/100 gr clay	-	48-49	53-54
TAXONOMIC FEATURES	Diagnostic horizon	Cambic	Argillic	Argillic Plinthite
	Soil order	Inceptisol	Alfisol	Ultisol

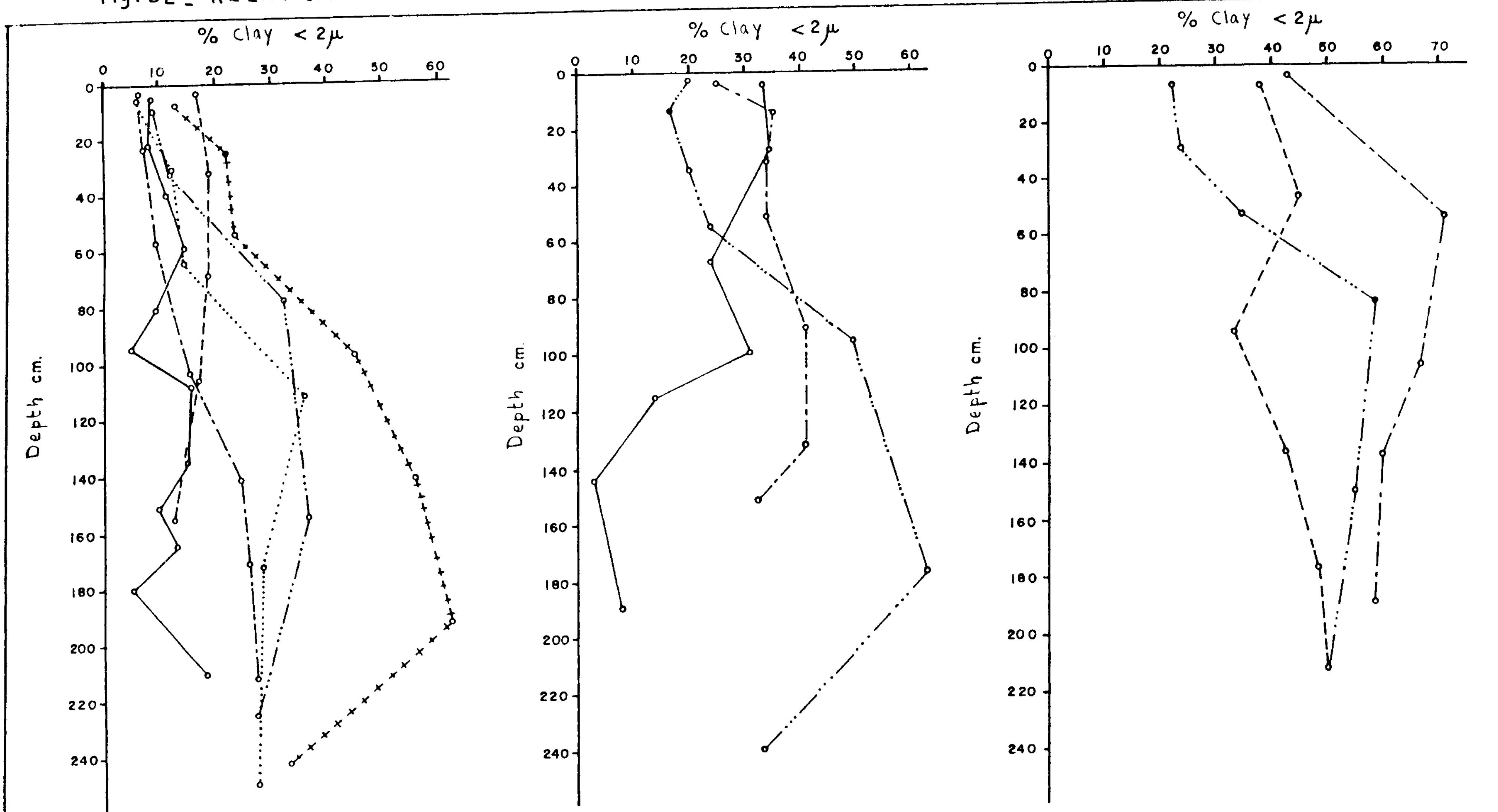
A. Zinck - P.L. Urriola, 1970.

Table 16 - SOIL DEVELOPMENT ATTRIBUTES
Soils formed from overflow basin deposits (Guarapiche river, Venezuela)

	Relative age parent material	Q1	Q2	Q3
	Soil series	Canaguaima	El Bejucal	Cañitos
CHARACTERISTICS OF MORPHOLOGICAL DEVELOPMENT	Dominant color subsurf. horizons	Grayish brown to dark brown	Brownish yellow to reddish yellow	White Red, grey mottles
	Pedogenetic structure	Blocky sub. strong, med.	Prismatic	Blocky ang. to prismatic
	HCl effervescence	Absent over strong	Absent over strong	Absent
	Solum thickness (cm)	110	230	245
	Texture of parent material	sic	sic	sic
LEACHING INDICES	% Eq. CaCO3	1.0 - 4.7	0.3 - 4.2	0
	Decarbonatation index	4.7	8.4	-
	Clay translocation index	-	-	2.47
ADSORPTION COMPLEX	pH 1:1 water	7.0 - 8.3	5.2 - 7.7	4.4 - 4.9
	% Base saturation	77-100	72-100	13-41
	Exchangeable acidity me/100 gr soil	0.5 - 3.5	3.0 - 8.0	3.0 - 18.5
	CEC-Sum cations me/100 gr clay	59-69	41-51	27-37
	CEC in Bt horizon me/100 gr clay	-	-	37
TAXONOMIC FEATURES	Diagnostic horizon	Mollic Cambic	Cambic	Argillic Plinthite
	Soil order	Mollisol	Vertisol	Ultisol

A. Zinck - P.L. Urriola, 1970.

Fig. 32 _ RELATIONSHIP BETWEEN CLAY DISTRIBUTION AND RELATIVE AGE



Soils developed from splay and levee deposits

————	Series Guatatal	Q_0
— — —	Series San Felix	Q_1
—·—·—	Series El Tomate	Q_2
—··—··	Series El Zamuro	Q_3
· · · · ·	Series Maturin	Q_4
+ + + +	Series Sabaneta	Q

Soils developed from overflow mantle deposits

————	Series Guarapiche	Q_0
—·—·—	Series El Viboral	Q_2
—···—	Series Plantaciones	Q_3

Soils developed from overflow basin deposits

— — —	Series Canaguaima	Q_1
—·—·—	Series El Bejucal	Q_2
—···—	Series Cañitos	Q_3

Q refers to the relative age of the parent material.

Fig. 33 – RELATIONSHIP BETWEEN CALCIUM CARBONATE AND RELATIVE AGE

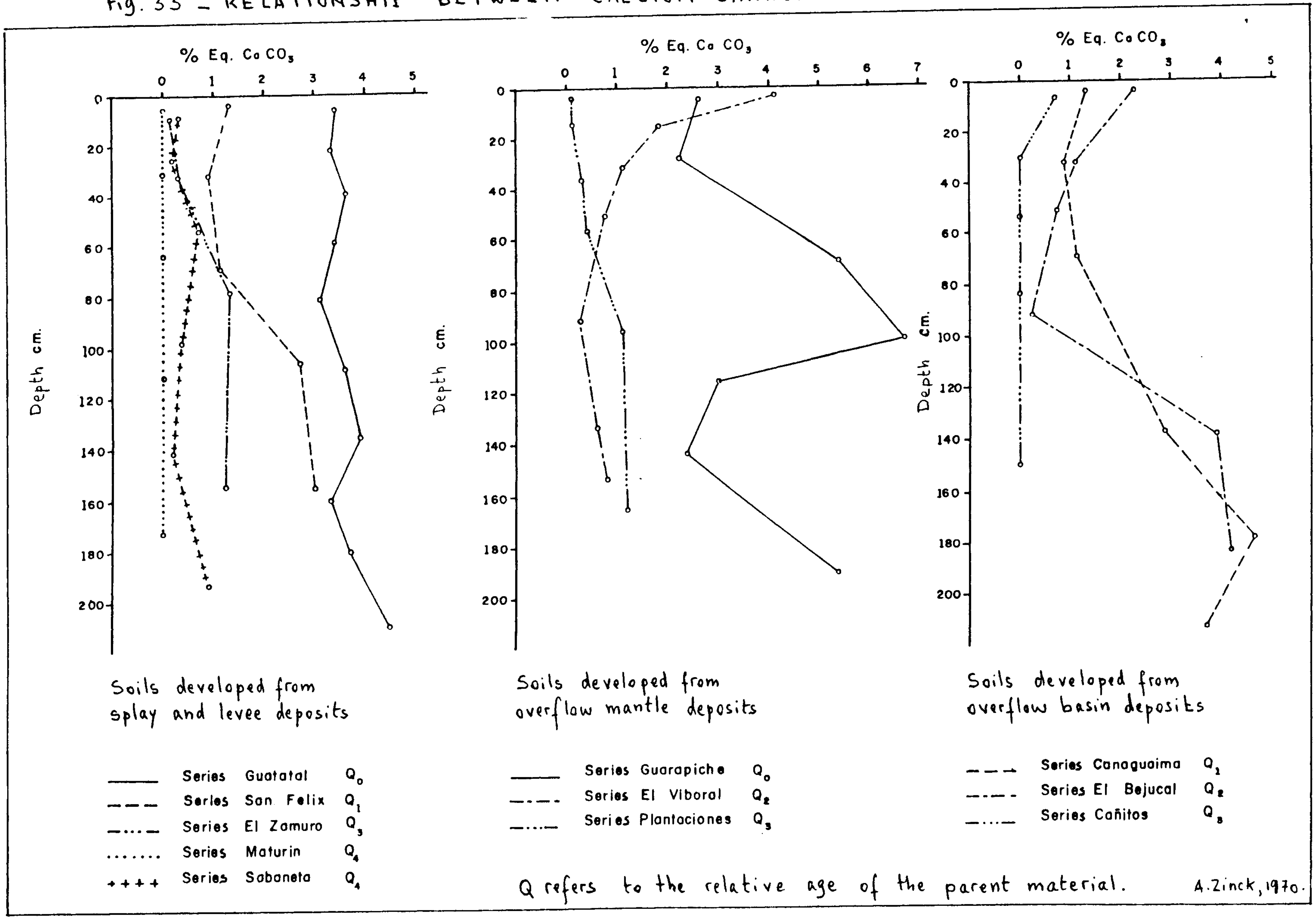


Fig. 34 _ RELATIONSHIP BETWEEN SOIL REACTION AND RELATIVE AGE

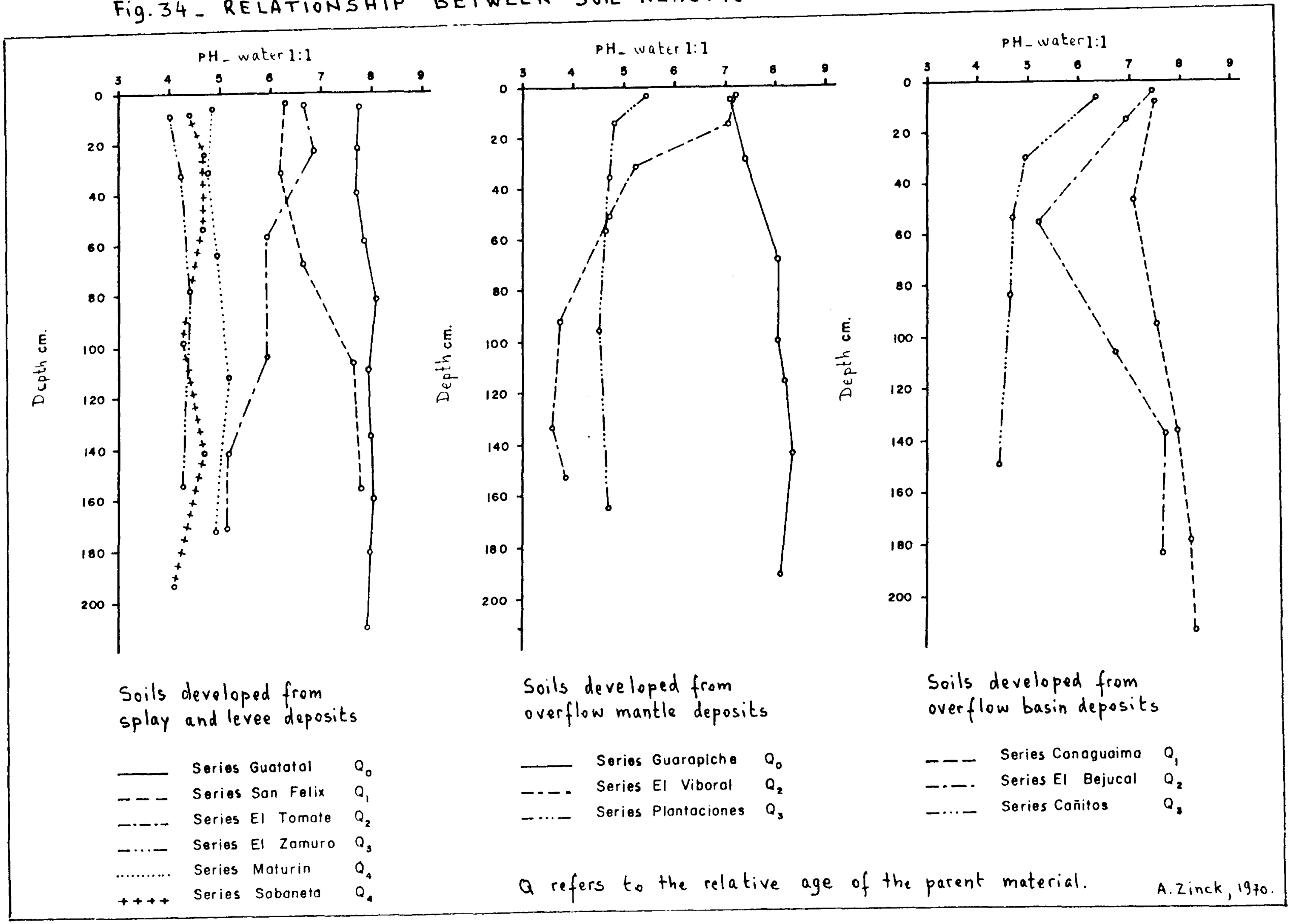


Fig. 35 – RELATIONSHIP BETWEEN BASE SATURATION AND RELATIVE AGE

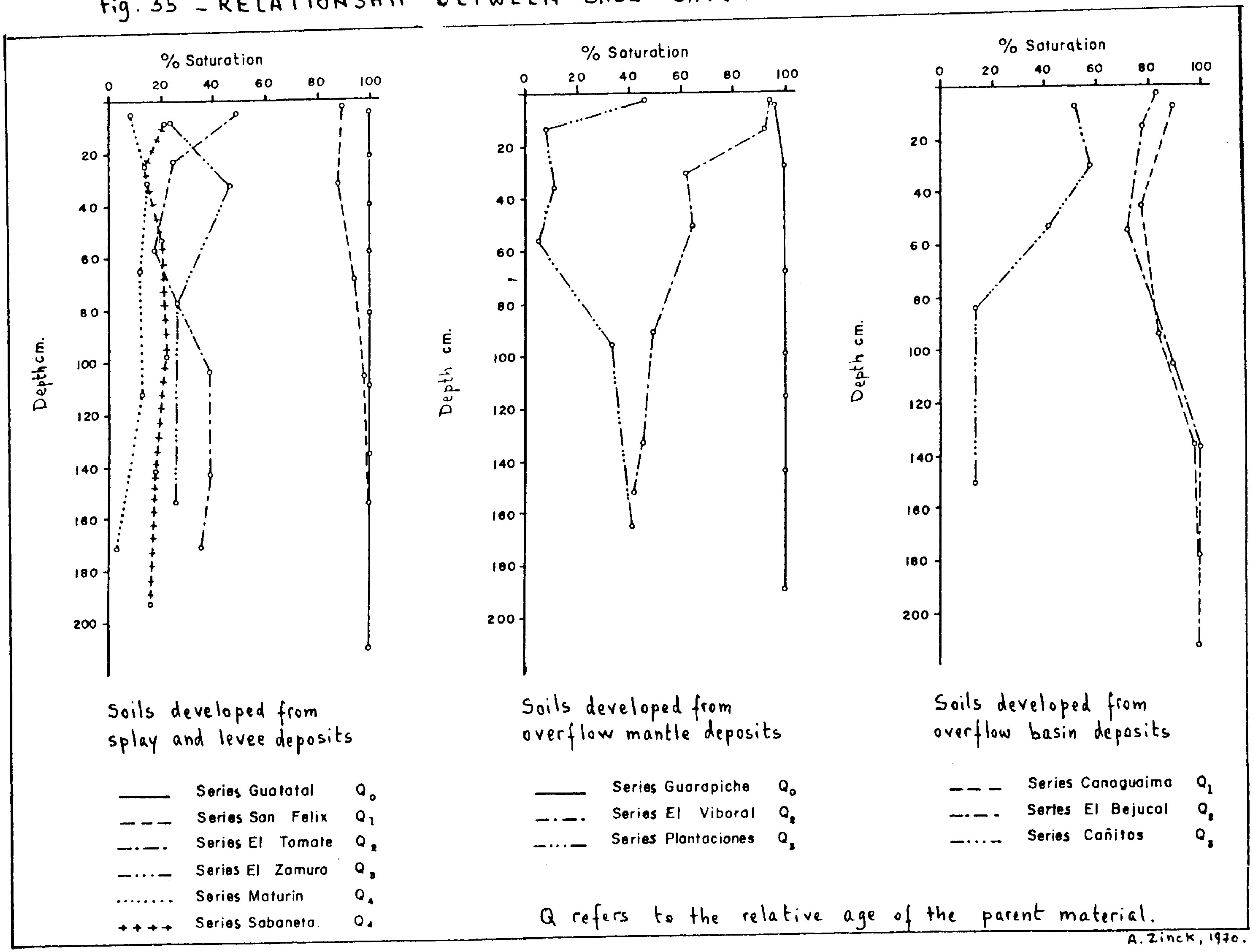


Fig. 36 _ RELATIONSHIP BETWEEN CATION EXCHANGE CAPACITY AND RELATIVE AGE

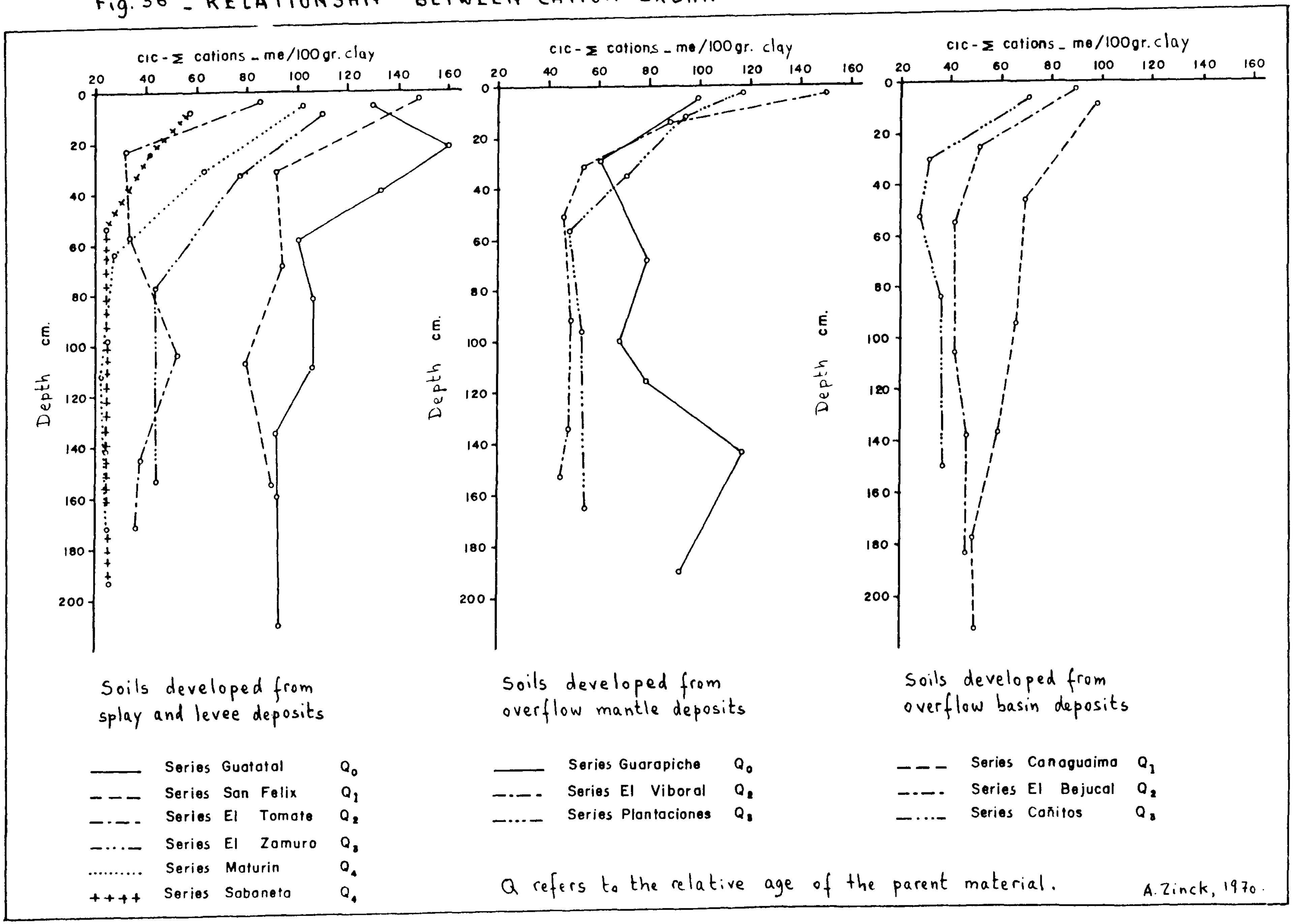
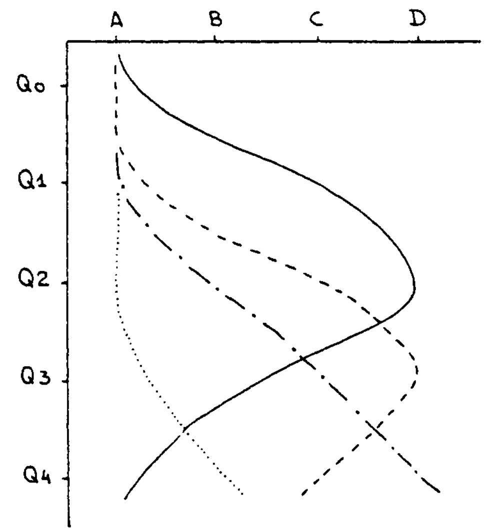


Fig. 37 - SUBSTITUTION OF SOIL DEVELOPMENT PROCESSES OVER TIME

Guarapiche river valley - Venezuela



TYPES OF PEDOGENETIC PROCESSES

- ——— Decarbonatation
- - - - - Clay illuviation
- —.— Bases leaching
- .... Degradation of the adsorption complex

INTENSITY OF PEDOGENETIC PROCESSES

A - None
B - Weak
C - Moderate
D - Strong

RELATIVE TIME SCALE

Qo - Holocene
Q1 - Upper Pleistocene
Q2 - Late middle Pleistocene
Q3 - Early middle Pleistocene
Q4 - Lower Pleistocene

A. Zinck, 1970.

Table 17 - RELATIVE AGE OF PARENT MATERIALS AND MAIN SOIL CHARACTERISTICS (Guarapiche river valley, Venezuela)

Relative age parent material	CaCO3 Eq. %	Clay illuviation index B/A	pH 1:1 H2O	% Base saturation	CEC me/100 gr.clay	Main taxa
Q0	+ 3	-	± 8	100	80-120	Entisols Inceptisols
Q1	1-3	-	6-7.5	80-100	60-95	Inceptisols Mollisols
Q2	1-2	1.2-1.6	4.5-6	40-60	40-60	Alfisols Vertisols
Q3	0.5-1	2.1-2.7	4-5	20-40	40-50	Ultisols
Q4	< 0.5	2.4-2.5	4-5	< 20	20-30	Ultisols Oxic subgroup

A. Zinck - P.L. Urriola, 1970

Q0 = Holocene
Q1 = Upper Pleistocene
Q2 = Late Middle Pleistocene
Q3 = Early Middle Pleistocene
Q4 = Lower Pleistocene

Table 18 – THE SOILS OF TWO CHRONOSEQUENCES
(Guarapiche river valley, Venezuela)

(a) Soils of a well-drained chronosequence

Age (1)	Soil series	Taxonomic classification (2)
Q0	Guatatal	Coarse loamy, mixed (calcareous), Typic Ustifluvent
Q1	San Felix	Fine loamy, mixed, Cumulic Haplustoll
Q2	Cardones	Fine loamy, mixed, Udic Haplustalf
Q3	Perú	Fine loamy, oxidic, Typic Plinthustult
Q4	Maturin	Fine, kaolinitic, Oxic Paleustult

(b) Soils of a poorly-drained chronosequence

Age (1)	Soil series	Taxonomic classification (2)
Q0	Guarapiche	Fine silty, mixed, Fluventic Ustropept
Q1	Matutes	Fine, mixed, Vertic Tropaquept
Q2	Bejucal	Very fine, mixed, Entic Chromustert
Q3	Cañitos	Fine, oxidic, Typic Plinthaquult
Q4	Sabaneta	Fine, kaolinitic, Plinthoxic Paleustult

(1) Refers to the relative age of the soil parent materials.
Q0 = Holocene; Q1 = Upper Pleistocene;
Q2 and Q3 = Middle Pleistocene; Q4 = Lower Pleistocene

(2) All taxa belong to the isohyperthermic family

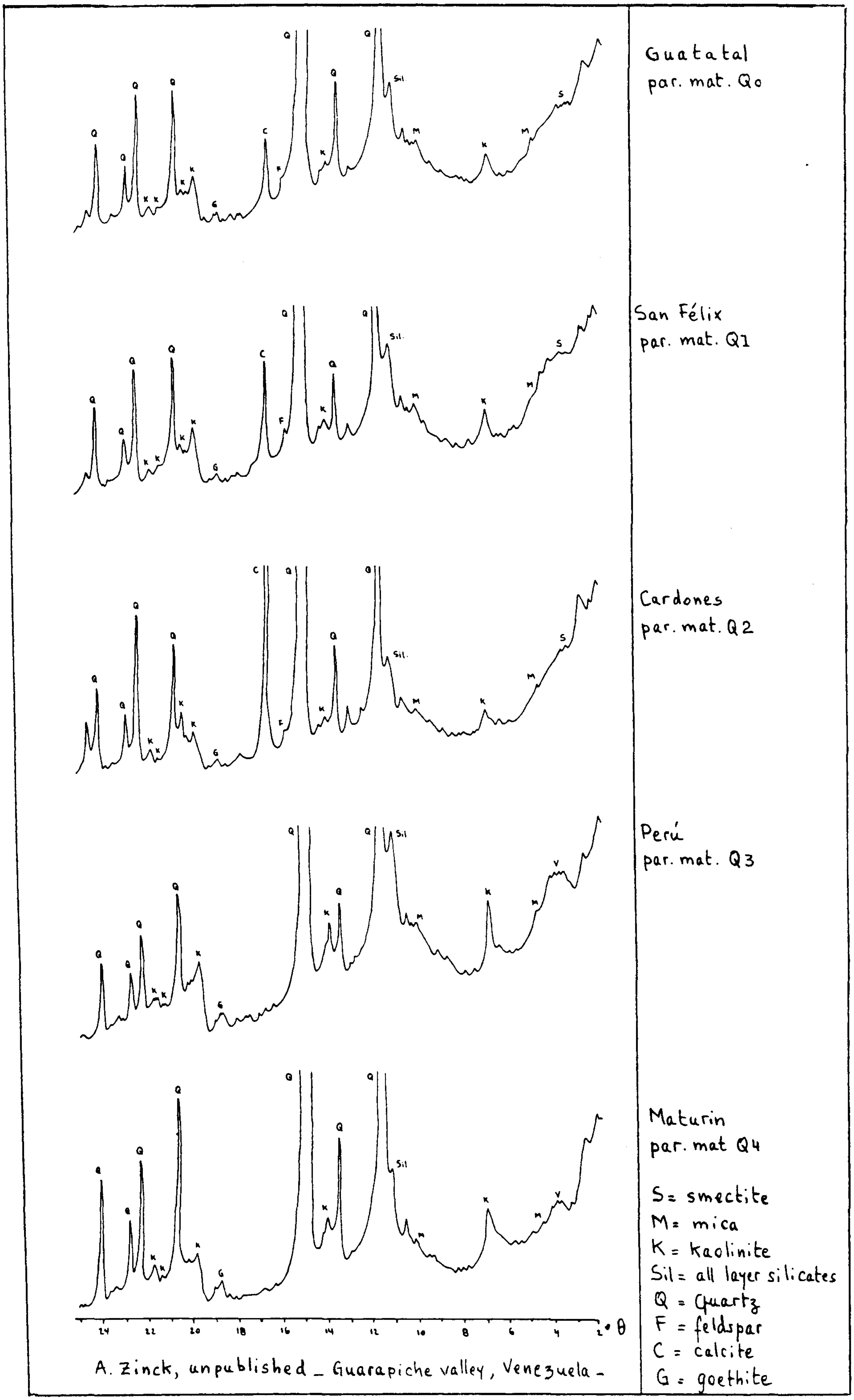
Table 19 – SOIL CHARACTERISTICS AND CLAY MINERAL ASSOCIATIONS
(Guarapiche river valley, Venezuela)

Relat. age parent mater.	SOIL IDENTIFICATION				SOIL CHARACTERISTICS				CLAY MINERAL ASSOCIATIONS
	Series	Classification	Depth cm	Horizon	% Clay	pH	% B.S.	CEC me/100gr clay	
(1) Well-drained chronosequence									
Q0	Guatatal	Entisol	79- 91	C	9	8.1	100	106	S > K = M
Q1	San Felix	Mollisol	83-130	Ck	17	7.7	98	80	S > K > M
Q2	Cardones	Alfisol	69-120	Bt	29	5.2	76	50	S > K > M
Q3	Perú	Ultisol	120-179	Btv	43	4.7	15	30	V > K > M
Q4	Maturin	Ultisol	78-147	Bt	36	5.2	13	21	K>>>V>M>HIV
(2) Poorly drained chronosequence									
Q0	Guarapiche	Inceptisol	47- 90	Bk	24	8.1	100	74	S > K = M
Q1	Matutes	Inceptisol	182-230	2Czky	58	7.5	96	43	S>> K > M
Q2	Bejucal	Vertisol	125-150	Cky	60	7.8	100	46	S>> K > M
Q3	Cañitos	Ultisol	109-190	Btvc	55	4.5	13	36	V > K > M
Q4	Sabaneta	Ultisol	121-161	Btvc	56	4.7	17	24	K>>>HIV>M = V

S = smectite; K = kaolinite; M = mica; V = vermiculite; HIV = hydroxy-interlayered vermiculite

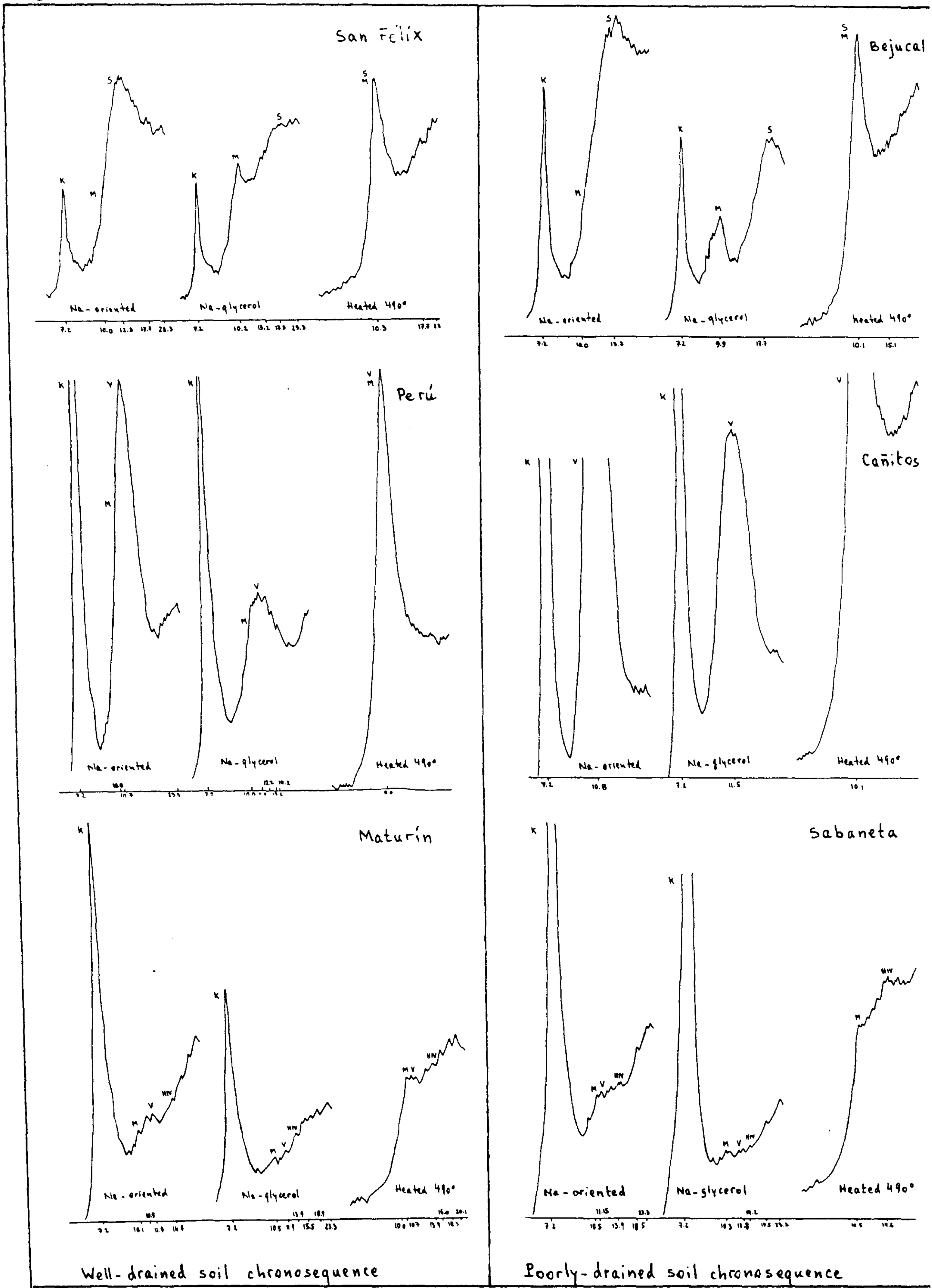
A. Zinck, unpublished

Fig. 38 _ POWDER DIFFRACTOGRAMS OF SELECTED C HORIZONS



A. Zinck, unpublished _ Guarapiche valley, Venezuela -

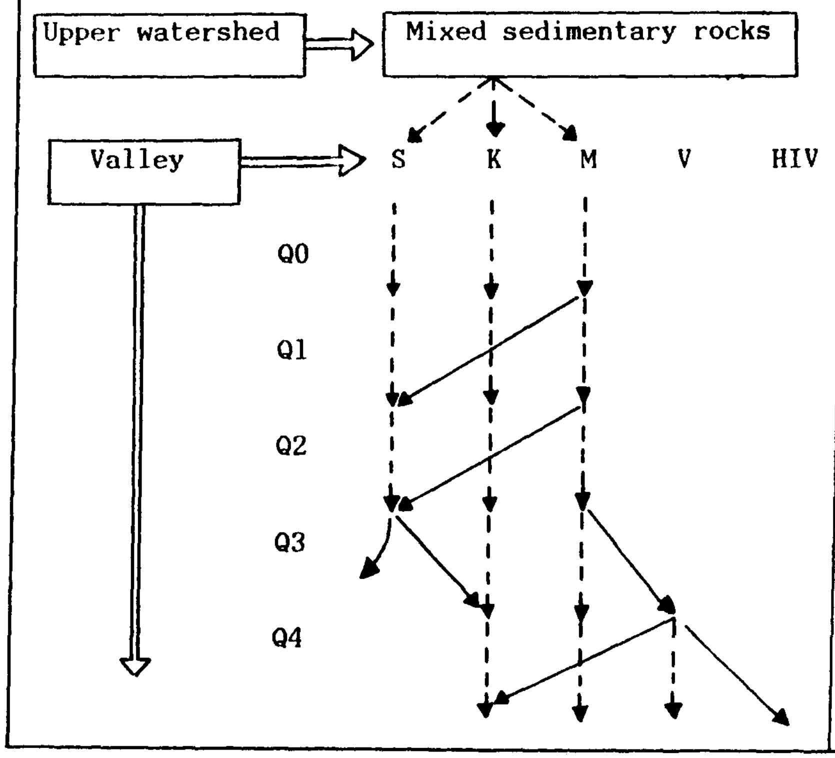
Fig. 39_ CLAY DIFFRACTOGRAMS OF B HORIZONS_ GUARAPICHE VALLEY, VENEZUELA



S = smectite ; K = kaolinite ; M = mica ; V = vermiculite ; HIV = hydroxy-interlayered vermiculite

A. Zinck, unpublished.

Table 2o _ RELATIONSHIPS BETWEEN CLAY MINERAL ASSOCIATIONS AND SOIL DEVELOPMENT
(Guarapiche river valley, Venezuela)



Age	Major clay mineral forming processes	Major soil forming processes	Principal soil taxa
Q0	Mixed mineral inheritance	Structure formation	Entisols Inceptisols
Q1	Smectite formation	Melanization Decarbonatation	Mollisols Inceptisols
Q2	Smectite formation	Clay illuviation Shrink-swell	Alfisols Vertisols
Q3	Smectite degradation Vermiculite formation	Clay illuviation Decalcification	Ultisols
Q4	Kaolinite and Hydroxy-interlayered minerals formation	Desilication	Ultisols (oxic)

A. Zinck, unpublished.

——→ Mineral formation
- - - -→ Mineral inheritance

S = smectite; K = kaolinite; M = mica
V = vermiculite; HIV = hydroxy-interlayered vermiculite

Relative age of parent materials: Q0 = Holocene; Q1 = Upper Pleistocene;
Q2 and Q3 = Middle Pleistocene; Q4 = Lower Pleistocene

* Integration of criteria for soil development estimation

According to J.W. Harden - "A quantitative index of soil development from field descriptions: examples from a chronosequence in Central California", Geoderma 28 (1982), 1-28.

A soil development index has been developed in order to quantitatively measure the degree of soil profile development. This index, which combines eight soil field properties with soil thickness, is designed from field descriptions of the Merced River chronosequence in Central California. These eight properties are: clay films, texture plus wet consistence, rubification (color hue and chroma), structure, dry consistence, moist consistence, color value, and pH. Other properties described in the field can be added when more soils are studied. Most of the properties change systematically within the 3 m.y. age span of the Merced River chronosequence. The absence of properties on occasion does not significantly affect the index. Individual quantified field properties, as well as the integrated index, are examined and compared as functions of soil depth and age.

* Conclusion

Pedostratigraphy is based on:

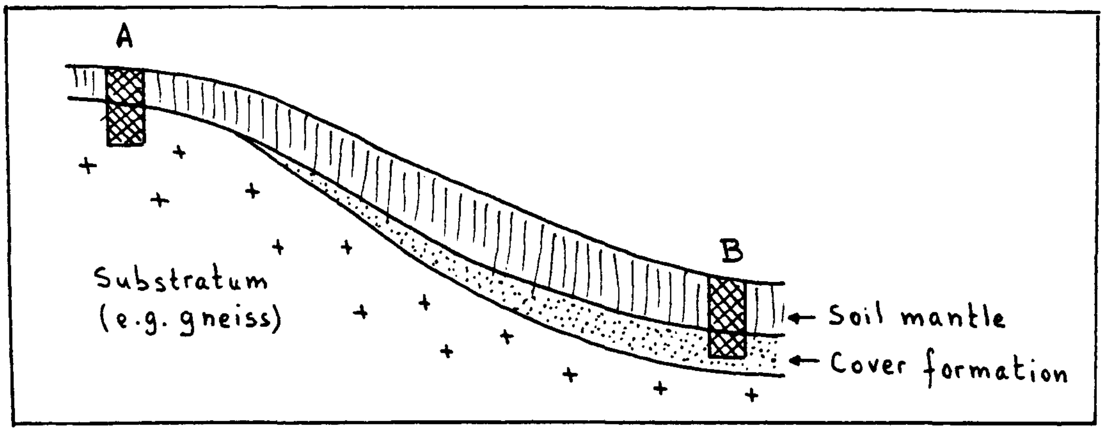
- soil horizon development and substitution,
- transformation, replacement and/or removal of soil components through mechanical, biological, physical and chemical processes,
- sequential development of soil types, supported by their differential taxonomic classification.

e) Precautions to be taken

* Difference between age of the parent material and age of the soil

- In depositional areas: relatively good concordance. For instance, in an alluvial area generalized deposition may have gradually stopped at the beginning of the Holocene (10-12.000 years ago), allowing soil development to start. The resulting soil is younger than 10.000 years.
- In erosional areas: in general no concordance. A big gap may exist between the age of the soil and the age of the geologic substratum. The latter is frequently not the real soil parent material. Soils actually develop from slope cover formations derived from rock substratum.

Fig. 40 _ AGE OF PARENT MATERIAL AND AGE OF SOIL



. Soil A formed directly from the hard rock in-situ by isovolumetric weathering (parent material = gneiss $400x10^6$ years old).

. Soil B formed from a soft detritic material transported along the hill slope and deposited on the footslope (parent material = slope cover formation not older than 10.000 years).

. Both A and B soils are younger than 10.000 years.

* Constraints for age estimation in depositional areas because of:
  - lateral shifting of main depositional axes within the system,
  - contamination by flooding.

* Polycyclic soils

  Many Quaternary soils are polycyclic, reflecting the influence of changing climatic conditions. As a consequence, pedogenetic features belonging to successive periods are found superimposed in the same profile, making it difficult to assign a global age to the corresponding soil.

* Relative validity of pedostratigraphic criteria

  Local or regional conditions may have a strong influence on soil properties and development, such as climate, mineralogy of the parent materials, presence or absence of calcium carbonate in the geochemical system, drainage, etc. Eventhough the pedostratigraphic concepts can be applied everywhere, the ranges of values for each criterion are only valid for a given spatial system. Geopedological models must be developed regionally (see Part VI).

B. DIFFERENTIAL IMPORTANCE OF THE ATTRIBUTES

Not all attributes are equally important for classifying geoforms. For instance, the granulometry of the material is more important than the relative height of a landform. The former attribute bears more taxonomic weight.

1. ATTRIBUTE WEIGHT

Attributes can be arranged into three classes according to their differential weight for taxonomic purposes, namely differentiating, accessory and accidental attributes.

a) Classes of taxonomic attributes

* Differentiating attributes

An attribute is a differentiating one if it allows to distinguish one type of geoform from another at a given categorical level. A change in the state of the attribute, expressed by a given range of values, would lead to a change in classification. An attribute bearing this faculty is considered as diagnostic. It contributes, together with other differentiating attributes, to the identification and classification of geoforms.

Examples:
- A slope facet must be concave to be classified as a footslope. In this case, the topographic profile is a differentiating attribute and "concave" is the specific attribute state required.
- The material of a decantation basin has normally more than 60% of clay fraction. Particle size distribution is here a differentiating attribute and the state of attribute is expressed by 60-100% clay.

* Accessory attributes

An attribute is accessory when it reinforces the differentiating ability of a diagnostic attribute without being itself able to do so (= covariant attribute).

Example: depositional structure. "Lenticular" is a type (state) of depositional structure which may occur in several alluvial facies types, but is more common (not exclusive) in deposits originated by sediment load excess, accompanied by mechanical frictions (levee). Taken alone, the lenticular structure would not be enough to identify a levee position.

* Accidental attributes

An accidental attribute does not contribute to the identification of a geoform but adds useful information to its characterization. This type of attribute can be used for creating phases of taxonomic units for mapping purposes (cartographic units, legend).

Example: relative height, slope, etc.

b) Application to the categorization of geomorphic attributes

* Morphographic attributes

They are mainly accessory, sometimes differentiating.

- Accessory weight. For instance, a newly formed levee has a very typical morphology (narrow, elongated, sinuate, convex landform), allowing easy recognition on aerial photographs. But older levees, the contours of which have been obliterated over time, may not be so easy recognizable by external features. In the case of buried levees, contour tracing must be reconstructed by means of borings. In both cases, the identification is mainly based on granulometric composition and accessorily supported by morphographic features.
- Differentiating weight in mountainous and hilly landscapes.

* Morphometric attributes

They are mainly accidental ones. They contribute to geoform characterization but not to its identification. For instance, the difference of altitude (relative height or internal relief) between the top surface of a plateau and the surrounding lowlands (plain or valley) may be 100-150 m (e.g. northeastern Mesas of Venezuela) or 1000-1500 m (e.g. Altiplano of Bolivia). In both cases, however, the identified geoform at the level of landscape would be a plateau, as far as all required diagnostic attributes are met. Therefore, dimensional features have low taxonomic weight, but are important to the interpretation of geomorphic information for environmental impact assessment and land use planning. Phases of relative height, valley density and slope can be implemented.

* Morphogenetic attributes

They are mainly differentiating ones, taken either individually or as a set, especially when reinforced by accessory attributes. For instance, Atterberg limits control mass wasting processes and resulting forms. Depositional landforms show always specific ranges of granulometric composition, which is therefore a highly diagnostic attribute in this case.

* Morphochronologic attributes

They are mainly differentiating ones, because the relative age of a geoform is an integral part of its identity. Whether an alluvial levee has formed during the Holocene (Qo) or during the Middle Pleistocene (Q2) may not change its configuration, although the contour design may have been obliterated over time. But the stratigraphic position of a geoform determines a time frame having strong influence on morphogenesis and soil development.

2. ATTRIBUTE HIERARCHIZATION

a) Categorical differentiation of attributes (Tables 21 - 22).

Not all attributes are used at every level of the system. A differential hierarchization has still to be worked out. Some rules appropriate for this purpose are proposed here.

* **Number of attributes**
  - Higher levels: less attributes needed
  - Lower levels : more attributes as a result of a downwards summing up of information

* **Nature of attributes**
  - Higher levels: mostly descriptive, based on external characteristics (morphographic, morphometric)

- Lower levels : more genetic, based on internal characteristics (morphographic, morphochronologic)

*** Function of attributes**

- Higher levels: generalizing, aggregating
- Lower levels : particularizing, detailing

*** Implementation of attributes**

- Higher levels: more by means of aerial photointerpretation or visual interpretation of satellite images
- Lower levels : need for more input of field and laboratory data, and digital processing of satellite images.

Table 21 - ATTRIBUTE HIERARCHIZATION

CATEGORIES				
Upper	Few	Descriptive External characterization	Generalizing Aggregation	Photo-image interpretation
Lower	Many	Genetic Internal characterization	Detailing Disaggregation	Field Laboratory
ATTRIBUTES	Amount	Nature	Function	Implementation

b) Hierarchical implementation of attributes (Table 22)

ATTRIBUTES	LANDSCAPE	RELIEF MOLDING	LITHOLOGY	LANDFORM
MORPHOMETRIC				
Relative altitude	x	x		.
Valley density	x	x		
Slope steepness	x	x		x
MORPHOGRAPHIC				
Shape of topography	x	.		
Profile of topography		x		x
Exposure		x		x
Configuration		x		x
Contour design		x		x
Drainage pattern	x	x		
Surrounding conditions	x	x	x	x
MORPHOGENETIC				
Granulometry		.	x	x
Structure			x	x
Consistence			x	x
Mineralogy			x	x
Morphoscopy			x	x
MORPHOCHRONOLOGIC				
Weathering degree of par.mat.			x	x
Degree of soil development			.	x
Leaching indices			.	x
Status of adsorption complex			.	x
Clay mineralogy			x	x

x = very important attribute
. = moderately important attribute

V. GEOFORM SYSTEMATICS (RELIEF AND LANDFORM TYPES)

A. INTRODUCTION

1. This is only an introduction to systematics of geoforms. Selection and validation of diagnostic attributes are still incomplete, hierarchization of geoforms has to be improved, an actual identification key has yet to be worked out.

2. The list of geoform taxa presented here is not exhaustive. Many synonymous terms can be found in specialized literature. New geoform types may be identified as geomorphic cartography is advancing.

3. Taxa belonging to the higher and middle levels of the system have been defined in Part III of this chapter. The present section deals mainly with the lower levels taxa (relief and landform).

4. A convenient and conventionally used criterion to display families of geoforms is their origin. The concept of origin is used here in a broad sense and may indistinctly refer to a type of environment (e.g. structural), agent (e.g. wind), morphogenetic system (e.g. periglacial), or single process (e.g. splay).

5. The concept of origin, as synonymous of genesis, is implicitely or explicitely used at all levels of the taxonomic system, but its diagnostic weight increases downwards. Origin as controlled by internal geodynamics is more important at higher categories, origin as controlled by external geodynamics is more important at lower levels. As a consequence, there is a differential hierarchization of diagnostic attributes according to the origin of the geoforms. For instance, genetic features have maximum weight at the level of relief type in the case of geoforms of structural origin. For geoforms originated by a subaerial agent (e.g. water, wind, ice), genetic features have maximum weight at the lower levels of the system (facies and landform).

6. The same morphogenetic agent (e.g. water, wind, ice) can generate erosional and depositional features according to the context in which action takes place. Therefore, differentiation is made between erosional and depositional landforms. Similarly, structural geoforms may have been

strongly modified by erosion, leading to the distinction between original and derived forms.

7. Erosional landform is used wherever erosion, by removal of material and/or dissection, is responsible for creating the main shape of the form. Local modifications affecting a landform, such as rill and gully incision or wind deflation, are considered as phases of the taxonomic units.

8. Point features are represented by spot symbols. They are not considered as taxonomic units (e.g. geyser, erratic blocks, pingo, etc.).

9. The reader is invited to consult basic textbooks for the definition of the landforms listed here. The influence of the properties and degree of activity of each landform type on soil properties and evolution will be covered by future developments, similar to the development given here to alluvial landforms as an example (point E).

B. GEOFORMS MAINLY CONTROLLED BY GEOLOGICAL STRUCTURE

Geological structure control acts through tectonics, volcanism and/or lithology. Therefore, internal geodynamics is determinant, combined in variable degrees with external processes such as:

- erosion:
  - . mechanical: dissection of primary structural reliefs into derived geoforms;
  - . chemical : dissolution of calcareous rocks (karstism) or arenites (pseudo-karstism);
- deposition : air-borne (ash, cinder) or subaerial (lava flow) volcanic materials.

1. STRUCTURAL GEOFORMS

a) Monoclinal

- Dipslope of the rockbeds in one direction.
- Hard rocks (sandstone, quartzite, limestone) overlying softer material (marl, lutite, shale).
- The duo hard rock/soft rock may be recurrent, leading to relief doubling.

b) Folded (jurassic style)

- Symmetrical folds in regular sequences of anticlines (structural ups) and synclines (structural downs).
- Related to stratified sedimentary rock complexes.

c) Folded (appalachian style)

Advanced dissection and downwasting state of originally folded relief systems.

e) Folded (complex relief types)

Primary or derived, overthrust-controlled relief types.

f) Faulted

- Primary or derived relief types caused by faults or fractures.
- The faulting style (normal, inverse, conform, contrary) has a strong influence on the resulting types of relief, the primary as well as the derived ones.

Table 23 - STRUCTURAL GEOFORMS

RELIEF TYPES		LANDFORM TYPES
PRIMARY	DERIVED	
MONOCLINAL		
Cuesta (1-10°) Creston (10-30°) Hogback (30-70°) Bar (>70°)	Doubled cuesta Flatiron Outlier hill Orthoclinal (subsequent) depression Cataclinal (consequent) depression Anaclinal (obsequent) vale Cataclinal gap	Scarp Debris talus Structural surface Substructural surface
FOLDED (JURASSIC)		
Mont (anticline) Val (syncline)	Excavated anticline Hanging syncline Combe Cluse Ruz Chevron Creston	
FOLDED (APPALACHIAN)		
	Truncated anticline Bar Hanging syncline Gap	
FOLDED (COMPLEX)		
Overthrust sheet Klippe	Creston of overturned flank Escarpment of faulting fold Combe on ejective fold	
FAULTED / FRACTURED		
Fault escarpment Horst Graben Tilted fault-block	Faultline escarpment Fault escarpment facet	

2. VOLCANIC GEOFORMS

Volcanic materials may constitute the main substratum or only top cover formations in a large variety of landscape types including mountain, plateau, piedmont, plain and valley.

Table 24 - VOLCANIC GEOFORMS

RELIEF TYPES	LANDFORM TYPES
Depression	Crater Caldera Maar Lake
Cone	Ash cone Cinder cone Spatter cone Shield volcano (hawaian volcano) Strato volcano Cumulo volcano
Flat	Lava flow Block (aa) lava Ropy (pahoehoe) lava Pillow lava Fluvio-volcanic flow Cinder field Ash mantle
Mesa Cuesta Hogback	Planèze Hanging lava flow Sill
Bar Dike Escarpment	Longitudinal dike Annular dike (ring-dike) Volcano scarp Neck Volcanic plug

3. KARSTIC GEOFORMS

By chemical erosion of soluble rocks, karstism creates complex topographic land surfaces, characterized by residual geoforms of either positive or negative relief. Specific taxa enter the system essentially at the level of relief type.

Table 25 - KARSTIC GEOFORMS

RELIEF TYPES	LANDFORM TYPES
Conical karst (dome) Tower karst Labyrinth karst Hill (hum) Poljè (karstic "plain") Blind vale Dry vale Canyon (collapse vale)	Lapies Swallow hole (ponor) Sinkhole (doline) Intergrown sinkhole (uvala)

C. GEOFORMS MAINLY CONTROLLED BY MORPHOGENETIC AGENTS

Specific agents such water, wind or ice work either by erosion or deposition according to the environmental conditions. The resulting geoforms are generally more homogeneous and have more conspicuous configurations than the broad, structurally controlled geoforms. Therefore, many of them can be classified at the level of landforms. Six main families of landforms are distinguished according to their origin such as follows:

- Nival, glacial and periglacial
- Eolian
- Alluvial and colluvial
- Lacustrine
- Gravity and mass movements
- Coastal

Table 26 - NIVAL - GLACIAL - PERIGLACIAL LANDFORMS

EROSIONAL (DENUDATIONAL)	DEPOSITIONAL (ACCUMULATIVE)
NIVAL	
Snow avalanche corridor (track) Nivation cirque	Perenne snow mantle Snow avalanche "fan"
GLACIAL	
Crevasse field Polished and striated surface (roches moutonnées) Glacial cirque Threshold Overexcavation hollow Glacial trough Glacial shoulder Hanging "valley" (gorge)	Glacier ice Inlandsis ice Dead-ice depression Ground moraine Frontal (terminal) moraine Lateral moraine Median (central) moraine Push moraine Drumlin Blocks stream
PERIGLACIAL	
Horn (nunatak) Gelifraction crest Solifluction scar	Fluvio-glacial mantle Fluvio-glacial outwash "fan" (sandur) Proglacial "fan" Kame Esker Ös (osar) Patterned ground Stone stripes Gelifraction scree "fan" Gelifraction scree talus Periglacial solifluction

Table 27 - EOLIAN LANDFORMS

EROSIONAL	DEPOSITIONAL
Yardang Deflation basin (blow-out hollow) Stony deflation surface (reg) Rocky deflation surface (hamada)	Barkhane Nebka Parabolic dune Longitudinal dune Transversal dune Star-shaped dune (oghroud) Pyramidal dune (ghroud) Reticulate dune Eolian levee (associated with defl. basin) Generalized sand mantle Loess mantle

Table 28 - ALLUVIAL AND COLLUVIAL LANDFORMS

EROSIONAL	DEPOSITIONAL
Ablation surface Rill Gully Gully complex (badlands)	Load excess facies Point bar complex River levee Distributary levee Deltaic levee Splay axis Splay mantle Crevasse splay Splay "fan" Splay "glacis"
	Overflow facies Overflow mantle Overflow basin
	Decantation facies Decantation basin Backswamp Ox-bow lake Infilled channel
	Colluvial facies Colluvial "fan" Colluvial "glacis"

Table 29 - GRAVITY AND MASS MOVEMENT LANDFORMS

MATERIAL STATES (PROCESS FAMILIES)	LANDFORM TYPES
Solid (gravity)	Rock fall Scree "fan"
Semi-solid (sliding)	Rockslide Blockslide Debris slide Landslide Creep mantle Slump
Plastic (heave)	Rock flow Earth flow Debris flow Generalized solifluction Solifluction lobe Solifluction sheet Solifluction stream Solifluction stripe
Liquid (flow)	Mudflow Torrential lava

Table 30 - COASTAL LANDFORMS

EROSIONAL	DEPOSITIONAL
	MECHANICAL
Cliff	Beach
Wavecut platform (abrasion bench)	Beachridge (coastal bar)
Tidal creek	Off-shore bar (barrier beach)
Grao	Baymouth bar
Through	Cuspate bar
	Spit
	Tombolo
	Trough
	Slikke-shore (mudflat)
	Tidal levee
	Bay
	Coastal swamp
	Salt marsh
	Dune
	Sand cay
	Beachrock platform
	BIOGENIC
	Reef edge
	Reef "flat"
	Reef "knoll"
	Reef cap
	Lagoon
	Lithothamnium ridge

D. BANAL GEOFORMS (DISSECTION HILLS AND RIDGES)

1. GENERAL CHARACTERISTICS

- General topography of hills and ridges, originated by dissection.
- No or weak structural influence, in particular no specific tectonic setting controlling the topography.
- Homogeneous rock substratum over large distances.
- Material of moderate to weak resistence, including
  . igneous rocks (granite, diorite, gabbro)
  . metamorphic rocks (gneiss, schist, slate)
  . sedimentary rocks (lutite, marl).
- Existence of fractures favoring and controlling the incision and organization of the hydrographic network. The drainage pattern in turn has a fundamental influence on the configuration of the resulting dissection topography, especially in landscapes such as peneplains and hillands.

2. MAIN CLASSES AT DIFFERENT CATEGORICAL LEVELS

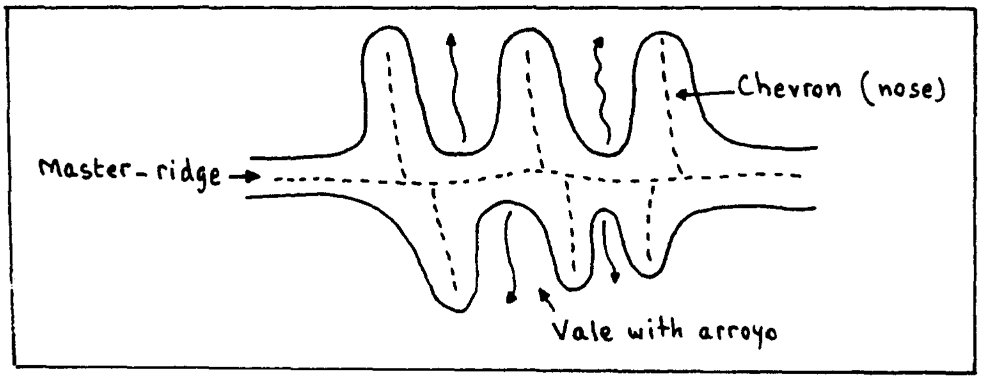
a) Landscape type

- Mountain
- Hilland
- Peneplain
- Piedmont (parts).

b) Relief types

- Backbone configuration consisting of an association of longitudinal master ridges and perpendicular lateral ridges (chevron, rafter, nose) separated by vales. It is frequent in fractured sedimentary rock environments. Further evolution of the relief generates horseback-like, elongated hills.

Fig. 41 _ BACKBONE-LIKE CRESTS SYSTEM



- "Half-orange" configuration consisting of the systematic repetition of similar, rounded hills or knolls. Such a relief configuration is typical of a peneplain landscape, developed from homogeneous but intensively fractured (dense joint systems) igneous or metamorphic substrata. The associated drainage pattern is strongly reticulate.
- Association of irregular hills lacking distinctive topographic features.

c) Landform types

Slope facet seems to be the most convenient concept to subdivide any hilly relief. Several slope models have been developed for that purpose.

3. SLOPE MODELS

a) <u>Dalrymple's model</u>

It consists of 9 slope facets.

See Fig. 47, p. 49, Chapter 1.

b) <u>Ruhe's model</u>

It consists of 5 slope facets.

See Fig. 48, p. 49, Chapter 1, and Table 31 hereafter.

Table 31 – RUHE'S SLOPE MODEL

SLOPE FACET	TOPOGRAPHIC PROFILE	DOMINANT DYNAMICS
Summit	Flat/convex	Ablation/erosion
Shoulder	Convex	Erosion
Backslope	Straight	Transport (transitory accumulation)
Footslope	Concave	Accumulation (lateral)
Toeslope*	Concave/flat	Accumulation (longitudinal)

* The toeslope facet is actually not a hill slope facet and belongs rather to the associated valley or vale (slope perpendicular to the hill slope, alluvial deposits).

4. COMPLICATIONS

Models are convenient generalizations of real situations. Many complications must be taken care of when mapping geoforms or soils. These complications derive either from the heterogeneity of the local geological substratum or from the local slope morphodynamics.

a) <u>Local rock heterogeneity</u>

The model convexo-concave slope of a hill may be interrupted by flat treads, embossments or scarps reflecting changing tectonic layout or changing lithologic nature of the rockbeds.

b) <u>Local slope morphodynamics</u>

Local disruption of the general slope topography by water erosion (rill, gully) or mass movement features (slides, solifluction scars and tongues, etc.).

E. FLUVIAL LANDFORMS AND DEPOSITIONAL SYSTEMS

1. INTRODUCTION - BASIC CONCEPTS

a) Geomorphic facies

- Concept referring to a set of properties of a geomorphic material derived either from the depositional or weathering processes and/or environment. Properties concerned are: granulometry, geogenetic structure, mineralogy, fossiles, etc. (mainly lithofacies).
- Concept commonly used in sedimentology: lacustrine facies, brackish-water facies, pelagic facies, etc.
- Main purpose: to help summarize the genetic properties of a material.

b) Depositional system

A depositional system is a framework of geomorphic units formed under the prevailing influence of a specific agent (e.g. water, ice, wind), having genetical as well as spatial relationships and showing an organized distribution on the landscape.

2. FLUVIAL FACIES AND SOIL PROPERTIES

a) Spatial organization of sedimentation in a fluvial system

Concept = spatial particle size selection:

- vertical anisotropy
- horizontal anisotropy

Figure 42 _ FLUVIAL PARTICLE SIZE DISTRIBUTION SYSTEM

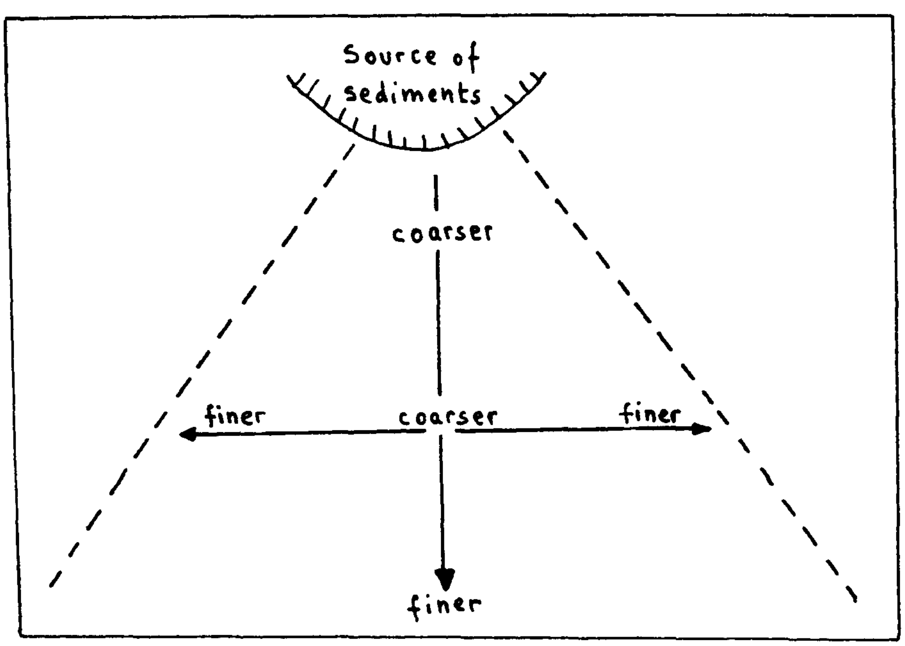
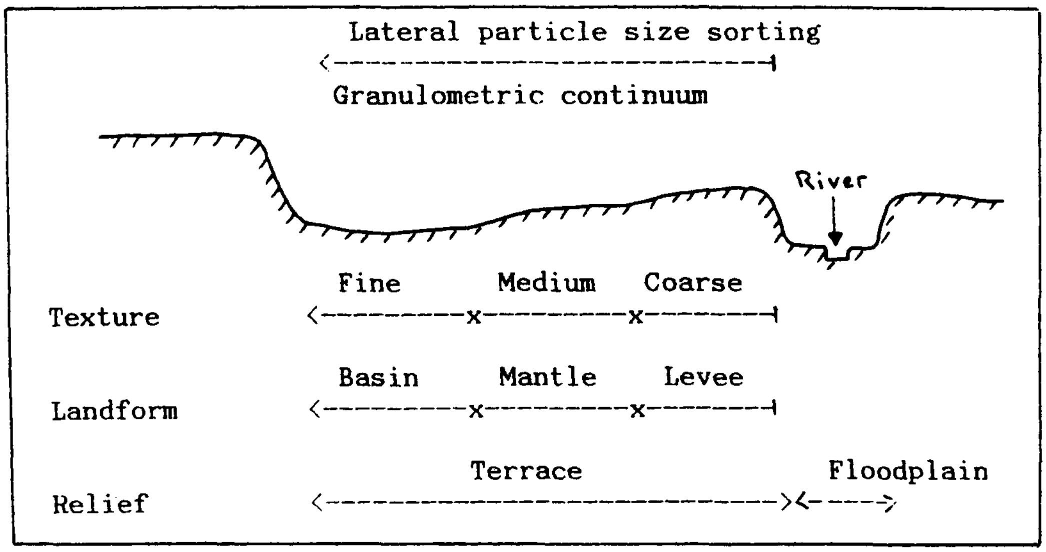


Figure 43 _ SPATIAL (TRANSVERSAL) GRANULOMETRIC SEGREGATION



b) <u>Facies types</u>

Three main types: - by load excess
- by overflow
- by decantation

* <u>Load excess facies</u>

(1) <u>Depositional conditions</u>

- Caused by a torrential exit of a concentrated water flow from a transport channel during high water period (high energy environment).
- Two modes of water exit:
  . by generalized overflow (over the channel banks)
  . by local rupture of channel banks (downstream of concave meander side).
- The water current is slowed down by mechanical frictions causing:
  . loss of competence of the waterflow
  . deposition of the coarser materials corresponding essentially to bedload (sand, gravel).

(2) <u>Characteristics of the load excess-generated positions</u>

- Morphographic: high, convex, narrow, elongated and sinuate.
- Morphogenetic:
  . common textures are loamy sand, sandy loam and sandy clay loam with lenticular or cross-bedding inclusions of coarse sand and gravels;

. logarithmic granulometric cumulative curve.

(3) Landform types

- River levee: reference pattern (modal position); located along the main rivers in (dis)continuous stretches.
- Distributary levee: branching and more sinuate configuration, connected to a main channel; coarser textures.
- Deltaic levee: very branching and sinuate; always pairs of levees (twin levees); coarser textures.
- Splay axis: larger, less sinuate; typically sandy clay loam (very low sorting) with dispersed and/or concentrated gravel inclusions.
- Splay mantle: massive configuration; typically sandy clay loam.
- Crevasse splay (or splay "fan"): triangular configuration with head plugged on a main river, distributary stream or deltaic arm; formed by local ruptures of river banks or levees; invading lateral depressional positions (basins); sandy loam and loamy sand, with coarser textures in the apical sector.

(4) Resulting soil properties

- Coarse to medium - textured materials (on the sandy side).
- Low water retention capacity, high infiltration rate, high permeability, well drained.
- Easy workability, good bearing capacity.
- Favourable conditions for lixiviation of soluble and colloidal compounds.

* Overflow facies

(1) Depositional conditions

- Deposition takes place in flat areas, more retired from main transport channels, adjacent to levee or axis positions.
- Material is retained by the vegetation cover, especially grasses and forbs, causing biotic trapping of sediments. Suspended silt fraction tends to deposit in such conditions.

(2) Characteristics of the overflow-generated positions

- Morphographic: medium high, flat or slightly concave, large, elongated or massive.

- Morphogenetic:
  . common textures are silt, silt loam, silty clay loam and silty clay,
  . silt fraction: commonly 40-50% or more,
  . sigmoidal granulometric cumulative curve,
  . frequently laminar geogenetic structure.

(3) Landform types

- Overflow mantle (bench): flat, large, elongated, bench-like position; well to moderately well drained; mainly silt loam and silty clay loam, with high silt fraction (> 60%).
- Overflow basin: concave, large, massive or oval depressional position; imperfectly drained; mainly silty clay and light clay, with similar silt and clay contents (approximately 50% of each).

(4) Resulting soil properties

- Well to imperfectly drained.
- Moderate water retention capacity but high water availability.
- Prone to structure degradation because of excessive silt content, leading to surface sealing and crusting, low infiltration rates and decreased permeability.
- High available and potential nutrient content.

* Decantation facies

(1) Depositional conditions

- Marginal position within in the depositional system, lying far away from transport channels.
- Material is deposited by decantation (= levigation) in a low energy environment.

(2) Characteristics of the decantation-generated positions

- Morphographic: low-lying, concave, massive or oval.
- Morphogenetic:
  . common texture is clayey, with more than 60% of clay fraction,
  . ribbon-like (varve-like) geogenetic structure, reflecting rhythmical deposition.

(3) Landform types

- Decantation basin: meets the general characteristics.
- Backswamp: poorer drained, inclusion of organic layers.

(4) Resulting soil properties

- Poorly to very poorly drained; very evident signs of strong hydromorphism (reduction mottles, sesquioxide nodules).
- High water retention capacity but only moderate water availability; low infiltration rate and slow permeability.
- Pedogenetic structure: prismatic, columnar or massive (generally massive in depth).
- Occasional presence of salts and/or high exchangeable sodium.
- Common fossile roots in deeper strata.
- Frequent worm excreta mounds on the soil surface.

3. FLUVIAL DEPOSITIONAL SYSTEMS AND SOIL DISTRIBUTION

- Fluvial landforms are not randomly distributed on the landscape. They are geographically associated to form depositional systems (B.E. Butler).
- A depositional system is in general characteristic of a given river dynamics and the specific conditions of the environment where sediments are distributed.

a) Types of depositional systems

Four main types of fluvio-depositional systems may be recognized:

- Valley system
- Deltaic system
- Splay system
- Drowned system.

* Valley system (Fig. 44)

An ideal, complete transverse section from main river channel to the margin of the system, from higher to lower position, includes 5 types of landforms:

- River levee:
  . Sandy loam and sandy clay loam with lenticular inclusions of loamy sand and sandy material
  . Well drained to somewhat excessively drained.

- Overflow mantle:
  . Silt loam and silty clay loam material
  . Well drained.
- Overflow basin:
  . Silty clay and clay material
  . Moderately well to imperfectly drained.
- Decantation basin:
  . Very fine clay material
  . Poorly drained.
- Backswamp, frequently derived from abandoned river channels, partially or completely filled in with clayey sediments underlying undecomposed histic cover material; very poorly drained position.

* Deltaic system (Fig. 45)

Deltaic system refers here to internal deltas formed in low-lying alluvial plains. Litoral deltas where alluvial and coastal actions combine are no considered. The main landforms are as follows.

- In axial position: deltaic levee formed by two parallel, sinuous, convex banks, which merge frequently when the deltaic channel has been completely filled in. Soils are sandy, excessively drained, of rapid permeability and low water retention capacity.
- In lateral position:
  . Overflow mantle: silt loam and silty clay loam.
  . Crevasse splay: sandy loam and loamy sand; formed by local ruptures of deltaic levees, especially in diffluence sites; the splay invades generally pre-existing basin positions.
- In marginal position:
  . Overflow basin: silty clay and clay
  . Decantation basin: very fine clay.

* Splay system (Fig. 46)

The basic structure of a splay system rests on the presence of elongated but unchanneled flow axes. Infilled paleochannels can scarcely be identified. In turn, sandy and gravelly lenticular structures are frequent, reflecting elementary concentrated rill flow to embryonic braided stream flow. Most of the material is translocated by generalized splay (sheet flood) process, generating extensive splay mantles. Splay axes exhibit homogeneous but poorly sorted granulometric composition (often sandy clay loam) over long distances (40-50 km). Past or present semi-arid conditions favor this type of depositional system.

The main landforms resulting from a generalized splay system forming process are:

- Splay axis:
  . High, flat, elongated, almost rectilinear bench, lacking channel traces.
  . Sandy loam material, with coarser lenticular inclusions; well drained.
- Splay mantle:
  . Large, flat, middle-lying position.
  . Sandy clay loam with loamy sand and sandy loam inclusions; moderately well drained.
- Crevasse splay (or splay "fan"):
  . Lower-lying triangular position, formed following a rupture occurring at the disjunction of two splay axes. Crevasse splay material fills in pre-existing concave basin positions.
  . Sandy material (loamy sand and sandy loam), coarser than the splay axis and mantle deposits because of the energy concentration taking place along the axis rupture gap; moderately well to imperfectly drained.
- Basin positions (overflow and decantation) increase in extension in the frontal sector of the system.

* Drowned system

In many valleys of tectonic origin, the lower stretches are frequently submitted to a gradual subsidence trend and are therefore occupied almost exclusively by basin positions. The spatial structure of such a type of depositional system has not yet been well documented.

b) Model structure of a fluvio-depositional system

A structural model of a generalized fluvio-depositional system can be derived from the spatial composition of the system types previously analyzed. A double spatial hierarchization of geomorphic positions (= landforms in this case), both longitudinal and transverse, controls the general structure of a fluvio-depositional system (Fig. 48).

Figure 44 _ VALLEY DEPOSITIONAL SYSTEM

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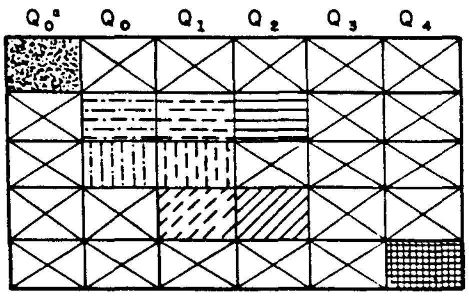
ALLUVIAL SEDIMENTS (LONGITUDINAL DEPOSITS)

Recent flood deposits
River levee
Overflow mantle
Overflow basin
Splay mantle



COLLUVIAL SEDIMENTS (LATERAL DEPOSITS)

Q_0-Q_1 Q_0-Q_2 Q_0-Q_3 Q_0-Q_{3-4}

Terrace riser

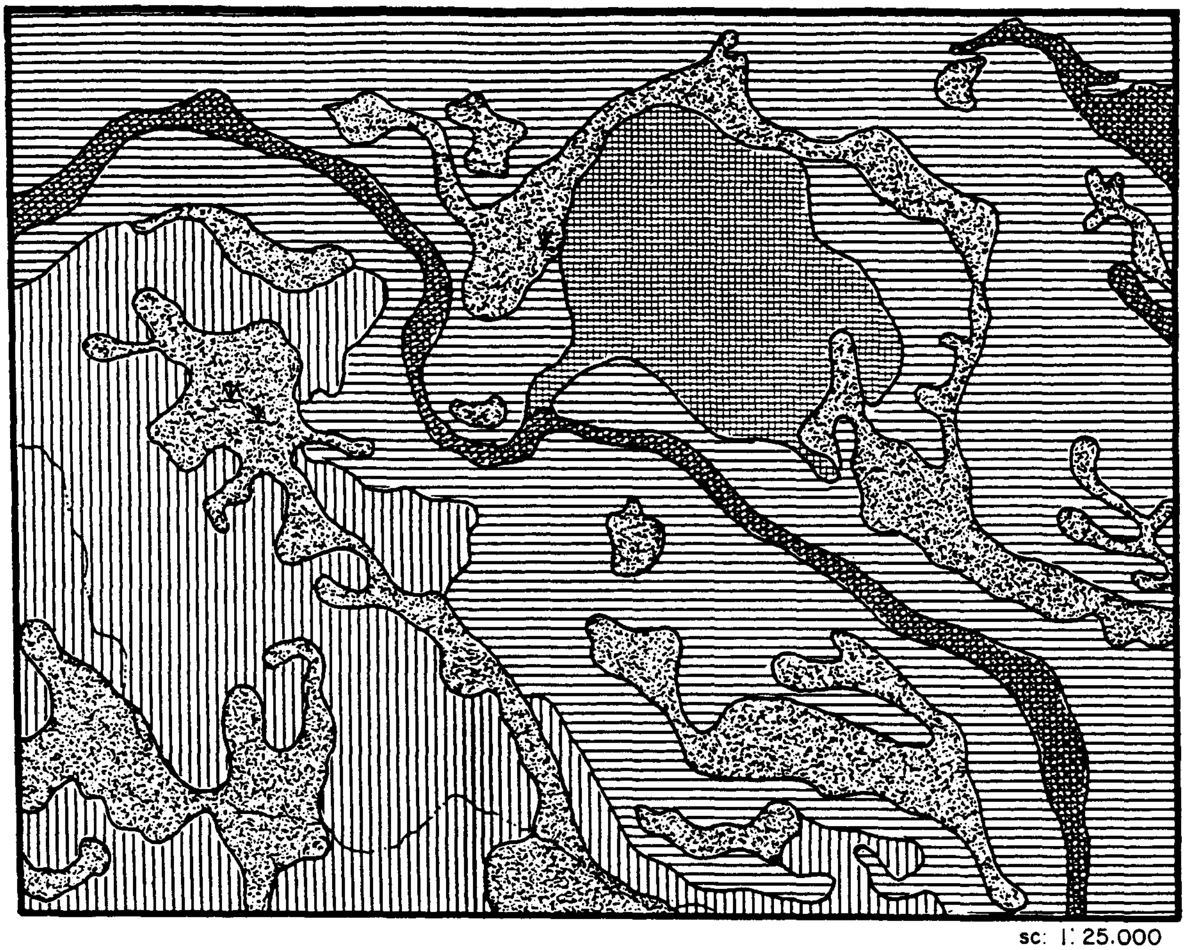
Terrace scarp

COMMENT: Strip of young alluvial deposits (mainly Holocene and Upper Pleistocene), flanked on both sides of the valley by colluvial deposits in continuous aggradation (stepped colluvial glacis and in-filled colluvio-alluvial vales).

SOURCE : Extract of a soil series map at 1:25.000 scale.
A. Zinck and P.L. Urriola - Soil survey report, Guarapiche river valley, Venezuela (1970).

A. Zinck, 1970.

Figure 45 - FLUVIO-DELTAIC DEPOSITIONAL SYSTEM



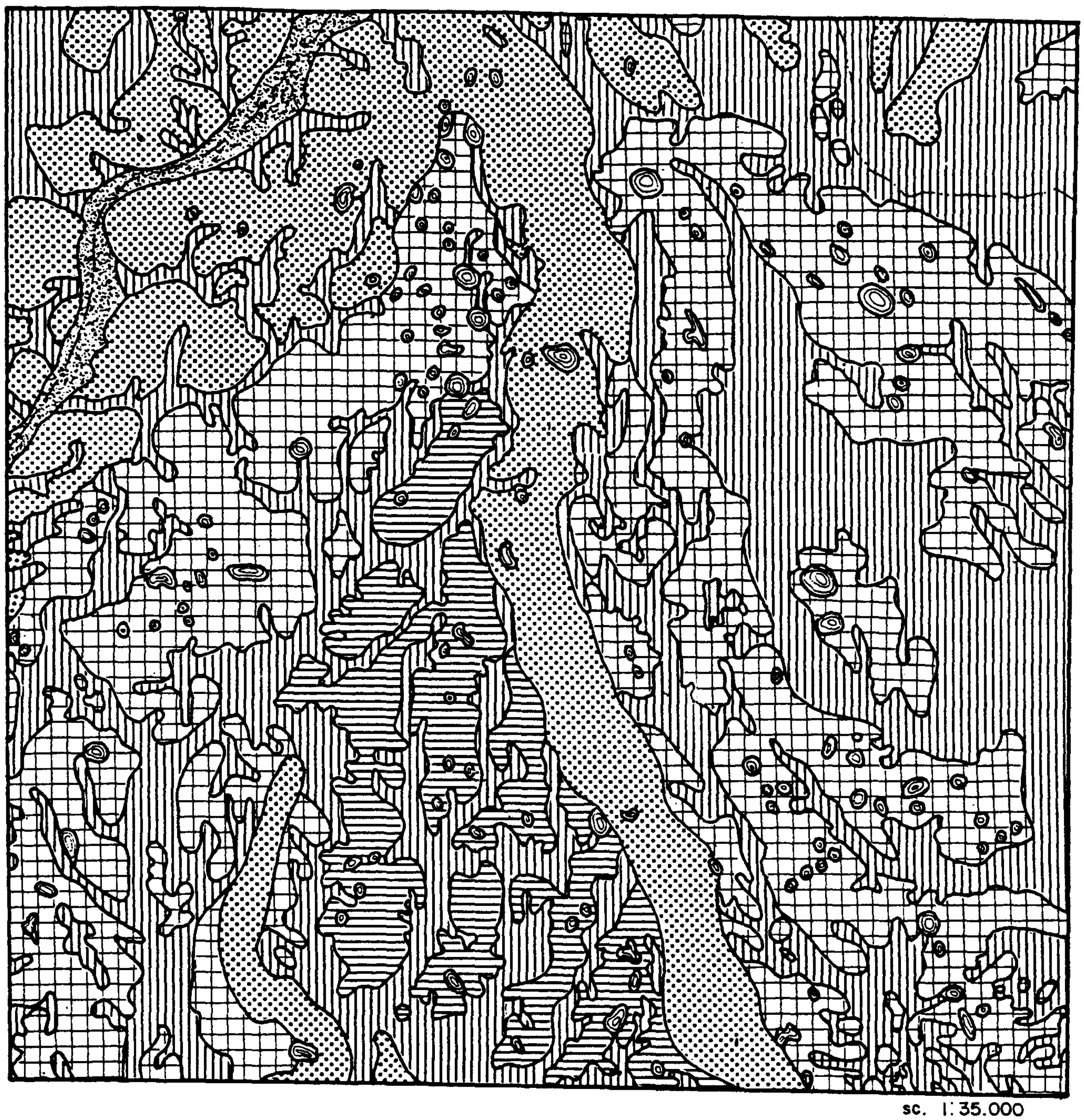
- Deltaic levee Q1
- Crevasse splay Q1
- Overflow mantle Q1
- Overflow mantle Q2
- Overflow basin Q2

COMMENT: Recent deltaic system (mainly Q1 with local extensions into Q0), overlying an older depositional system (Q2). The map extract shows a contact area between the two successive alluvial cover formations. The younger deltaic accumulation surface expanded by invading the lower-lying depressional areas of the older one, out of which some remnants subsist as spatial inclusions. The connection between the deltaic levee and the crevasse splay as well as the triangular configuration of the latter can be easily noticed.

SOURCE : Extract of a soil series map at 1:25.000 scale.
J. Pèrez Materàn - Soil survey report, Santo Domingo river plain, Venezuela (1967).

A. Zinck, 1970.

Figure 46 _ SPLAY DEPOSITIONAL SYSTEM



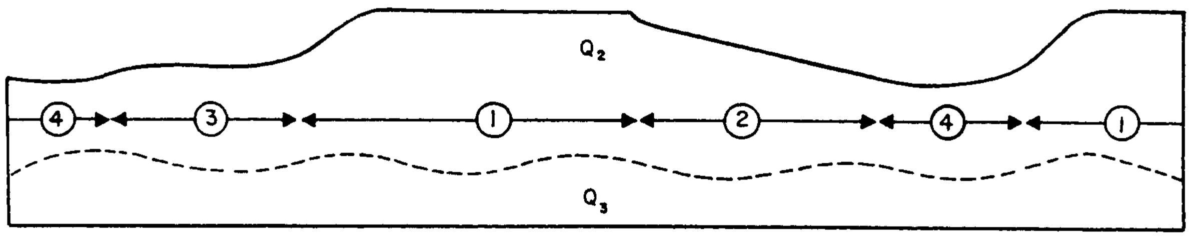
- Splay axis Q2
- Crevasse splay Q2
- Overflow mantle Q2
- Overflow basin Q2
- Floodplain Q0-Q1
- Lagoon (suffosion depression)

COMMENT:
- Local ruptures at the disjunction of two splay axes originating a crevasse splay (head of the crevasse splay).
- Gradual dismantling of the original depositional configuration through regressive erosion by small floodplain streams (NW corner)

SOURCE:
Extract of a soil series map at 1:35.000 scale.
A. Zinck and P. Stagno - Soil survey report, Santo Domingo-Saguey plain, Venezuela (1966).

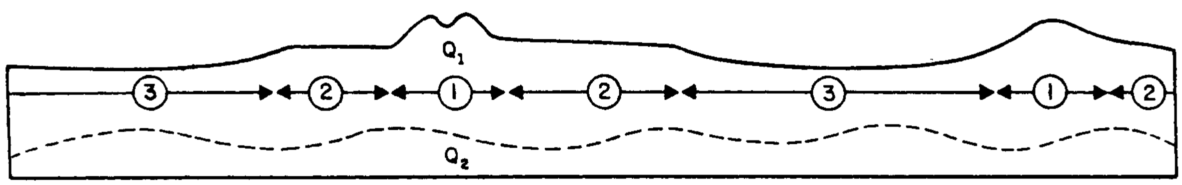
A. Zinck, 1970.

Figure 47 - CROSS-SECTIONS THROUGH THREE ALLUVIAL DEPOSITIONAL SYSTEMS
VENEZUELAN LLANOS PLAIN



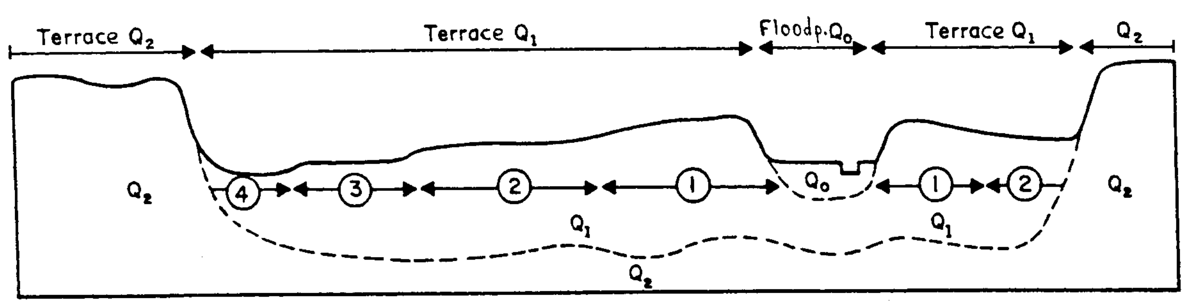
Splay system Q2 - Santo Domingo river

(1) Splay axis: Barinas series (sl - scl)
(2) Crevasse splay: Garza series (sl)
(3) Overflow mantle: Gasperi series (sil - sicl)
(4) Overflow basin: Jaboncillo series (sic - c)



Deltaic system Q1* - Boconó river

(1) Deltaic levee: Boconó series (s - ls)
(2) Overflow mantle: Fanfurria series (l - sil - sicl)
(3) Overflow basin: Mendez series (sic-c)
* Local extension of sedimentation into QO^b period



Valley system Q1 - Guarapiche river

(1) River levee: San Felix series (sl - scl)
(2) Overflow mantle: Santo Domingo series (sil - sicl)
(3) Overflow basin (lateral basin): Canaguaima series (sic - c)
(4) Decantation basin (marginal basin): Matutes series (c)

Note: Textures refer to parent materials

A. Zinck, 1970.

* Longitudinal hierarchization

The longitudinal hierarchization is based on the presence of three spatially and dynamically related depositional sectors:

- Apical or proximal sector:
  . Weak individualization of specific landforms.
  . Mainly formed by generalized splay deposits.

- Central or trunk sector:
  . Maximum individualization of landforms: broad variety of landforms showing conspicuous configuration, having high internal homogeneity and clear spatial relationships.
  . Types of landform present: levees, splay axis, overflow and splay mantles, overflow basin.

- Frontal or distal sector:
  . Moderate individualization of landforms: spatial haploidization increases along the rim of the depositional system, where fine sediments become predominant.
  . Overflow and especially decantation basins cover extensive parts of the frontal sector; they are frequently invaded by frontal crevasse splays originating from breaking of deltaic levees.

* Transverse hierarchization

Transversely, a fluvio-depositional system is characterized by three types of geomorphic positions going from the main stream to the margin of the system:

- Matric or axial positions: levees, axes.
- Lateral positions: mantles, benches, "fans".
- Marginal positions: basins.

c) Conclusion

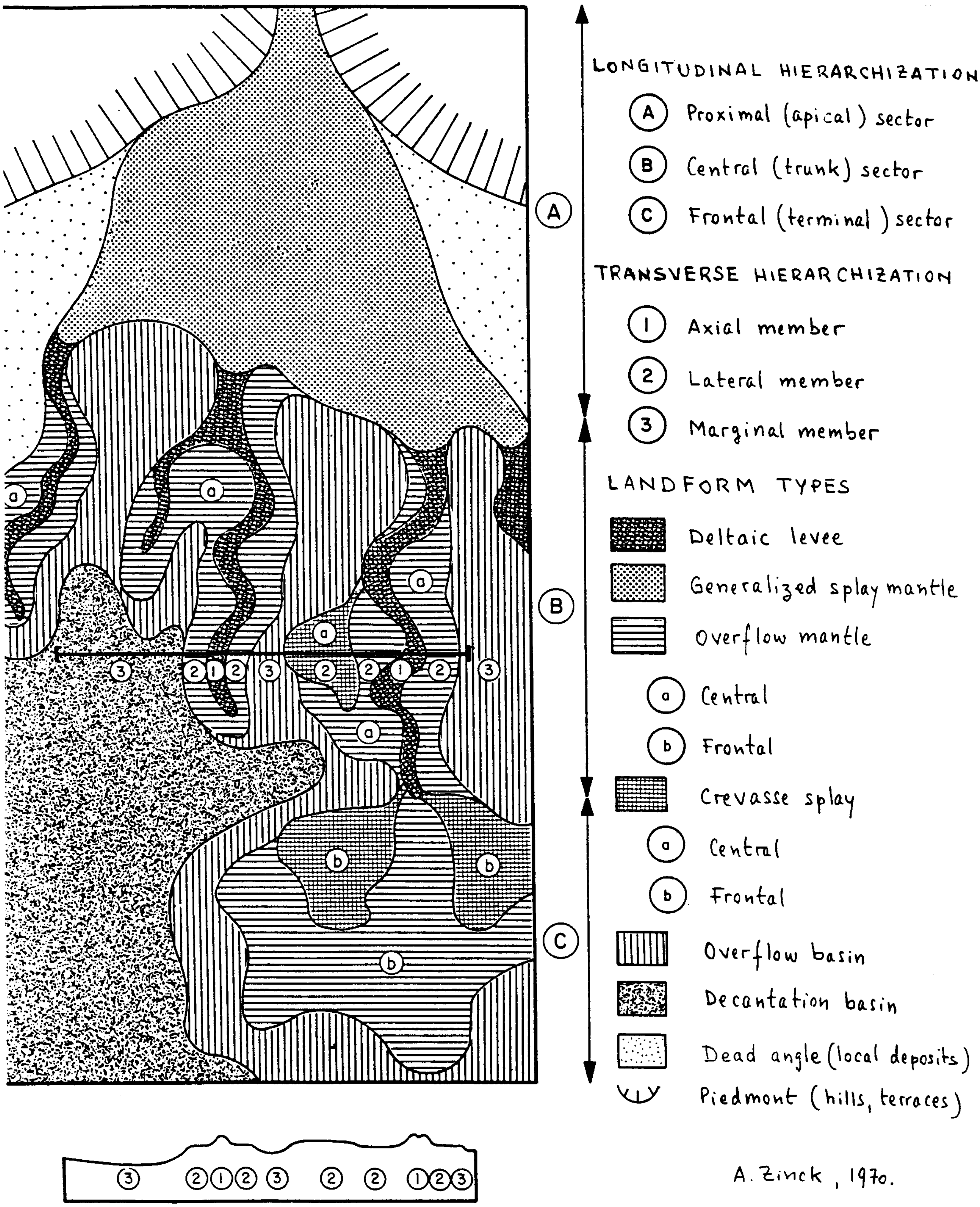
The examples displayed are extracts of real soil maps using geopedologic approach. They show an intimate linkage between geomorphic and soils units as to their properties and geographic distribution.

Table 32 - RELATIONSHIPS BETWEEN ALLUVIAL LANDFORMS AND SOILS

TYPE OF LANDFORM ATTRIBUTES	TYPE OF RELATIONSHIPS	PREDOMINANT CONTRIBUTION Landform Soil
Morphographic (geometry of landforms) Morphometric (dimension of landforms)	Soil cartography	——————→
Morphogenetic (dynamics of landforms) (a) Fluvial facies (b) Fluvio-depositional system	Soil genesis (a) Soil parent material (litho.) (b) Soil geography (topo.)	——————→
Morphochronologic (history of landforms)	Soil stratigraphy (chrono.)	←——————

A. Zinck, 1970

Fig. 48 - SPATIAL STRUCTURE AND HIERARCHIZATION OF AN ALLUVIAL DEPOSITIONAL SYSTEM



A. Zinck, 1970.

VI. SYSTEM VALIDATION

Two main aspects are addressed here to validate the geomorphic classification system:

- evaluation of the system efficiency in warranting consistency of the taxonomic units and purity of the cartographic units;
- evaluation of geoform - soil relationships models.

A. SYSTEM EFFICIENCY

1. INTRODUCTION: HOW TO EVALUATE SYSTEM EFFICIENCY?

a) By its implementation through photo-interpretation and on the field for soil mapping. If the system contributes to easier and better soil grouping into more homogeneous mapping units, allowing to improve predictions on soil behavior and suitability, then it may be considered as efficient (see physiographic analysis in API).

b) By comparison with a reference system, allowing to validate the classification results and calibrate the parameters used for it. For that end, numerical classification is a good instrument for being:
   - neutral : the objective is to group by similarity, in the least biased way, objects belonging to the same universe;
   - numerical: the classification operates on the basis of quantitative or quantified parameters.

   By this way, the consistency (or purity) of the taxonomic units can be evaluated.

c) By purity control of the mapping units using geostatistical techniques.

2. NUMERICAL CLASSIFICATION AND TAXA CONSISTENCY

a) Introduction

- The method has been created about the middle of the 18th century by the botanist Adanson, working contemporarily to Linneus. Its original objective was to classify plants taking into account all their observed characteristics and giving them equal weight. The attempt was not successfully accepted at that time, but recently the method has been applied to a wide range of disciplines such as experimental floristics, petroleum geology, microbiology and also soil taxonomy as a means for creating and calibrating taxonomic classes.

- Referring to the soils field, the use of the method was particularly in fashion during the epoch in which the new Soil Taxonomy was established and tested (1960-1975). There was a need for creating new classes and determining their limits as well as for calibrating existing ones. Scientists such as Arkley, Arneman, Bidwell, Grigal, Hironaka, Hole, Rayner and others used actively numerical classification for that purpose.

- The basic theory and calculation techniques are presented in: R. Sokal and P. Sneath - Principles of numerical classification.

b) <u>An example: the method applied</u>

Numerical classification is applied to 24 soil-geomorphic profile materials (Guarapiche river valley, NE of Venezuela), in order to determine the efficiency with which the soil classification and the geomorphic classification respectively operate to separate taxonomic units. The efficiency is evaluated by comparison with the units generated by numerical classification and taken as reference units.
The method applied consists of successive steps as follows.

- Selection of the characteristics:
  . The widest number possible in order to approach the complexity of the soil and geomorphic material composition.
  . Redundancy between related characteristics such as CEC + sum of exchangeable bases + exchangeable acidity (one parameter is in excess) is avoided. Redundancy may reinforce the weight of a characteristic taken into account more than once.
  . Only material characteristics are selected and morphographic attributes are purposely excluded, in order to avoid reinforcing the geomorphic classification as compared to the soil classification. The assumption is made here that the same characteristics may be used for describing a pedogenetic material as well as a parent material (= geomorphic material).
  . Finally 25 characteristics are selected.

- **Coding of the attributes:**

  Soil characteristics presenting several states but no ranges are difficult to code (e.g. structure types). In the case of structure, an ordering of the types has been established on the basis of assumed genetic development (from minor to major).

- **Standardization:**

  For the purpose of comparing the selected profiles, several options can be used. An appropriate one consists of comparing horizons, either genetic ones, or diagnostic ones, or standardized ones. The last solution is chosen because it allows for a weighting out of the quantitative/ quantified attributes. Standardized horizons 25 cm thick are used.

- **Normalization:**

  All attribute values are normalized (0-100) with proportional redistribution of the values between the minimum value (= 0) and the maximum value (= 100).

- **Calculation of the similarity indices:**

  The similarity index of Sörensen is used:

$$Is = \frac{2C}{A+B}$$

  where: Is = similarity index

  A = sum of all attribute values concerning profile A

  B = sum of all attribute values concerning profile B

  C = sum (x2) of the attribute values for which profiles A and B are similar

- **Establishment of the similarity matrix:**

  Shows the similarity index of each profile pair.

  See Fig. .

- **Clustering of the profiles:**

  Clustering is done using the single linkage method. Grouping starts with the profile pair having the highest Is, to which the next highest related Is is joined and so successively. After each clustering step, a new Is is calculated using single arithmetic mean.

- **Dendrogram:**
  Profile clusters are graphically displayed on a dendrogram allowing to show phenetic relationships (Fig. 49).

- **Calculation of mean similarities:**
  . Mean similarity per profile cluster ($\bar{r}$) allows to estimate the internal homogeneity of each cluster.
  . General (weighted) mean similarity ($\bar{R}$) allows: (1) to estimate the general level of similarity for the whole population of profiles, and (2) to compare the efficiency of various classification systems.

- **Comparison of the various classification systems by means of $\bar{R}$**

c) Results of the experiment

The experiment provides two main outputs:
- an estimation of the profile clustering efficiency,
- a determination of classes and hierachization of attributes.

(1) Profile clustering efficiency

* Numerical classification
  - Similar homogeneity in all clusters generated by numerical classification.
  - Mean similarity at about 75%.

* Soil classification
  - At Order level:
    . ample variation: $\bar{r}$ from 53% to 83%
    . in some Orders clustering works well, in others less well (the ones including more heterogeneous properties)
    . $\bar{R}$ = 66%
  - At Suborder level:
    The clustering is somewhat more homogeneous:
    . $\bar{r}$ = 64-84%
    . $\bar{R}$ = 72%
  - At Great Group level:
    The homogeneity of the clustering is similar to the one of the Suborder level:

. $\bar{r}$ = 64-84%

. $\bar{R}$ = 72%

- At the Subgroup level:

  Comparison is not possible because the selected profiles belong to many different Subgroups.

* Geoform classification

- Pedostratigraphic units:

  The phenetic levels of clustering are very similar to the ones shown by the soil Orders:

  . $\bar{r}$ = 55-75%

  . $\bar{R}$ = 67%

- Landforms:

  The clustering is better than for the Great Groups of soils:

  . $\bar{r}$ = 68-83%

  . $\bar{R}$ = 75%

* Global comparison

NUMERICAL CLASSIFICATION

8 primary groups: $\bar{R}$ = 75.3%

GEOMORPHIC CLASSIFICATION

11 landform types: $\bar{R}$ = 74.8%

SOIL CLASSIFICATION

9 great groups: $\bar{R}$ = 72.9%

* Conclusion

- Mean similarities reached by all 3 classification systems are not substantially different.
- Mean similarities are high, indicating that all 3 systems are efficient and generate relatively homogeneous profile clusters.
- The mean similarity of the geoform classification is nearer to the reference similarity (numerical classification) than the mean similarity of the soil classification. Therefore, geomorphology can help improve soil classification and mapping.

Table 33 - SELECTED SOIL CHARACTERISTICS FOR NUMERICAL CLASSIFICATION

1. - Sand fraction (%)
2. - Clay fraction (%)
3. - Moist color hue
4. - Moist color value
5. - Moist color chroma
6. - Reduction mottles with chromas ⩽ 2 (%)
7. - Oxidation mottles (%)
8. - Plinthite (%)
9. - Structure type
10. - Structure grade
11. - Size of cracks (mm)
12. - Slickensides (presence or absence)
13. - Hardness
14. - Friability
15. - Stickiness
16. - Plasticity
17. - Clay-skins
18. - $CaCO_3$ nodules (%)
19. - Sesquioxides nodules (%)
20. - Soil reaction (pH water 1:1)
21. - Bases saturation (%)
22. - CEC by sum of cations (me/100 gr soil)
23. - $CaCO_3$ eq. %
24. - Organic carbon (%)
25. - Electric conductivity (mmhos/cm)

A. Zinck, 1982.

Table 34 _ MATRIX OF SIMILARITY INDICES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	1,00	0,710	0,392	0,317	0,793	0,606	0,539	0,746	0,649	0,607	0,547	0,473	0,661	0,476	0,514	0,507	0,460	0,458	0,467	0,397	0,443	0,548	0,490	0,497	0,468	0,498
2		1,00	0,397	0,335	0,740	0,577	0,584	0,780	0,709	0,663	0,595	0,521	0,603	0,549	0,555	0,455	0,426	0,428	0,442	0,422	0,475	0,437	0,407	0,442	0,313	0,352
3			1,00	0,700	0,382	0,624	0,555	0,308	0,233	0,342	0,228	0,185	0,334	0,441	0,225	0,287	0,272	0,253	0,308	0,209	0,227	0,386	0,292	0,659	0,444	0,522
4				1,00	0,319	0,576	0,572	0,253	0,184	0,330	0,196	0,218	0,411	0,263	0,247	0,300	0,309	0,264	0,361	0,246	0,266	0,419	0,295	0,561	0,415	0,437
5					1,00	0,623	0,579	0,246	0,775	0,683	0,628	0,527	0,711	0,562	0,557	0,568	0,536	0,537	0,515	0,458	0,516	0,596	0,552	0,487	0,484	0,503
6						1,00	0,748	0,513	0,463	0,618	0,443	0,426	0,647	0,432	0,472	0,369	0,476	0,472	0,494	0,403	0,443	0,612	0,492	0,722	0,557	0,592
7							1,00	0,536	0,456	0,628	0,445	0,484	0,636	0,449	0,488	0,511	0,503	0,497	0,557	0,442	0,455	0,532	0,485	0,615	0,486	0,503
8								1,00	0,878	0,728	0,719	0,604	0,648	0,623	0,632	0,584	0,540	0,555	0,529	0,514	0,577	0,566	0,542	0,411	0,443	0,444
9									1,00	0,700	0,746	0,624	0,628	0,652	0,638	0,567	0,522	0,554	0,495	0,535	0,600	0,534	0,536	0,345	0,414	0,406
10										1,00	0,726	0,686	0,719	0,644	0,702	0,642	0,648	0,654	0,614	0,582	0,655	0,623	0,620	0,492	0,533	0,519
11											1,00	0,683	0,600	0,756	0,673	0,594	0,554	0,600	0,524	0,606	0,653	0,501	0,551	0,338	0,435	0,379
12												1,00	0,533	0,714	0,791	0,616	0,559	0,607	0,563	0,726	0,741	0,484	0,602	0,327	0,440	0,373
13													1,00	0,558	0,595	0,731	0,680	0,666	0,644	0,546	0,556	0,733	0,667	0,622	0,610	0,617
14														1,00	0,648	0,569	0,520	0,539	0,506	0,615	0,630	0,482	0,523	0,336	0,401	0,347
15															1,00	0,628	0,586	0,609	0,302	0,771	0,768	0,533	0,627	0,351	0,464	0,402
16																1,00	0,811	0,810	0,740	0,657	0,638	0,743	0,788	0,471	0,632	0,603
17																	1,00	0,819	0,785	0,632	0,614	0,743	0,798	0,448	0,624	0,586
18																		1,00	0,745	0,663	0,678	0,597	0,781	0,421	0,606	0,556
19																			1,00	0,663	0,612	0,703	0,694	0,465	0,568	0,529
20																				1,00	0,828	0,532	0,689	0,320	0,524	0,417
21																					1,00	0,618	0,665	0,310	0,530	0,412
22																						1,00	0,743	0,565	0,644	0,678
23																							1,00	0,445	0,668	0,599
24																								1,00	0,587	0,694
25																									1,00	0,763
26																										1,00

A. Zinck, 1972.

Table 35. MEAN SIMILARITIES OF THE PRIMARY GROUPS GENERATED BY NUMERICAL CLASSIFICATION

Groups	Profiles	Levels of similarity %
1	20-21	82,8
2	12-15	79,1
3	25-26	76,3
4	11-14	75,6
5	8-9-5- 1-2-10	74,0
6	17-18-16-23- 19-22-13	73,6
7	3-4	70,0
8	6-7-24	69,6

Weighted general mean similarity $\bar{R}$: 75,3%

Table 36. MEAN SIMILARITIES OF SOIL ORDERS

Orders	Profiles	Levels of similarity %
Entisols	1-3-4- 24-25-26	53,2
Inceptisols	2-6-7-10- 11-12-14	59,1
Mollisols	5-8-9	83,5
Alfisols	13-15	59,5
Ultisols	16-17-18-19- 20-21-22-23	71,0

A. Zinck, 1972.

Weighted general mean similarity $\bar{R}$: 65,8%

Table 37 _ MEAN SIMILARITIES OF SOIL SUBORDERS

Suborders	Profiles	Levels of similarity %
Psamments	3-4-24	64,1
Orthents	25-26	76,3
Tropepts	2-6-7-10	63,8
Aquepts	11-12	68,3
Ustolls	5-8-9	83,5
Ustults	16-17-18- 22-23	76,5
Aquults	19-20-21	70,6

Weighted general mean similarity $\bar{R}$: 72,1%

Note: Fluvents (1), Aqualfs (1), Usterts (1) not included

Table 38 _ MEAN SIMILARITIES OF GREAT SOIL GROUPS

Great Groups	Profiles	Levels of similarity %
Ustipsamments	3-4-24	64,1
Ustorthents	25-26	76,3
Ustropepts	2-10	66,3
Dystropepts	6-7	74,8
Tropaquepts	11-12	68,3
Haplustolls	5-8-9	83,5
Paleustults	16-22	74,3
Plinthustults	17-18-23	80,0
Plinthaquults	19-20	66,3

A. Zinck, 1972.

Weighted general mean similarity $\bar{R}$: 72,9%

Note: Ustifluvents (1), Haplustalfs (1), Tropaqualfs (1), Paleaquults (1), Chromusterts (1) not included

Table 39 _ MEAN SIMILARITIES OF CHRONOSTRATIGRAPHIC UNITS

Chronostratigraphic units		Profiles	Levels of similarity %
Holocene	Q0	1-2	71,0
Pleistocene			
Upper	Q1	3-4-5-6-7-8-9-10-11-12	54,6
Late middle	Q2	13-14-15	60,1
Early middle	Q3	16-17-18-19-20-21	71,6
Lower	Q4	22-23	74,3
Variable (colluvium)		24-25-26	68,3

Weighted general mean similarity $\bar{R}$: 66,8%

Table 40 _ MEAN SIMILARITIES OF LANDFORMS

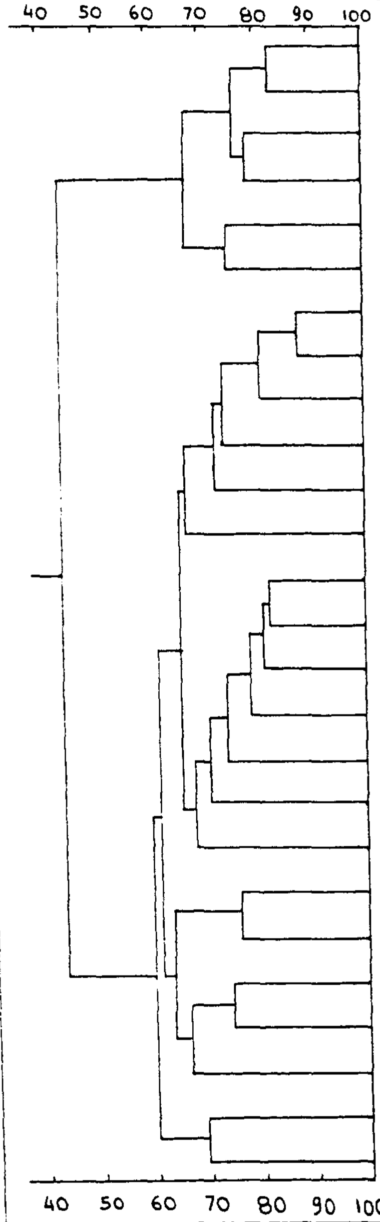
Landforms		Profiles	Levels of similarity %
Q0 + Q1	Deltaic levee	3-4	70,0
	River levee	1-5	79,3
	Splay mantle	6-7	74,8
	Overflow mantle	2-8	78,0
	Overflow basin	9-10	70,0
	Decantation basin	11-12	68,3
Q3	Splay axis	16-17	81,1
	Splay mantle	18-19	74,5
	Basin	20-21	82,8
Q4	Splay mantle	22-23	74,3
	Colluvial glacis	24-25-26	68,3

A. Zinck, 1972.

Weighted general mean similarity $\bar{R}$: 74,8%

Fig. 49 - SOIL DENDROGRAM - GUARAPICHE RIVER VALLEY - VENEZUELA

PHENETIC CLUSTERS
% Similarity



SOIL SUBGROUPS	LANDFORMS: Position	Relative age	Text.par.mat.
20 Typic Plinthaquult	Overflow basin	Q3	sic
21 Plinthic Umbric Paleaquult	Decantation basin	Q3	vfc
12 Aeric Tropaquept	Decantation basin	Q1	vfc
15 Aeric Tropaqualf	Overflow basin	Q2	sic
11 Vertic Tropaquept	Decantation basin	Q1	sic-c
14 Salic Entic Chromustert	Overflow basin	Q2	sic
8 Cumulic Haplustoll	Overflow mantle	Q1	sil-sicl
9 Cumulic Haplustoll	Overflow basin	Q1	sic
5 Cumulic Haplustoll	River levee	Q1	sl-scl
1 Typic Ustifluvent	River levee	Qob	sl
2 Fluventic Ustropept	Overflow mantle	Qob	sil-sicl
10 Fluvaquentic Ustropept	Overflow basin	Q1	sic
17 Epiaquic Plinthustult	Splay axis	Q3	sl-scl
18 Typic Plinthustult	Splay mantle	Q3	l-scl
16 Plinthic Paleustult	Splay axis	Q3	sl-scl
23 Oxic Plinthustult	Crevasse splay	Q4	sl-scl
19 Typic Plinthaquult	Splay mantle	Q3	sl-scl
22 Oxic Paleustult	Splay mantle	Q4	sl-scl
13 Udic Haplustalf	Splay mantle	Q2	sl-scl
25 Typic Ustorthent	Colluvial glacis	Q0-Q3	ls-sl
26 Typic Ustorthent	Colluvial glacis	Q0-Q3-4	ls
6 Ustifluventic Dystropept	Splay mantle	Q1	sl-l
7 Aquic Dystropept	Splay mantle	Q1	sl-l
24 Alfic Ustipsamment	Colluvial glacis	Q0-Q2	ls
3 Typic Ustipsamment	Deltaic levee	Q1	ls
4 Aquic Ustipsamment	Deltaic levee	Q1	s-ls

A. Zinck, 1972.

(2) Class determination and attribute hierarchization

* Attribute weight

The dendrogram shows 4 main profile clusters highlighting the following factors:

- drainage/topography;
- relative age of the parent materials;
- origin of the parent materials, distinguishing in particular between fresh and reworked materials.

These are precisely the 3 soil forming factors, out of the 5 state factors (H. Jenny), which derive directly from the geomorphic context. Therefore geomorphic attributes, whether morphographic, morphogenetic or morphochronologic, have high weight for soil clustering.

* Differential hierarchization of attributes

The dominant differentiating factor varies from cluster to cluster.

d) Constraints

- Numerical classification is not an operational system. It is suitable for conducting research on class identification and calibration but not for systematic application. Each time an additional profile is added to the population, all similarity indices have to be recalculated, leading frequently to changes in the existing clusters.
- The classification is not totally objective (e.g. coding of structure types).

3. GEOSTATISTICS AND PURITY OF MAPPING UNITS

a) Basic principles

- Geostatistics refer to statistical techniques which take into account the spatial variability of attributes. It is based on the theory of regionalized variables of Matheron (1971), as applied to geology. As applied here, the purpose is to describe and analyze lateral and vertical variability (spatial anisotropy) of soil and geomorphic properties.

- Geostatistics can be implemented in relation to two cartographic aspects:

. The delineation of mapping units by interpolation between observation points (grid system), where and when boundaries cannot be reliably traced by conventional approach using physiographic and geomorphic criteria by means of photo-interpretation and field exploration.
. The purity of the mapping units by establishing, through grid survey of sample areas, the precise range of variation of main properties.

- Statistical techniques used:
  . Semi-variance = spatial variance of properties between observation points
  . Semi-variogram = basis for interpolation
  . Kriging = interpolation technique.

b) <u>An application example</u>

- Taken from A. Bregt, J. Bouma and M. Jellinck - Comparison of thematic maps derived from a soil map and from kriging of point data. Geoderma 39 (1987): 281-291.

- Method applied:
  . Systematic (grid) checking of a previously established soil map.
  . Calculation of the (partial) purity of three individual soil properties:
    (1) thickness of the A horizon,
    (2) starting depth of gravel layer,
    (3) starting depth of boulder clay.
  . Calculation of the average purity.
  . Purity = % of agreement between test-boring data and data according to the legend of both maps, the conventional one and the systematic one (= quality control).

- Results:

Table 41 -

Validation of the thematic map derived from the soil map and the kriged thematic map, based on comparison between data from 60 independent borings (locations indicated in Fig. 1) and the corresponding units of the two maps (the 90% confidence interval is given in brackets).

Purity measure	Thematic map	
	derived from soil map	kriged
Partial purity: thickness A horizon (%)	80 (68-92)	83 (71-95)
Partial purity: starting-depth of gravel (%)	83 (77-89)	86 (75-97)
Partial purity: starting-depth of boulder clay (%)	68 (57-69)	61 (51-71)
Average purity: all data (%)	77 (72-82)	77 (69-85)

Fig 50 - COMPARISON OF THEMATIC SOIL MAPS

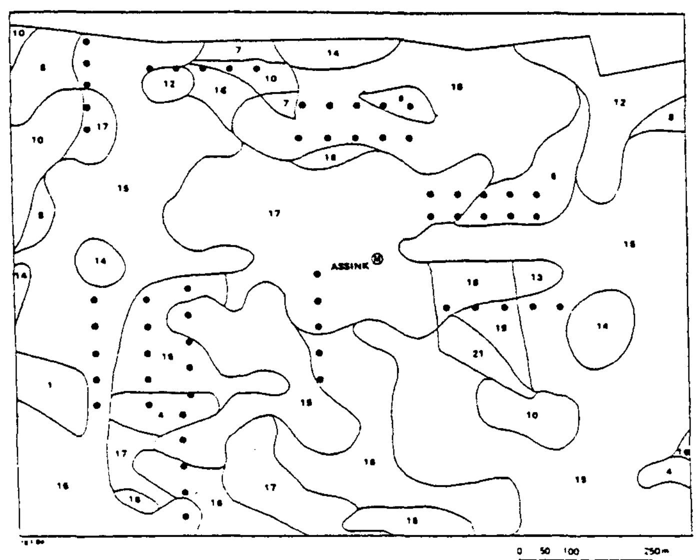


Fig. 1. Thematic map derived from the soil map (map 1) of the study area of 125 ha (legend in Table I); the locations of the 60 test borings are indicated.

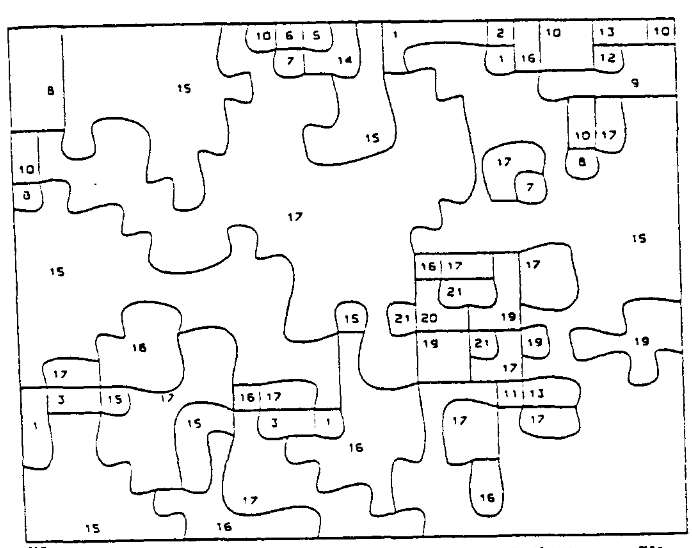


Fig. 2. Kriged thematic map (map 2) of the study area of 125 ha (legend in Table I).

A.K. Bregt et al., 1987.

c) Conclusion

One of the most important factors contributing to the purity of mapping units is the geomorphic one, which controls many soil properties through the nature of parent material and the time context. A soil map established using geomorphic criteria warrants a relatively high purity of the mapping units. The survey technique based on pre-selected observation points, using geomorphology through aerial photo-interpretation, is the most efficient one in operational surveys.

d) Other examples to be developed

- J. Viloria - Valencia Basin, Venezuela
- P.H.T. Beckett
- G. Elizalde

B. RELATIVITY OF THE GEOPEDOLOGIC MODELS

- The relationships between geomorphology and soil survey are based on the fact that three out of the five soil forming factors are intrinsic components of the geomorphic medium: topography, parent material and time.
- Combinations between these three factors may be very diverse and vary enormously from one site to another.
- In spite of this variability, relationship models can be established on the basis of regional or local factor combinations. Some of these models may be relatively simple, others are more complex.

1. SIMPLE RELATIONSHIP MODELS

They allow to sort out one of the three forming factors as variable and to keep the other two ones relatively constant.

a) Pedostratigraphic models (chronosequences)

* High pedodifferentiation: Guarapiche river valley (Venezuela)
  - Environmental conditions:
    . Clearly diversified terrace system covering the whole Quaternary
    . Ustic regional moisture regime (high soil differentiation power)

. Longitudinal supply of calcium carbonate (but no lateral)

. Encased terrace system (low lateral contamination of chemical components)

. No calcareous valley relief mold (Mesa Formation).

- These conditions have originated a large soil differentiation model according to factor time, including:

. Four main general pedogenetic thresholds

. Three main clay formation thresholds, especially evident for the older soil generations

. Eight different soil Orders are represented.

* <u>Moderate pedodifferentiation</u>: Neveri river valley (Venezuela)

- Environmental conditions:

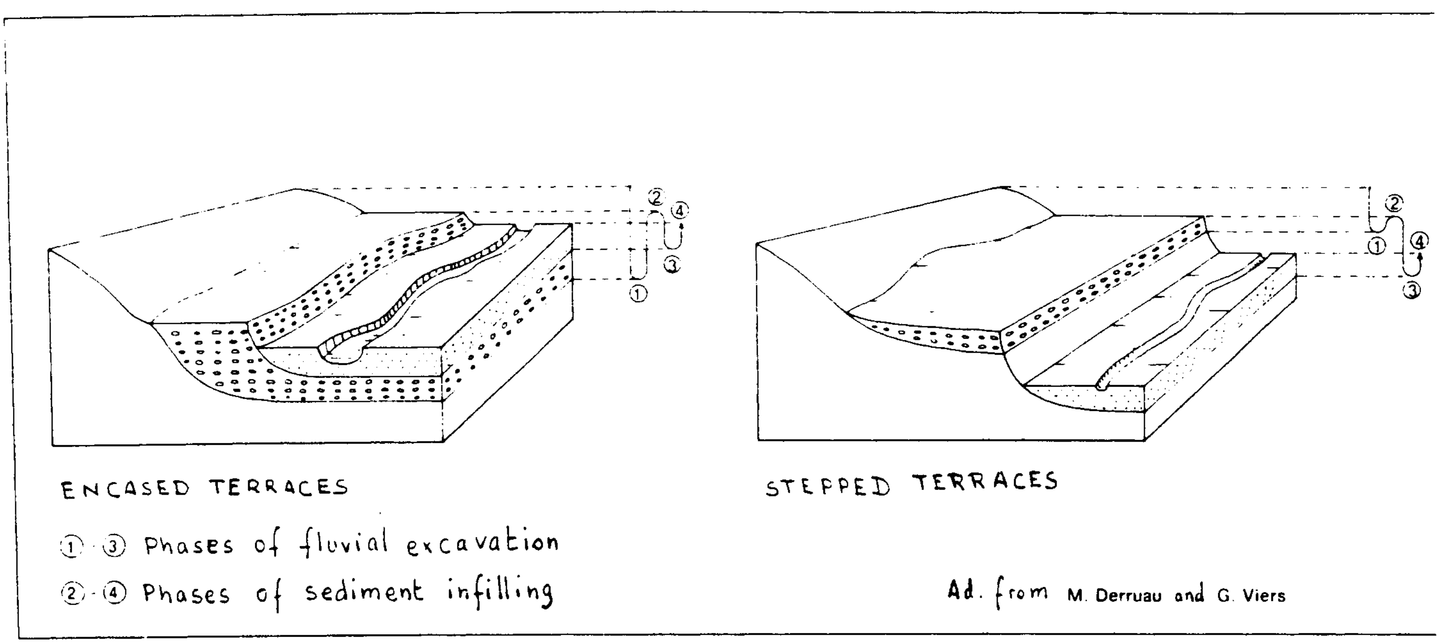
. Diversified set of terraces, stepped but not encased

. Ustic regional moisture regime

. Calcareous valley relief mold (marls).

- Moderate pedodifferentiation according to factor time. The richness in and continuous supply of calcium carbonate from marly valley relief mold contribute to stop soil evolution at the level of Alfisols.

Fig. 5 - TWO SYSTEMS OF FLUVIAL TERRACES AND THEIR MODES OF FORMATION



A. Zinck, 1980.

* Low pedodifferentiation: Quibor depression (Venezuela)
  - Environmental conditions:
    . Aridic regional moisture regime
    . High provision of calcium carbonate.
  - The lack of moisture inhibits soil evolution and differentiation:
    . Recent soils are mainly Torriorthents (Qo)
    . Soils formed from older depositional materials (Q1 and Q2) are mainly Camborthids. Soils on Q2 have Bt horizon but not argillic (cambic)
    . Clay mineralogy (D. Malagon) shows an ubiquitous species association of:
    Mica >> quartz > chlorite > kaolinite, talc, calcite > feldspar > stratified and expandible clays.
    This clay mineral association is the same in the soils, soil parent materials, and rocks of the higher watersheds (lutites and marls).

* Low pedodifferentiation: Cauca river valley (Colombia) (Fig. 52).
  - Environmental conditions:
    . Udic regional moisture regime: 2000-4000 mm of annual rainfall in spite of a dry period of 4 months
    . Evergreen forest vegetation.
  - Soil haploidization due to the effect of constant moisture (and high temperatures) on soil evolution:
    . Sequence of highly evolved but weakly differentiated soils covering the whole span of the Quaternary (Ultisols and Oxisols)
    . Clay mineralogy: kaolinite is dominant even in the most recent terrace soils.

* Conclusion: influence of the climate factor on soil chronosequence models
  - Ustic regime = highly pedodifferentiating; the alternating of dry and moist periods favors soil physico - chemical processes (soil structuration, leaching, etc.).
  - Aridic regime: soil homogeneization due to low moisture availability; soil properties reflect intimately parent material properties.
  - Udic regime: soil homogeneization due to moisture excess favoring strong weathering and leaching. Soil material evolved for away from original parent material.

Fig. 52 - SOIL CHRONOSEQUENCE ALONG THE CAUCA RIVER - COLOMBIA

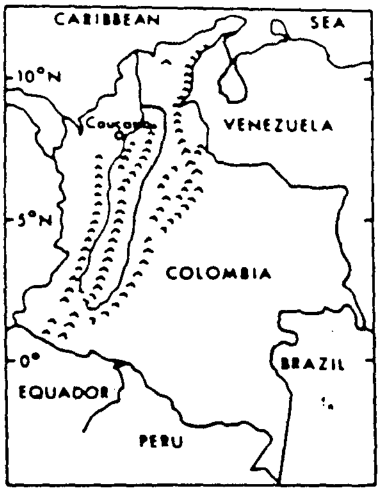


Fig. 1—This map shows the Andes Mountains as they are split into three distinct ranges in Colombia separated by the Magdalena and Cauca Rivers. Caucasia, location of the study area, is on a coastal plain near the departure of the Cauca River from the mountains.

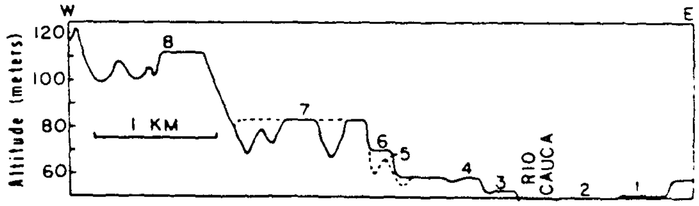


Fig. 2—A schematic cross section of terraces along the Rio Cauca at the sample pedon locations. The vertical exaggeration is 20×. Numbers 1 through 8 are placed above the approximate locations of pedon sites.

Table 1—Elevation above the lower floodplain of the Cauca River, physiographic position, and classification of the soil at the eight sampling sites.†

Site number	Eleva- tion, m	Floodplain or terrace level	Soil classification
2	0	Lower floodplain	Typic Tropaquent coarse-silty over sandy mixed, nonacid
1	0.5	Upper floodplain	Aeric Tropaquept coarse-loamy, mixed, nonacid
3	3	Caucasia Terrace	Oxic Haplustult clayey, mixed
4	8	Aeropuerto Terrace	Petroferric Haplustult clayey, mixed
5	17	A minor terrace level	Oxic Haplustult clayey, mixed
6	20	Velasquez Terrace	Typic Paleustult clayey, mixed
7	33.5	Candelaria Terrace	Typic Paleustult clayey, kaolinitic
8	62	Sajonia Terrace	Tropeptic Haplustox clayey, kaolinitic

† Soil Survey Staff (1975).
‡ All of the soils are in isohyperthermic families.

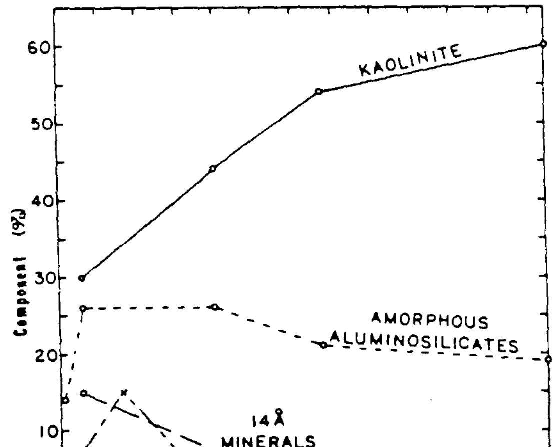


Fig. 1—Components of the clay fractions in the 75- to 150-cm depth range in relation to elevation above the Cauca River.

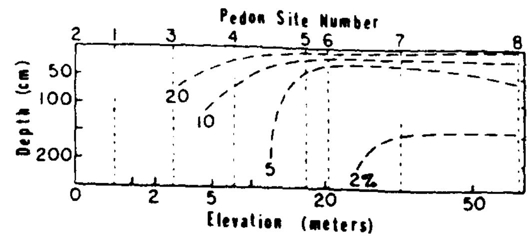


Fig. 4—Percent base saturation, based on the CEC at pH 8.2, in relation to elevation above the lower floodplain of the Rio Cauca and depth from the soil surface.

E.B. Alexander and N. Holowaychuk, 1983.

b) Pedotopographic models (toposequences)

Topography and associated drainage conditions constitute the main factors of soil differentiation in this type of model.

Examples:

- Alluvial environment (recent, Q1): Guarapiche river valley (Venezuela)
- Alluvial environment (middle, Q2): Barinas (Venezuela)
- Eolian environment (loess): Bilwisheim (France)
- Volcanic environment (tuff): Loita Plains (Kenya).

c) Pedolithographic models (lithosequences)

Examples:

- Alluvial environment: Guarapiche river valley (Venezuela), different depositional facies
- Volcanic environment: Colombia
- Rocks in situ (graphic)

2. COMPLEX RELATIONSHIP MODELS

Based on variable combinations of the three forming factors: topography, parent material and time.

a) Guarapiche river valley (Venezuela)

- Combination of geomorphic position and geochronologic unit: sequence of topo-litho-chronologic units.
- Parallel soil sequences in poorly and well drained conditions.

b) Rancho Grande (Venezuela)

- Superimposition of litho-topo-chronologic units along the same hillslope.
- Effect of paleogeographic evolution on soil distribution.

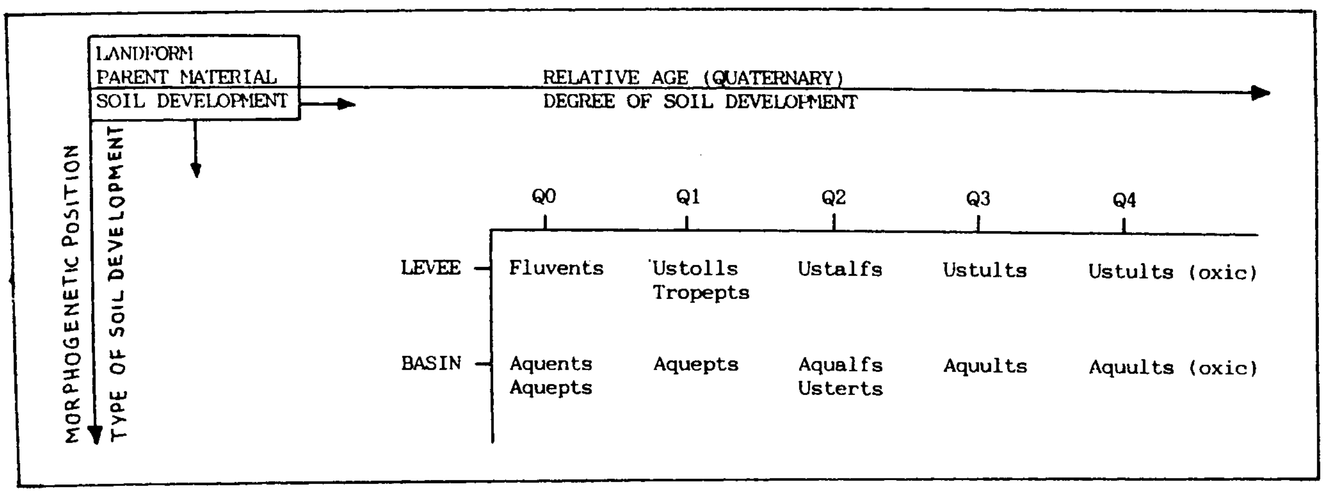
c) Glacial-periglacial environment

Superimposition of periglacial features on glacial substratum.

3. CONCLUSION

- Relativity of the contribution of geomorphology to soil survey.
- Feedback of pedology to geomorphology.

Fig. 53. MODEL OF GEOPEDOLOGIC RELATIONSHIPS IN A FLUVIAL SYSTEM
(Guarapiche river valley, Venezuela)



A. Zinck, 1970.

Fig. 54 _ COMPLEX RELATIONSHIP MODEL (RANCHO GRANDE)

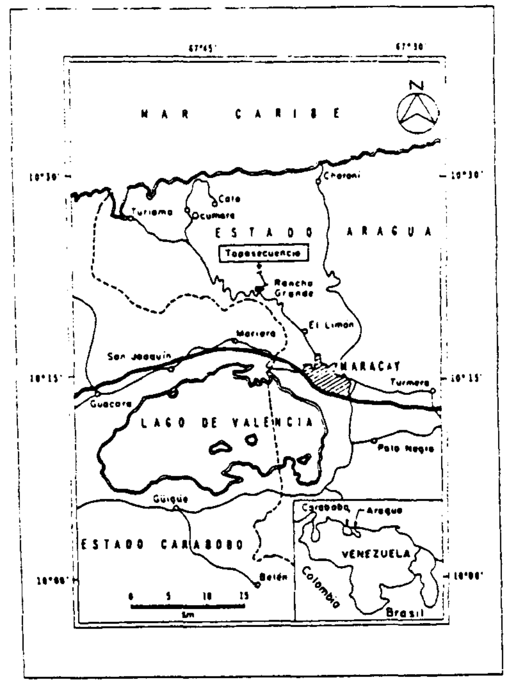


Fig. 1. Ubicación de la toposecuencia de suelos.

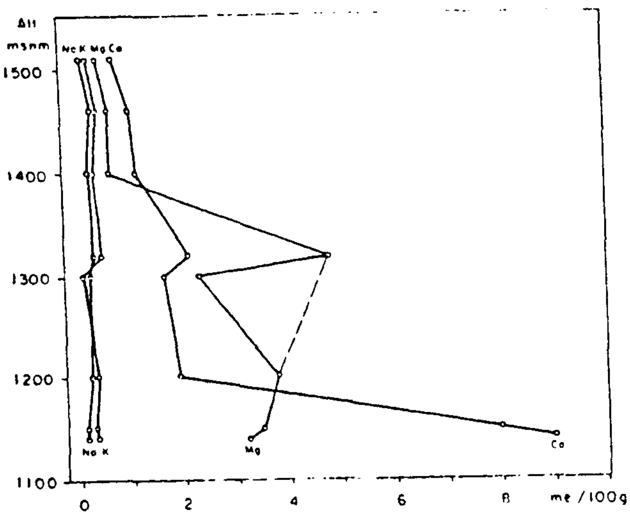


Fig. 7. Variación de las bases intercambiables (0-10 cm) en función de la altitud.

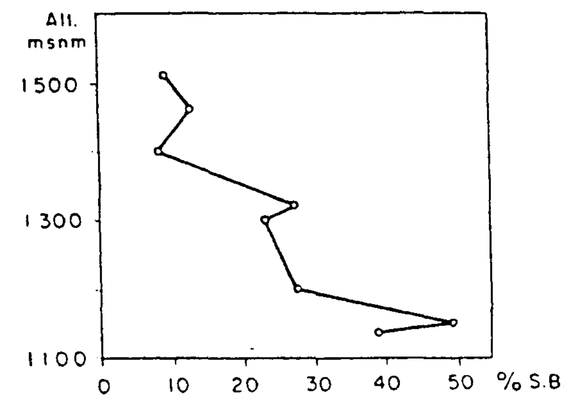


Fig. 5. Variación del % de saturación de bases (0-30 cm) en función de la altitud.

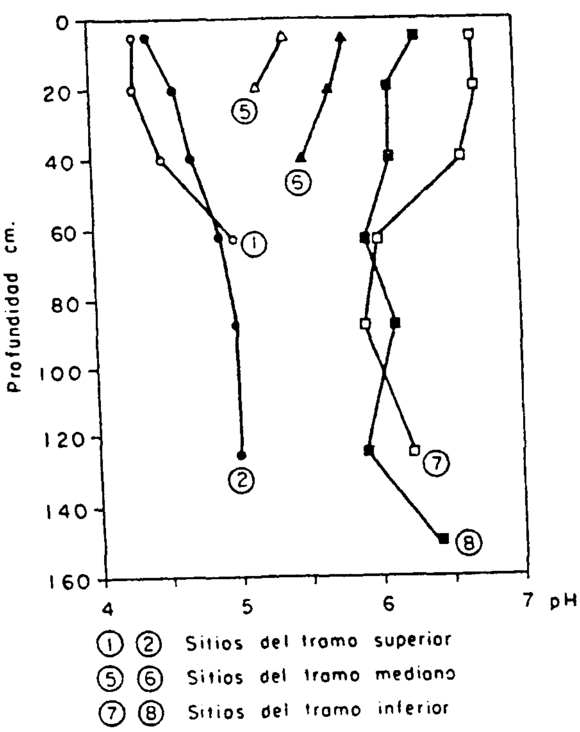


Fig. 8. Variaciones del pH en función de la profundidad y de la posición de los perfiles a lo largo de la vertiente.

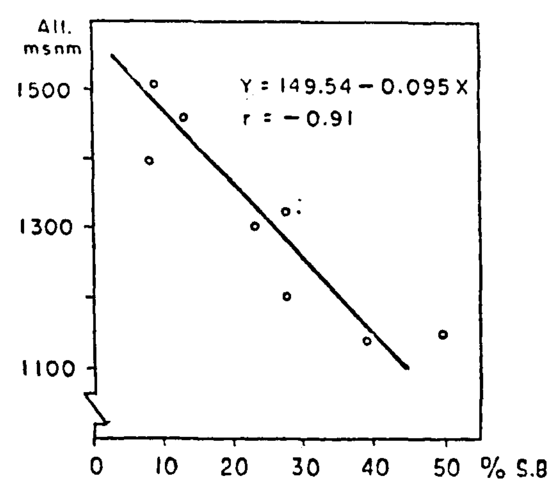


Fig. 6. Relación lineal entre % de saturación de bases (Y) y altitud (X).

A. Zinck, 1986.

Fig. 55 - A COMLEX RELATIONSHIP MODEL (RANCHO GRANDE)

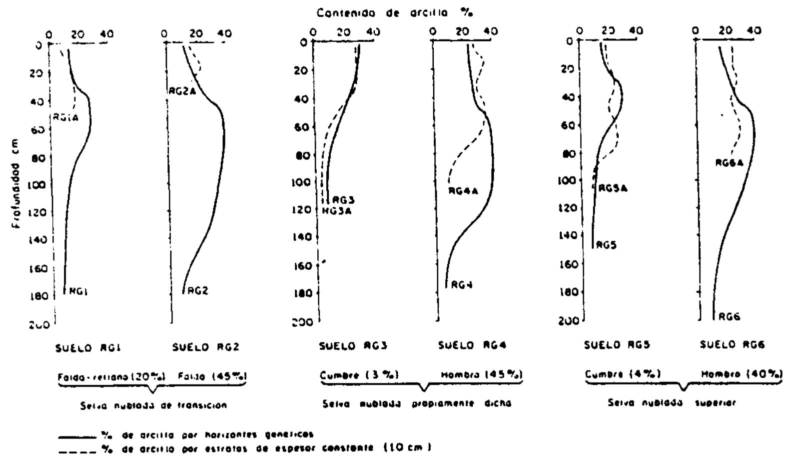


Fig. 9. Variaciones del contenido de arcilla con la profundidad.

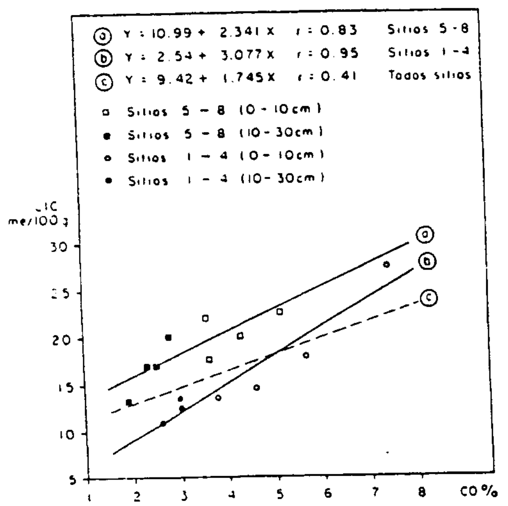


Fig. 13. Relaciones entre carbono orgánico (X) y capacidad de intercambio catiónico (Y).

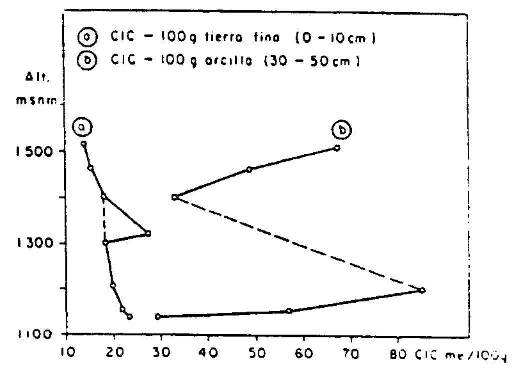


Fig. 14. Variación de la capacidad de intercambio catiónico en función de la altitud.

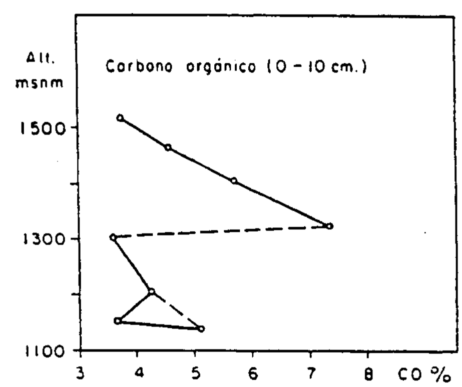


Fig. 12. Variación del carbono orgánico (0-10 cm) en función de la altitud.

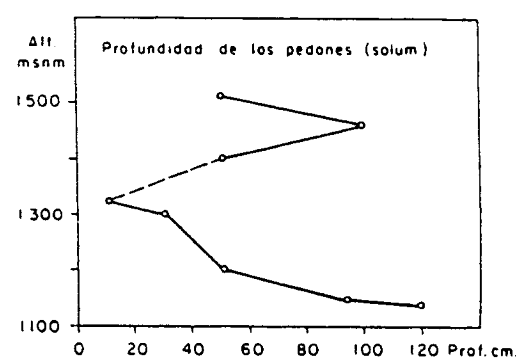


Fig. 15. Variación de la profundidad de los pedones en función de la altitud.

A. Zinck, 1986.

Fig. 56 _ COMPLEX RELATIONSHIP MODEL (RANCHO GRANDE)

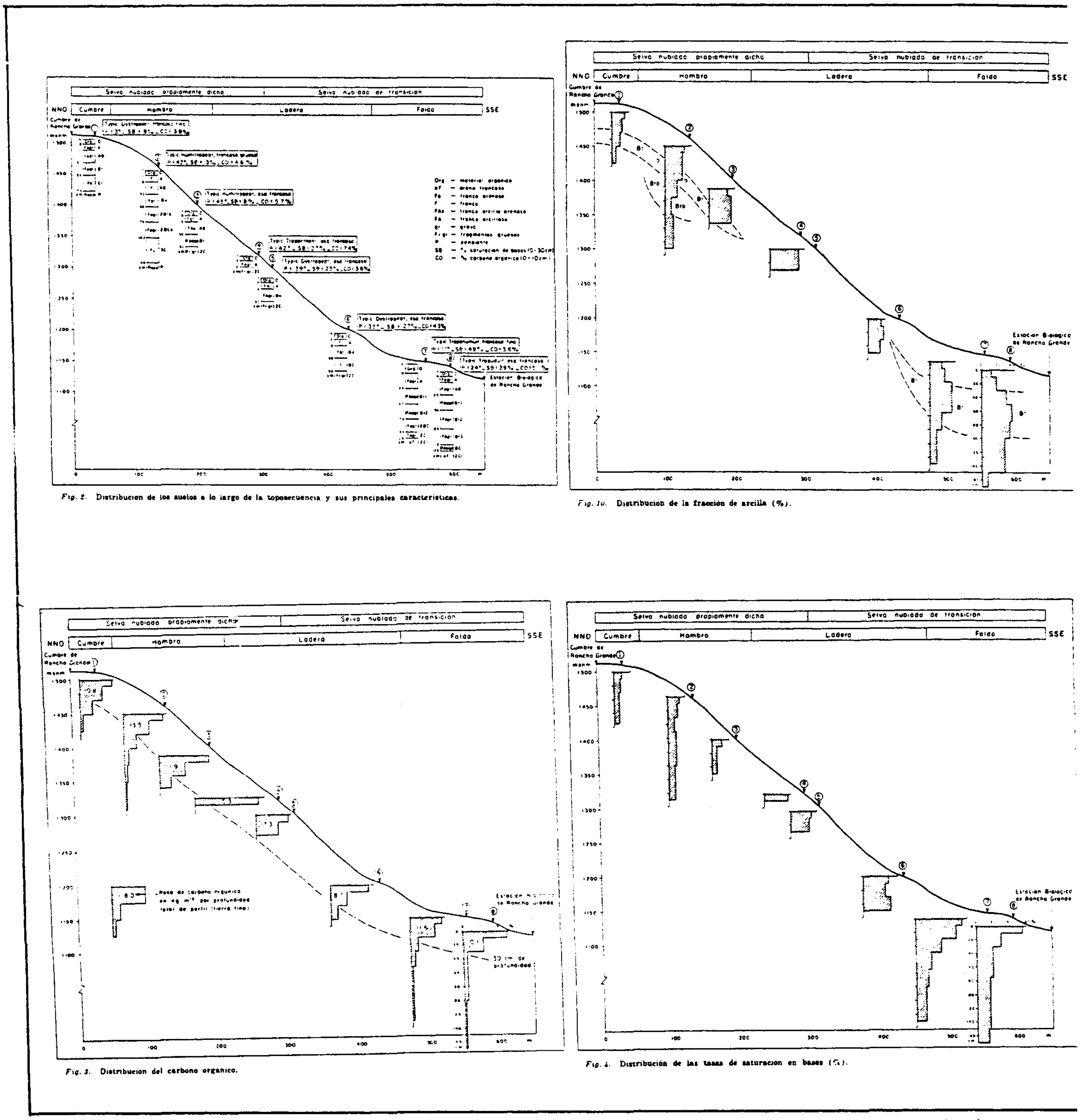


Fig. 2. Distribucion de los suelos a lo largo de la toposecuencia y sus principales caracteristicas.

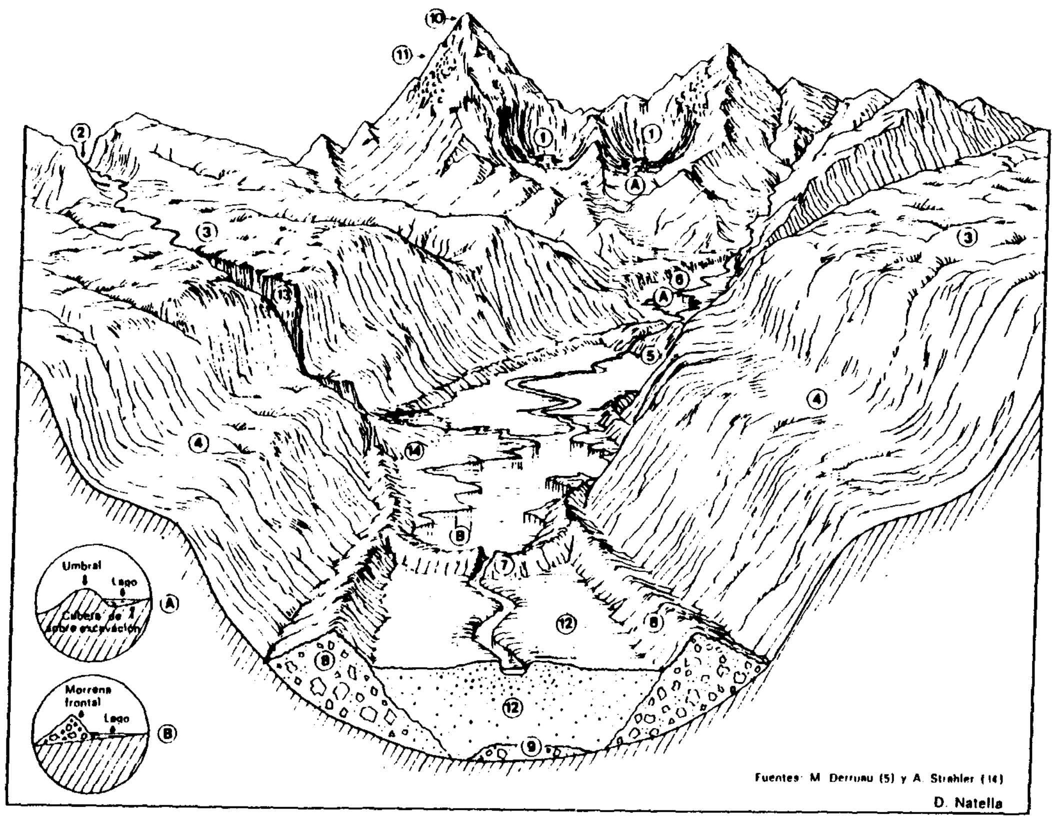
Fig. 10. Distribución de la fracción de arcilla (%).

Fig. 3. Distribucion del carbono organico.

Fig. 4. Distribución de las tasas de saturacion en bases (%).

A. Zinck, 1986.

Figure 57 _ CONFIGURATION AND COMPONENTS OF A GLACIAL VALLEY



GLACIAL EROSION MOLDING

(1) Glacial cirque with small lake
(2) Saddle of glacial diffluence
(3) Polished and striated ablation surface
(4) Glacial shoulder
(5) Glacial threshold with valley narrowing
(6) Over-excavation hollow with small lake

GLACIAL ACCUMULATION FORMS

(7) Frontal moraine with small lake
(8) Lateral moraine
(9) Ground moraine

PERIGLACIAL MOLDING

(10) Horn or gelifraction peak
(11) Talus of gravity debris

POSTGLACIAL FLUVIAL FORMS

(12) Infilled alluvial aggradation surface
(13) Lateral hanging gorge with confluence steps
(14) Alluvial fan

A. Zinck, 1980.

VII. APPLICATION TO SOIL CARTOGRAPHY

Purpose = to implement the geomorphic taxonomy system for soil cartography.

A. TAXONOMIC UNITS (SOILS-GEOFORMS)

A geoform has two main components:
- a molding = external features
- a material = internal features.

This specificity of the geoforms raises some basic problems about:
- the minimum area required to describe and measure the external features (epigenous morphon);
- the minimum volume required to describe and sample the geomorphic material (hypogenous morphon);
- the relationships between morphon, polymorphon (geomorphic individual) and taxonomic unit.

1. EXTERNAL FEATURES

- Refer to morphographic and morphometric attributes.
- Concern an area which must have a minimum surface (extension) to allow the description or measurement of the appropriate attributes (slope, contour, topographic profile, etc.). This requires frequently a perception of the whole geoform, as it can be seen through photo or image interpretation.

2. INTERNAL FEATURES

- Refer to morphogenetic and morphochronologic attributes.
- Concern a volume of material.

a) Minimum observation surface (morphon)

As for soil material: 1-10 m^2 according to the degree of spacial anisotropy:
- No cyclic variations: minimum of 1 m^2 (= 1 m lineal).
- Cyclic variations : maximum of 10 m^2 ($\simeq$ 3.5 m lineal).

b) Control section and diagnostic facies

- Geomorphic material = cover formation + upper part of rock substratum
  = C and R horizons or layers (= soil parent material).

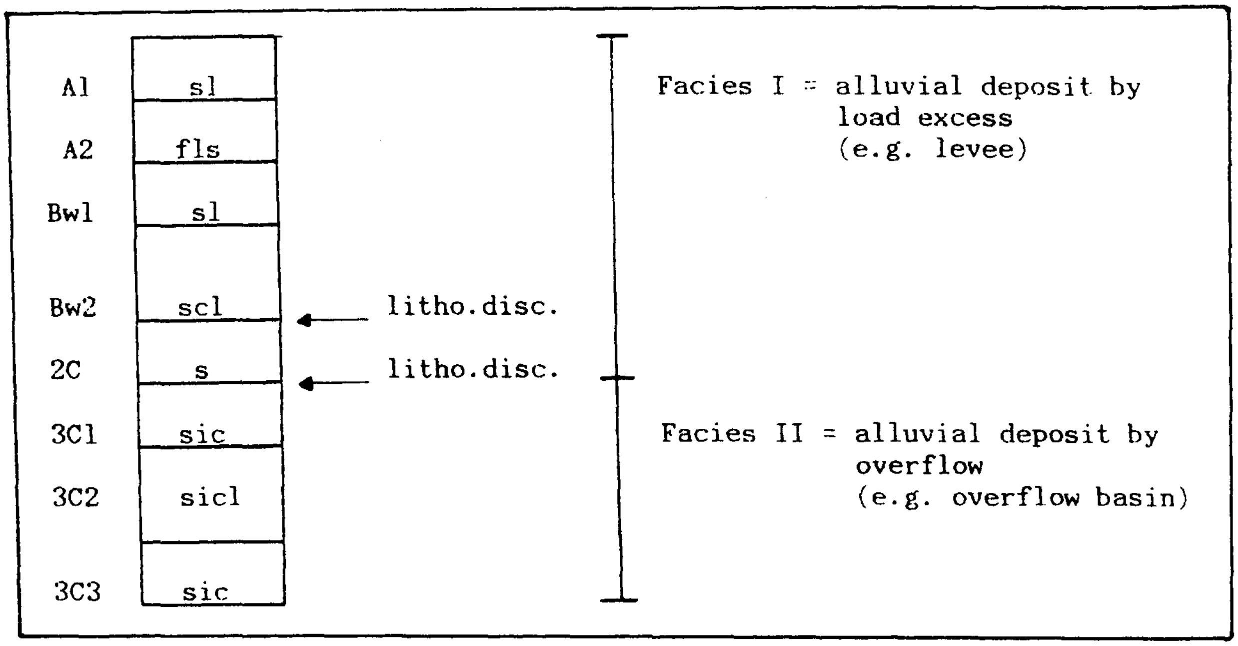
- The concept of facies allows to identify classes of materials according to their origin. The type of facies (eolian, fluvial, glacial, weathering, residual, etc.), identified using appropriate attributes, has diagnostic weight.

- Two extreme example cases:

  (1) **Recent soil materials** (e.g. Entisols, Inceptisols, etc.).
  The pedogenetic material is still very similar to the parent material.
  . If the profile is homogeneous, the diagnostic facies will be based on weighted average values of the attributes (e.g. weighted average of particle size distribution of all layers).
  . If the profile is heterogeneous, showing lithologic discontinuities = superposition of materials deposited by different processes and/or in different environments, then each set of layers (strata) must be described and sampled independently (Fig. 58).

  (2) **Developed soil materials** (e.g. Alfisols, Ultisols, etc.).
  - In soil having strongly developed genetic horizons (Bt, Bs, Bh, etc.), the diagnostic geomorphic facies must be identified beneath them.
  - Possibility of using sand/silt and silt/clay ratios to reconstitute the original particle size distribution of the pedogenized material (see Barshad's method).

Figure 58 _ VERTICAL VARIATIONS OF DEPOSITIONAL FACIES



. If facies I < 50 cm thick, then facies II is diagnostic for the whole geoform and facies I is a cover phase.

. If facies I > 50 cm thick, then facies I is diagnostic for the whole geoform and facies II is a buried phase.

B. CARTOGRAPHIC UNITS (SOILS-GEOFORMS)

1. CONTRIBUTION OF GEOMORPHOLOGY TO SOIL MAPPING UNITS

Traditionally there are no separate concepts for taxonomic unit and cartographic unit in geomorphology. However, geomorphic data can contribute substantially to the information conveyed by soil mapping units.

a) Soil and geomorphic phases

- Soil phase = subdivision of any soil class at any categorical level considered.

  Examples:

  . Mollisols, well drained

  . Typic Haplustolls, medium-textured

  . Typic Haplustoll, fine loamy, mixed, isohyperthermic, 1-3% slope.

- Many phases are derived from geomorphic context: e.g. "physiographic" phase, life zone phase, erosion phase, drainage phase, texture phase, slope phase, etc.

- Similarly to soil units, phases can be used to subdivide geomorphic units for mapping purposes on the basis mainly of morphographic and morphometric features
  e.g. Terrace (or glacis): low, medium, high
  e.g. Backslope: gentle, steep, very steep.

b) Soil mapping units
- Classes: consociation, association, complex, undifferentiated group.

- Geomorphology contributes to:
  . Delineation of soil mapping units through photo and image interpretation, supported by fieldwork, making appropriate use of morphographic and morphometric features.
  . Composition of soil mapping units: the use of geomorphic criteria to set up the internal composition of soil mapping units improves their homogeneity (e.g. association of basin soils, of levee soils).
  . Range of variation of soil properties can be reasonably derived from the specific nature of the geomorphic units (e.g. homogeneous decantation basin environment versus heterogeneous river levee environment). This approach should be combined with geostatistics.

2. RELATIONSHIP WITH SOIL SURVEY ORDERS AND MAPPING SCALES
Table 42 shows the most common geoform categories as related to soil survey orders.

Table 42. SOIL SURVEY ORDERS AND MAPPABLE KINDS OF GEOFORMS

ORDER	DETAIL	KINDS OF MAP UNITS	KINDS OF SOIL COMPONENTS	SCALE	KINDS OF GEOFORMS
1st	Detailed	Consociation, complex	Phases of soil series	<1:15.000	Landform
2nd	Semi-detailed	Consociation, association, complex	Phases of soil series and families	1:15.000 to 1:50.000	Landform and relief
3rd	Preliminary	Association, consociation, complex	Phases of soil families and subgroups	1: 50.000 to 1:100.000	Relief (and landform)
4th	Grand vision	Association	Phases of soil subgroups and families	1:100.000 to 1:500.000	Relief
5th	Exploratory	Association	Phases of soil subgroups to orders	>1:500.000	Landscape

Adaptated from USDA-SCS.

C. MAP LEGEND

1. GENERAL STRUCTURE (table 43)

Cartographic differentiators (geom. entries + soil taxa)	Thematic descriptors (possible soil phases) e.g. topog., drainage, veget., etc.

↓

GEOFORMS					SOILS		
Landscape	Relief	Lithology	Landform	Map unit	Soil components	Phases	Area

2. LEGEND ENTRIES

Different alternatives can be implemented.

a) Soil taxonomic entries

Pure soil taxonomic legend as a reaction against the use of soil forming factors for legend structuring (based on the reaction of the Soil Taxonomy against soil classification on the basis of soil forming factors instead of soil properties).

b) Climatic entries

- At small scale, latitudinal distribution of morpho-bioclimatic zones can be used as convenient legend entries for schematic soil maps at (sub)continental level.

- At broad scale:
  . Latitudinal morpho-bioclimatic zones are too ample to reflect significant geographic soil variations. Besides, latitudinal zonation is frequently disrupted by regional or local relief orientation and its influence on mesoclimates.
  . Altitudinal life zones controlled by temperature gradients along high elevation mountain slopes (e.g. Andes, Sierra Nevada Range in California) are vertical subdivisions of mountain or hilland landscapes. Their limits may vary according to the regional orientation of the relief mass and local exposures. Life zone levels can be therefore appropriately expressed as landscape phases such as for instance:

e.g. Tierra caliente, Tierra templada, Tierra fría phases along an Andean mountain slope,

e.g. Sonoran, Sierran, Canadian, Hudsonian, Arctic-alpine life zone phases along a Sierra Nevada mountain slope in Central California.

- At any scale, agro-ecologic or agro-climatic entries may be convenient for specific purpose interpretative maps.

c) Physiographic entries

- Comprehensive approach based on variable combinations of several soil forming factors with emphasis on geology, geomorphology, climate and vegetation.

- Some implementation problems:
  . Difficulty to specify the relative weight of the factors and to determine the leading factor (may vary from one place to another).
  . Decreasing homogeneity of the mapping units as more factors are combined for the entries.
  . Incongruencies may derive from the fact that different disciplines having their own taxonomic system classify at different levels (Fig.).

- It might be preferable to use only one or two factors for unit differentiation and the other ones for unit characterization (additional information expressed as phases). One factor must be the leading factor to provide internal consistency to the legend structure.

d) Geomorphic entries

- Geomorphology as the leading factor using the categorical levels, especially the 4 lower ones, as hierarchical entries to the legend.
- The other factors such as climate and vegetation vary often concurrently with major changes affecting the geomorphic context. Therefore, they can be efficiently expressed as phases (e.g. phases of bioclimatic altitudinal zones or life zone phases).

3. SIMBOLOGY

a) Map semiotics

- Refers to the use and combination of colors and symbols to convey the appropriate message to the user.
- See A.L. Salomé, H.J. van Dorsser and Ph.L. Rieff - A comparison of geomorphological mapping systems. ITC Journal 1982-3, pp. 272-274.

b) Basic symbology (alphanumeric)

- Landscape types

Valley	Va
Plain	Pa
Peneplain	Pe
Plateau	Pu
Piedmont	Pi
Hilland	Hi
Mountain	Mo

- Lower levels

  Numerical subscripts are used: e.g. Val, Vall, Valll for relief, lithology and landform levels successively, within a valley landscape (see application mode in Figure 58 and Table 44).

- Higher levels

  The higher levels, geostructure and morphogenetic environment, are mainly used for compiling schematic generalized maps. Symbology may be selected according to the purpose of the map.

c) Variants

Example:
Type of symbology used in a 4th order soil survey at the scale of 1:250.000 (Guayana Region, Venezuela).

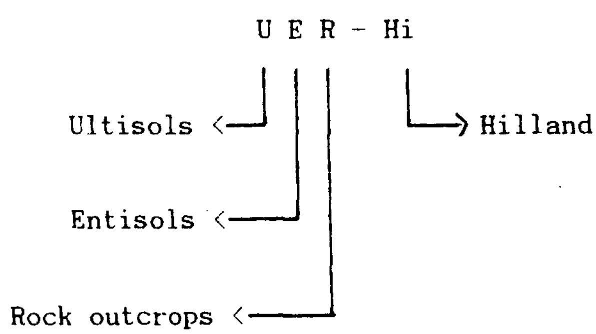
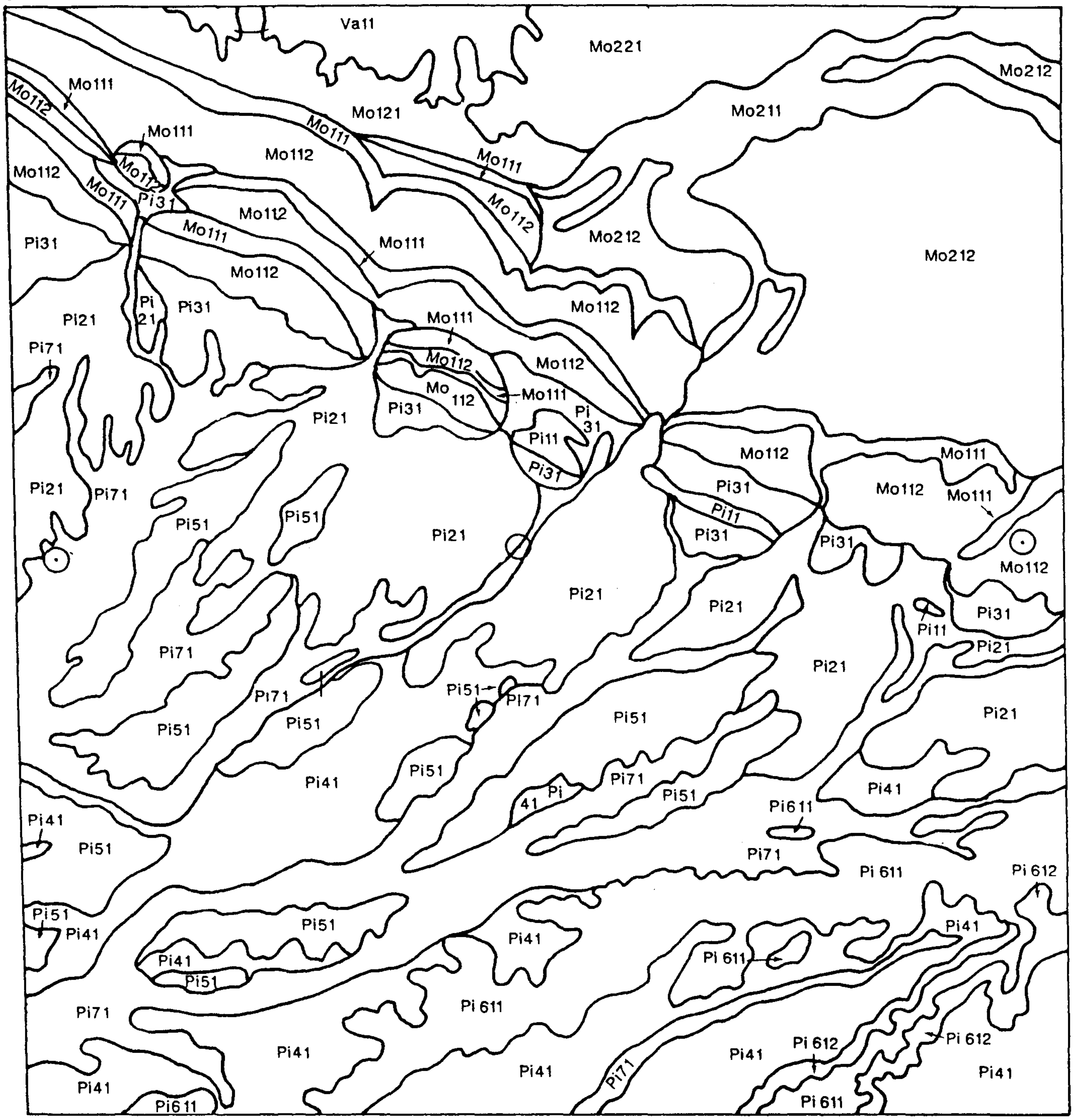


Fig. 58 _ APPLICATION OF THE SYSTEM TO PHOTOINTERPRETATION

SBEITLA - TUNISIA
Scale:



API-AZ-88

Photointerpretation Legend (A.Zinck - 88)

Sbeitla area, Tunisia - Scale 1: 25 000

Table 44.

Landscape (level 4)	Relief (level3)	Lithology (level 2)	Landform (Level 1)
Mo Mountain	Mo1 Monoclinal Ridge (Hogbacks -> flatirons)	Mo11 Limestone	Mo111 Front side scarp Mo112 Back side structural surface
		Mo12 Marl	Mo121 Front side talus
	Mo2 Anticlinal ridge	Mo21 Limestone	Mo211 Front side scarp Mo212 Back side structural surface
		Mo22 Marl	Mo221 Front side talus
Pi Piedmont	Pi1 Hogback	Pi11 Limestone	Pi111 (Front side scarp) Pi112 (Back side strutural surface)
	Pi2 Fan	Pi21 Alluvium	Pi211 ?
	Pi3 Glacis, steep	Pi31 Colluvio-Alluvium	Pi311 ?
	Pi4 Glacis, low	Pi41 Alluvium	Pi411 ?
	Pi5 Glacis, middle	Pi51 Alluvium	Pi511 ?
	Pi6 Glacis-terrace high	Pi61 Alluvium	Pi611 Tread Pi612 Riser
	Pi7 Swale	Pi71 Colluvio-Alluvium	Pi711 ?
Va Valley	Va1 Glacis	Va11 Colluvio-Alluvium	Va111 ?

D. APPLICATION PROCEDURE

1. PHOTO-INTERPRETATION

a) Systemic approach: stepwise interpretation according to the hierarchical levels of the geomorphic system.
b) Implementation of morphographic and morphometric attributes rather than genetic ones.

2. FIELDWORK

a) Selection of sample areas or transects.
b) Selection of observation points.
c) Description of the geomorphic environment (static and dynamic) and characterization of the soil parent material (nature + origin = facies).
d) Delineation of geoform - soil bodies = soilscape units (= objective of geopedology or soilscape approach to soil survey).

3. IDENTIFICATION KEY

Important structural problems have to be solved before an identification key can be established and made operational:

a) Categories: fixed number (closed y-direction of the taxonomic matrix)
b) Classes : the system can easily accommodate new classes (open x-direction of the taxonomic matrix)
c) Attributes: main problems are:
   - selection of the appropriate attributes for each level,
   - quantification of the attributes (class limits),
   - diagnostic states of the attributes for each type of geoform.

4. SOIL MAPPING IN SLOPING AREAS

When applying geomorphology to soil survey, a distinction is often made between flat areas and sloping areas based on the fact that processes and conditions prevailing in each one of these two broad natural domain types originate fundamental soil formation differences and control soil geography.

Some geoforms occur both in flat and sloping environments. For instance, glacial forms may develop on flat land in high latitude regions as well as in rugged land in high altitude zones (including tropical ones). On the other hand, some geoforms originated by the same transport and depositional process are either flat or sloping by definition: e.g. a flat sand cover mantle as compared to a rolling sand dunes field. Therefore, the distinction between flat and sloping areas in terms of geoforms distribution is rather artificial but may be convenient for soil mapping.

Neatly delineated geoforms, exhibiting conspicuous configuration as shown by depositional landforms, are rather unfrequent in sloping areas with exception of possible volcanic features, valley-bottom alluvial accumulations and (peri)glacial molding at higher altitudes. Geoforms are mainly of structural and erosional origin whose subdivision at the landform level can only be done by means of slope facets.

One practical approach to soil mapping in banal sloping areas should combine the following sources of information:

- Topography: slope gradients map and selection of representative topographic profiles for slope facet description.
- Geology: lithology and tectonic arrangement of bedrocks.
- Cover formations: weathering mantle (alterite), slope formations, allochtonous cover materials (eolian, volcanic).
- Slope dynamics: water-induced erosion, mass movements.

VIII. CONCLUSION: MULTIPURPOSE USE OF THE SYSTEM

The system can be used for many purposes such as the following ones:

1. Photo-interpretation for soil mapping (and other natural resources)
2. Field survey
3. Legend structuring of the taxonomic map
4. Legend structuring of interpretative maps
5. Interpretation of soil genesis
6. Geographical clustering of geopedologic units (homogeneous areas)
7. Soil correlation
8. Establishment of natural hazards maps (flooding, slope stability, etc.)
9. Procedure for information generalization (taxonomic and cartographic)
10. Main entries to the database of a GIS.

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