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ENGINEERING GEOLOGY FOR URBAN PLANNING AND DEVELOPMENT WITH AN EXAMPLE FROM TENERIFE (CANARY ISLANDS)

LA GÉOTECHNIQUE POUR LA PLANIFICATION ET LE DÉVELOPPEMENT URBAINS AVEC UN EXEMPLE DE TÉNÉRIFFE (ILES CANARIES)

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Summary:

An approach to engineering geological assessment for urban planning and development is presented. The engineering geological investigations for the urban planning of Santa Cruz de Tenerife (Canary Islands) are used as an example.

Résumé.

On présente la Géologie de l'Ingénieur comme un moyen d'étude utilisable pour la planification et le développement urbains en employant comme exemple les investigations géotechniques réalisées pour la planification urbaine de Santa Cruz de Tenerife (Iles Canaries).

Introduction

The role of engineering geology in urban planning has started to be recognized in practice only in the last ten years, (1), (9), (14). More recently an increasing general concern has been observed, (5), (10), (13), (11), etc. Engineering Geology can contribute significantly to the solution of many of the urban problems, as follows:

I. Selection of the most environmentally favourable urban settlements.

II. Selection of the most suitable areas for town development.

III. As a contribution to achieve the most economical and environmentally conservative solution for the Urban Plan.

IV. Specific assistance during the development, design and construction stages of the town.

Geology, geomorphology and hydrogeology must be known and investigated before any engineering geological study is carried out. The kind of information they can provide should be up-to-date, and at an adequate scale. After these basic investigations, the following, engineering geological problems should de considered:

- Foundations
- Ground stability
- Excavations
- Natural resources
- Water supply
- Waste disposal.

The incidence of geological hazards in towns is limited and normally is restricted to particular areas. However, if these occur the consequences can be catastrophic. This possibility places geological hazards in a very special position in land-evaluation for urban planning.

Land use planning based on zoning the area in sectors of different risk is the only way to cope with geological hazards. A general approach could be:

I. Evaluation of the problem.

II. Zoning and rating the area as to different grades of risk.

III. Planning and development in accordance with these zones.

IV. Application of special measures and the avoidance or restriction of development where recommended.

This approach can neither eliminate nor diminish the geological phenomena, but their effects on lives and property can be dramatically decreased (4).

This planning and design of site investigations to tackle the abovementioned engineering geological problems depends largely on the purpose and stage of the urban planning and development and on the geological complexity of the area. Fig. 1 is a suggestion of the different stages and purposes of the site investigations and how they are influenced by the urban planning conditions.

An approach to presentation of maps for urban planning purposes could suggest these categories:

- Basic maps
- Engineering geological maps
- Influence factor maps
- Urban suitability maps
- Land system maps.

Basic maps are represented by geological, hydrogeological and geomorphological maps. The engineering geological maps should be presented in the way recommended by (2). Normally they include the information in one sheet map, but where complex factors occur multiple maps are used which delineate special factors, hazards and purposes. These are the influence factor maps. Tables which describe the mapped units and their engineering properties are usually annexed. Although there is no general agreement as to the number and type of influence factors to be included, nor how they should be presented for urban planning purposes, the inclusion of the following is suggested:

- Slope
- Foundation conditions
- Groundwater conditions
- Construction materials
- Slope stability
- Waste disposal
- Mineral resources
- Geological hazards.

Examples of urban suitability maps are given by (8), (15) and (12). Land system maps are very useful when the analysis of a great number of variables or even the whole environment over large areas is required in a short time (3), (7).

The Santa Cruz de Tenerife Case

Engineering geological investigations were carried out to provide information on the physical environment and engineering geological characteristics of the urban planning of Santa Cruz de Tenerife (Canary Islands). The area studied has a surface of approximatly 100 sq.km with present population of 250,000 inhabitants, estimated to reach 350,000 in the next fifteen years.

Santa Cruz and La Laguna are the largest towns. These have experienced a rapid peripheral expansion over a region of particular and complex geological and morphological conditions.

The area (Fig. 2) is composed of three main lithological formations: The borders of the Anaga Massif, the alluvial clays of La Laguna, and the Basaltic Series III. The Anaga Massif, which is the oldest formation, extends through the north and north eastern borders of the area. It is formed of basaltic lava flows and large masses of pyroclastic flows. The alluvial clays, located in the centre of the area, are the consequence of the filling of a valley which was clogged by basalts and pyroclasts coming from near-by volcanoes. The Basaltic

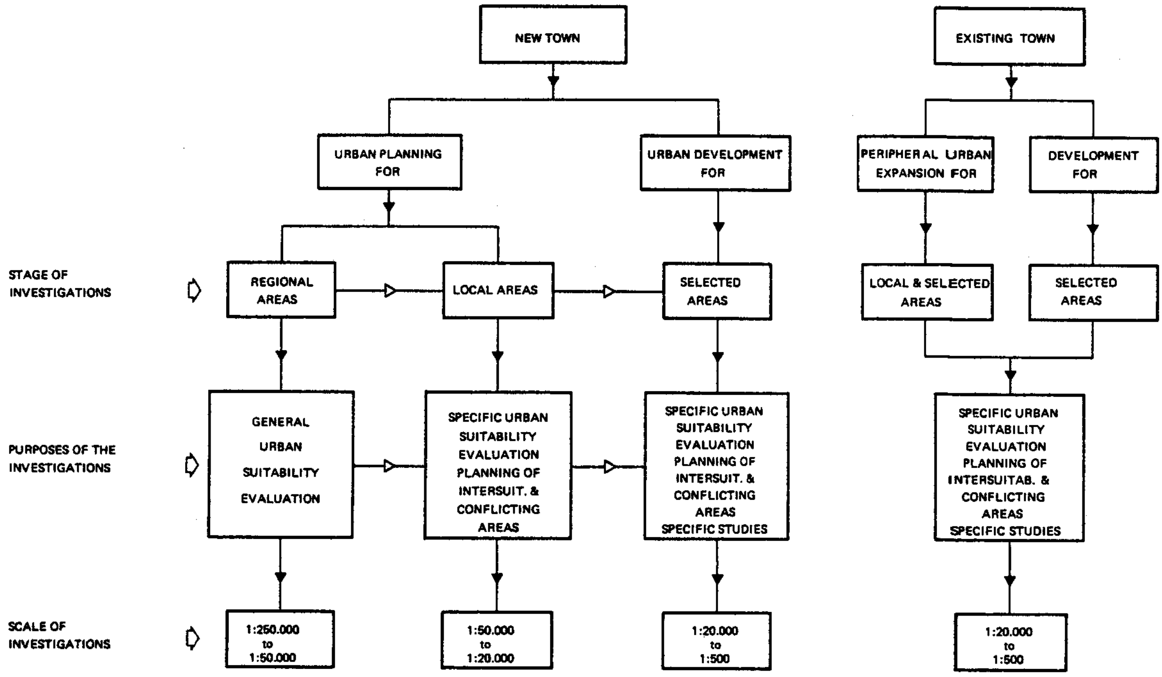


Fig. 1 : Stages and purposes of site investigations in the urban environment.

Series III, which cover the rest of the area, consist of lava flows of scoriaceous basalts. Quaternary volcanoes crossing this formation have built many cinder cones of lapilli and ashes (Fig. 3). In the northern areas residual soils have been developed by the weathering of pyroclasts and basalts.

Site Investigations

All the available information concerning geology, hydrogeology and seismology of the region was collected, before carrying out any site investigation. It was possible to get a summary log of 325 boreholes drilled on basaltic lavas during previous work. To obtain field information on geological, hydrogeological and geomorphological characteristics of the area a detailed survey was carried out. At the same time a geophysical survey using the electric resistivity method was performed to determine the thickness of the overburden, and the composition and structure of the most geologically complex areas. Soil samples were taken from 40 trial pits. Rock and water samples were also collected from outcrops and wells, respectively.

Site investigations for engineering geological purposes were carried out after the geological conditions of the area were known. Eighty-two boreholes were drilled in soils by the shell- and auger method at an average depth of 10 m, although a depth of 25 m was reached in some boreholes. S.P.T. tests, water level measurements, 77 dynamic penetration tests using the "Borro" penetrometer, and 42 trial pits, completed the site investigation on soils. Ten boreholes were drilled on basalts to a depth of 10 m, just to complete the information provided by the summary logs. Soil laboratory tests consisted of classification, compaction and swelling tests. Strength and compressibility tests were carried out on selected samples. Rock laboratory tests consisted of density, porosity and uniaxial compressive strength determinations. The point load test was extensively used.

Engineering Geological Aspects Considered in this Case

The following subjects were considered in the engineering geological investigations for the urban planning of this area:

- Geology
- Geomorphology
- Hydrology and hydrogeology
- Construction materials
- Geological hazards
- Engineering geology
- Waste disposal and ground water pollution.

Just to give a general idea of the engineering geological conditions of the site, some of the main aspects will be briefly described. Soil formations are covering the northern and western parts of the area. They consist of transported and residual soils both of volcanic origin formed by the weathering of pyroclasts and basalts.

Transported soils were deposited under alluvial conditions and they fill the La Laguna valley to variable thickness, as indicated by isopachous lines in Fig. 4. The middle of this valley was occupied by a lake which was desiccated in the year 1873.

The hydrogeological conditions determined an initial high water table which has been progressively lowered. Based upon index and classification tests it was possible to identify ten different soil units. Average values showed that they are of fine grain size, passing more than 80 % by the 200 sieve (ASTM), liquid limits between 35 and 55 %, plastic limits from 20 to 35 %, plasticity index from 15 to 22 %, and dry densities from 1.1 to 1.4 gr/cm^3.

Overconsolidated clays were formed in the higher levels of these clays as a result of the desiccation and lowering of the water table. It was also possible to recognize the presence of expansive clays permitting an evaluation in terms of swelling potential and swelling pressures (Fig. 4).

Rock formations cover more than 60 % of the total investigated area. They mainly consist of flows of basalts, 1 to 2 m thick, alternating with scoria. Basalts are generally fresh, highly fissured, and with occasional cavities, holes and tubes of very variable size. Inclusions of irregular bodies of scoria and/or pyroclasts are also present. In this formation there was a great variation in geotechnical properties. Lapilli generally build up cinder cones. They showed practically no cohesion and the average angle of internal friction was about 30°. The bulk density was between 1.2 and 1.5 gr/cm^3. Lapilli can be weathered very quickly to clayey soils.

The following points were considered in the description of the engineering geological characteristics of the area:

Classification of the area into engineering geological soils and rock units. Extent, distribution and thickness of each unit. Characteristics of the engineering geological units based on classification, strength and compressibility properties. Identification, origin, engineering properties and distribution of the expansive clays. Evaluation of foundation conditions. Slope stability and excavation evaluations.

Presentation of Data

The information was presented in the form of maps and plans accompanied by a 10,000 word report. The following list of coloured maps, all at a scale of 1 : 25,000, were included in an atlas:

I. **Basic Maps**

- Geological map and geological cross sections
- Geological map of surface formations
- Geomorphological map
- Hydrogeological map
- Construction materials resources map

II. **Engineering Geological Maps**

- Site investigations location map
- Engineering geological map
- Table of engineering geological characteristics

III. **Urban Suitability Maps**

- Slope steepness evaluation map
- Engineering geological evaluation map
- Waste disposal and ground water pollution evaluation map

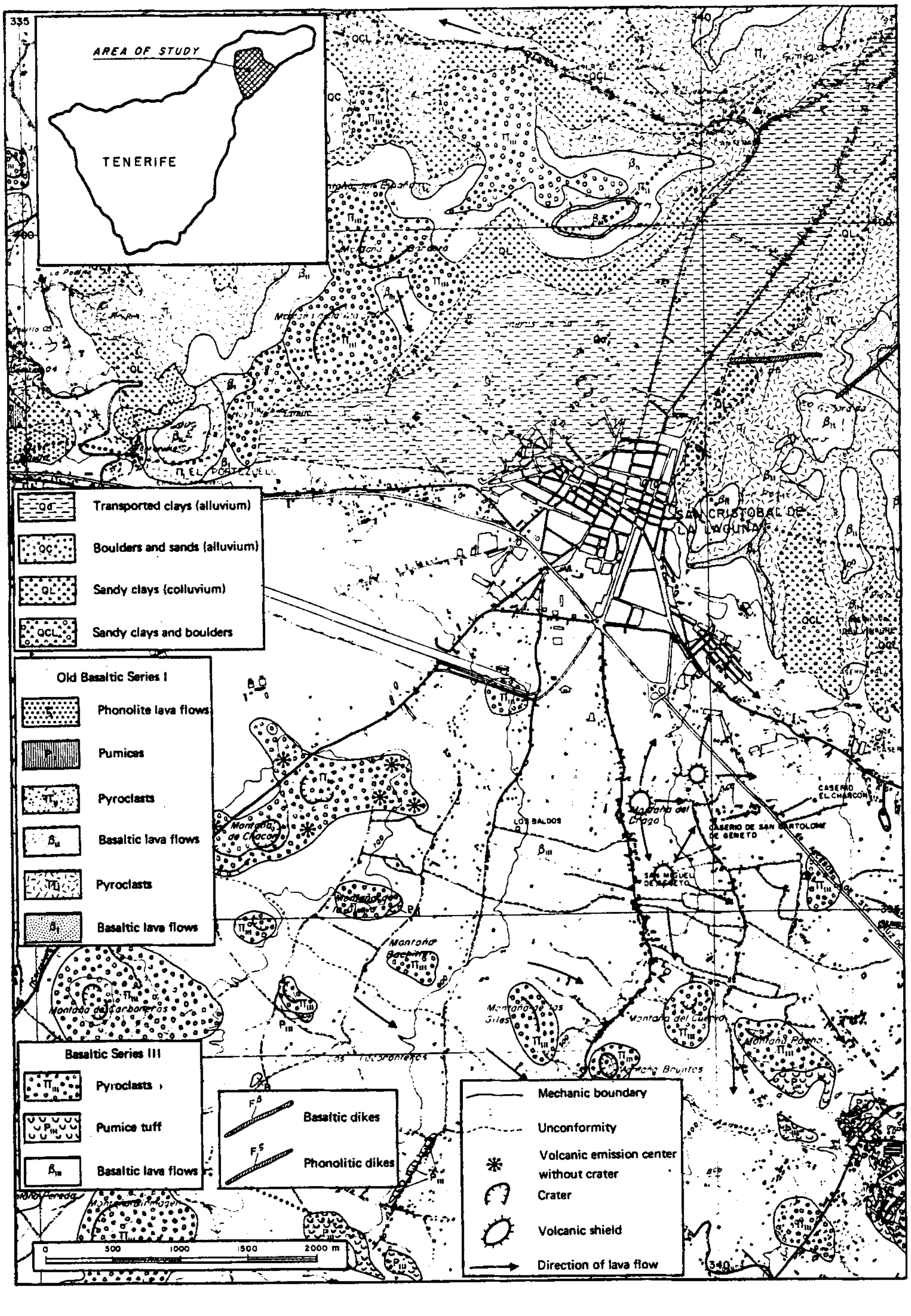
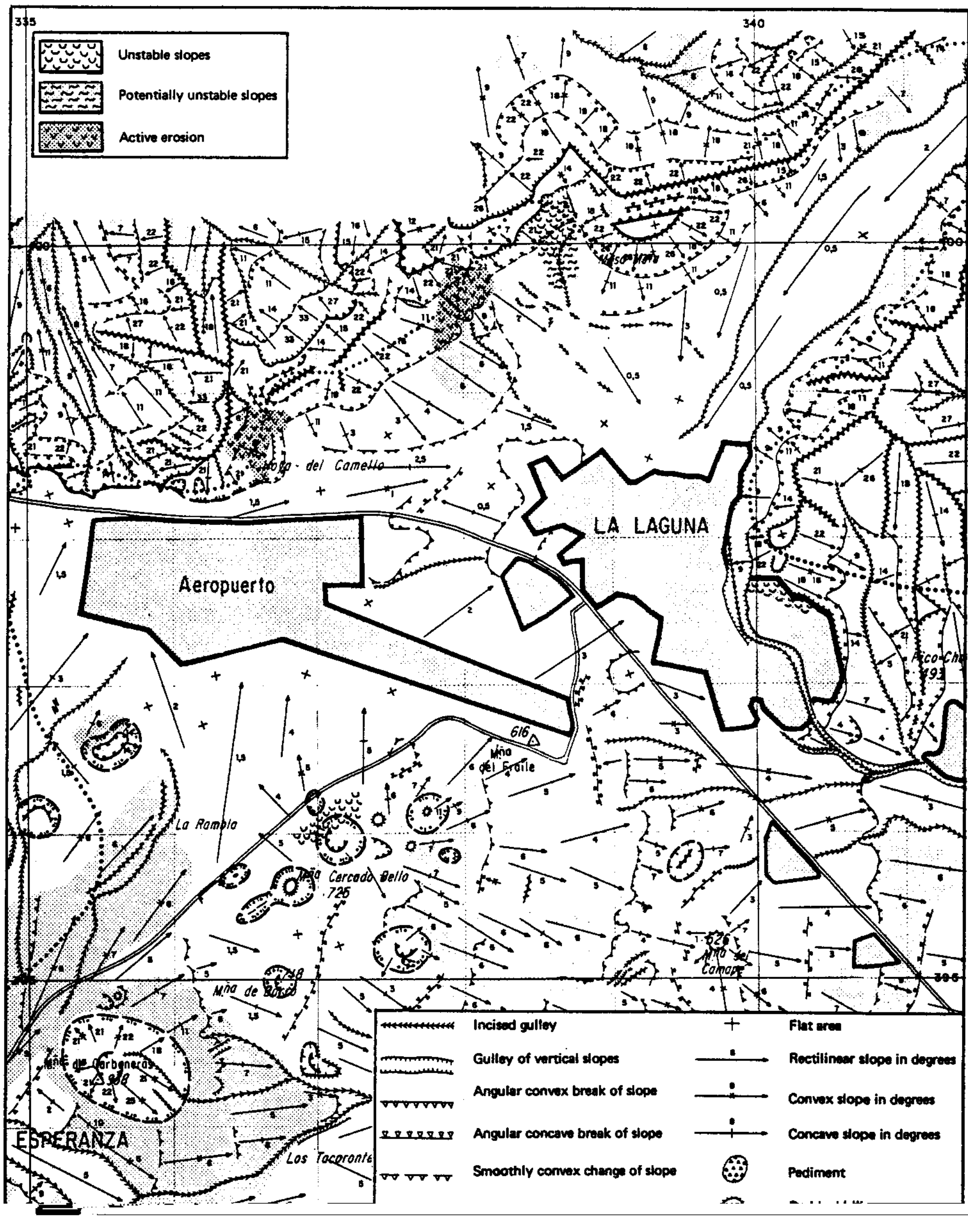


Fig. 2 : Geological map of an area from Tenerife

The following information was included in the engineering geological map: each soil/rock unit was represented by a different colour. Location of expansive clays and their related problems were represented by symbols. Isopachous lines of thickness of soils were shown by coloured lines. A table of engineering geological characteristics to accompany the engineering geological map was presented. This table was produced in a similar manner as the one carried out by the IGS at Milton Keynes (2). The table was divided in 10 main subjects, as follows:

- Name of the unit
- Equivalent geological unit
- Qualitative descriptions and thickness
- Geotechnical parameters
- Foundation stability
- Slope stability
- Workability
- Hydrogeological characteristics
- Waste disposal suitability
- Uses



The urban suitability maps were produced principally in order to assist planners – not necessarily for experts in Earth Sciences – and to give a quick idea of the most suitable or unsuitable areas for different factors. A "traffic light" code colour system was used to indicate green for favourable, yellow for restricted, and red for unfavourable conditions. Figs. 2, 3, 4 and 5, are shown just to illustrate some aspects of these maps, although in the figures only a part of the total investigated area is presented. These figures are shown without the original colours, due to the obvious printing limitations of this paper.

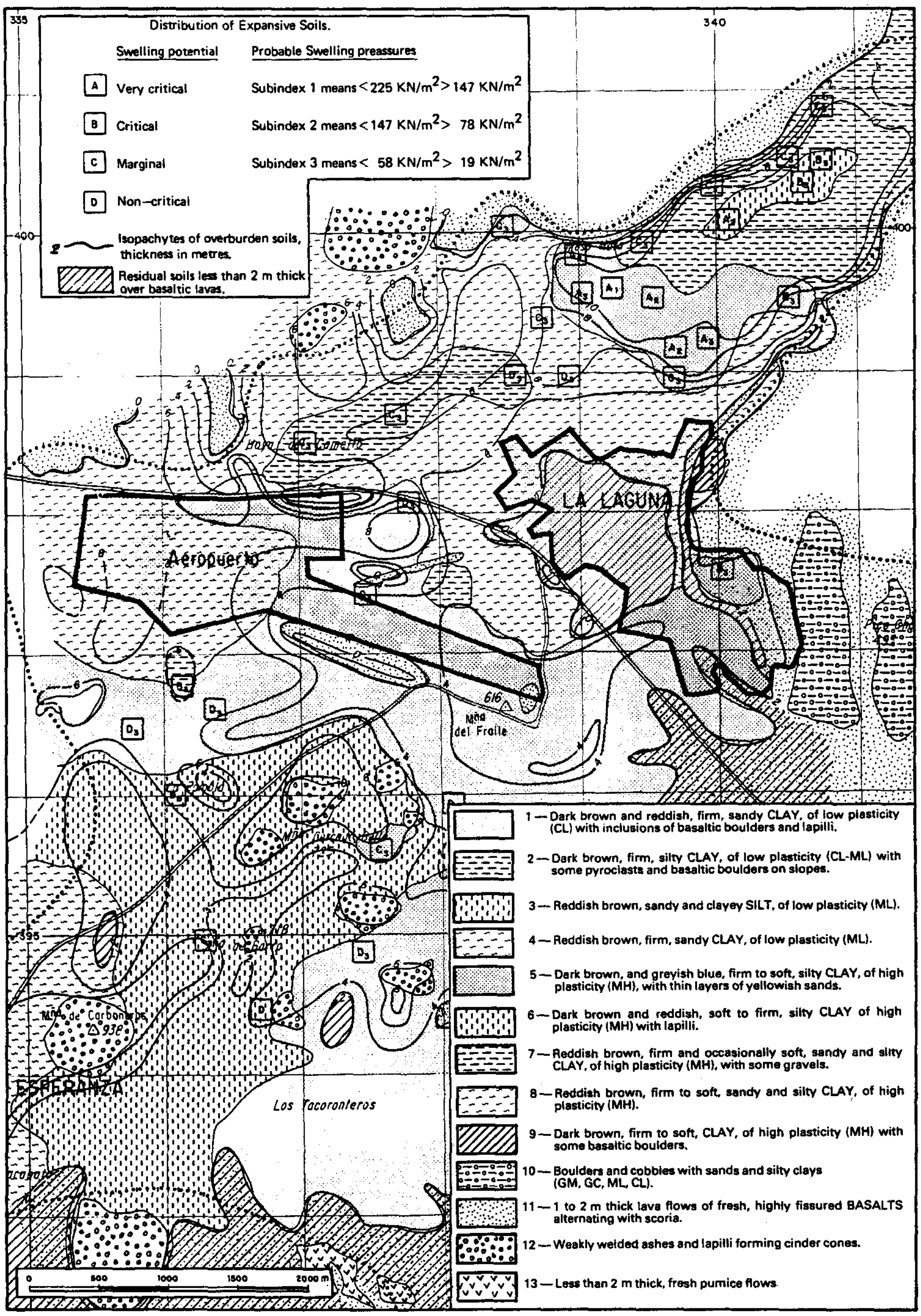


Fig. 4 : Engineering geological map of an area from Tenerife

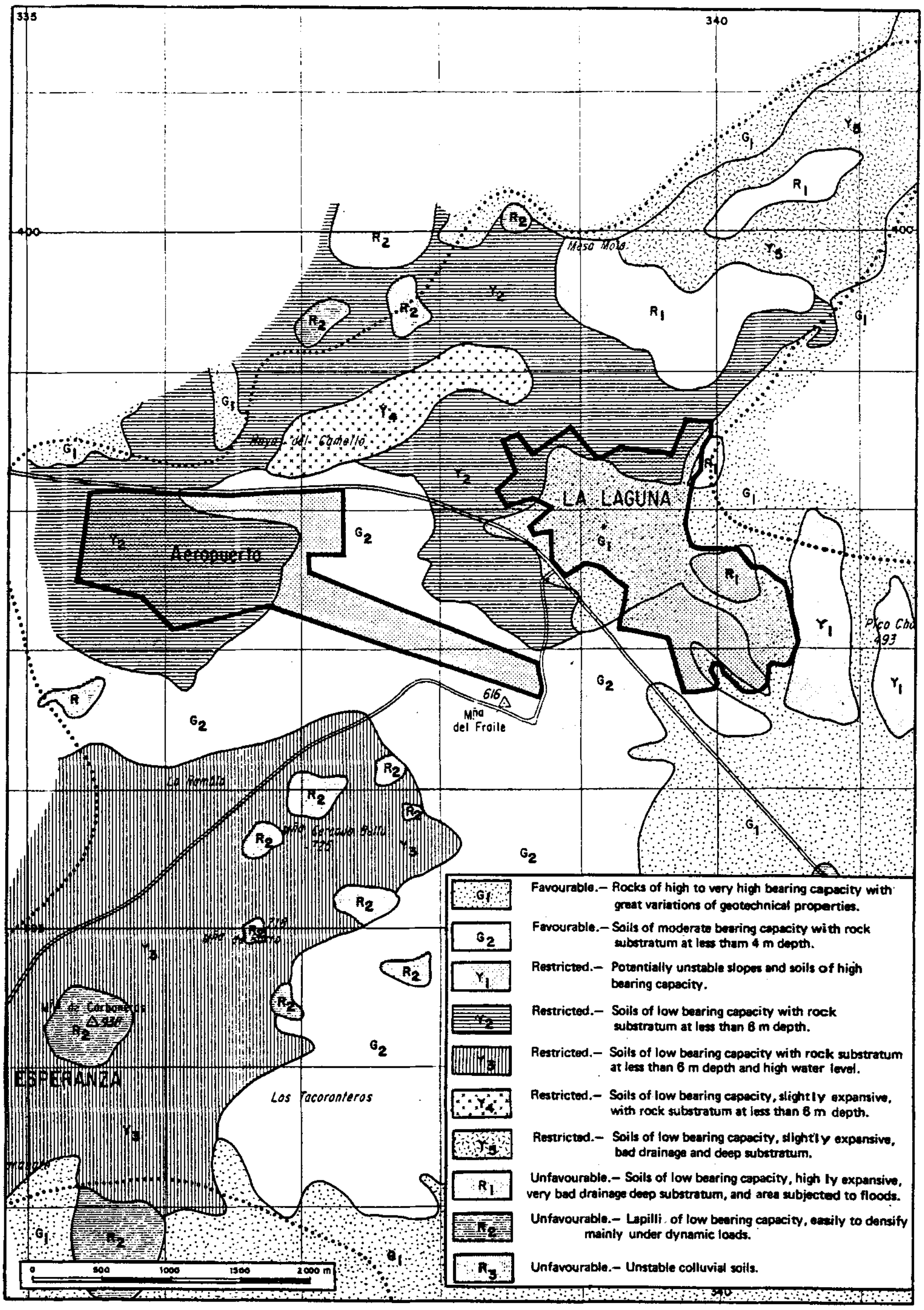


Fig. 5 : Urban suitability map for engineering geological conditions of an area from Tenerife

Discussion and Conclusions

Engineering geology can provide essential information for urban planning and development as follows:

I. Recognition of the problem
II. Evaluation of the problem
III. Anticipation of a general behaviour of the materials in relation to the engineering properties
IV. Prediction of general problems affecting the same engineering geological unit
V. Zoning the area in different ranges of urban suitability or risk
VI. Planning and development according to the characteristics of each zone
VII. Recommendation for detailed studies in order to apply remedial measures. and/or avoid or restrict development in appropriate areas.

The complexity of the urban environment, where no factor can be considered separately, makes it necessary to take into account some of the following questions when an evaluation of influence factors is carried out:

- Problems derived from intrinsic suitability evaluation, in which each factor is analysed independently, and restrictive criteria are applied, allowing the rating of different parameters.
- The evaluation of conflictive areas where there may be factors of the land in conflict at times with each other.
- Weighting different factors when considering a wide range of aspects; e.g. foundation conditions, waste disposal, earthquake hazards. In these cases it is quite difficult to establish rating systems and jointly to evaluate them as a whole. The suggested approach is:

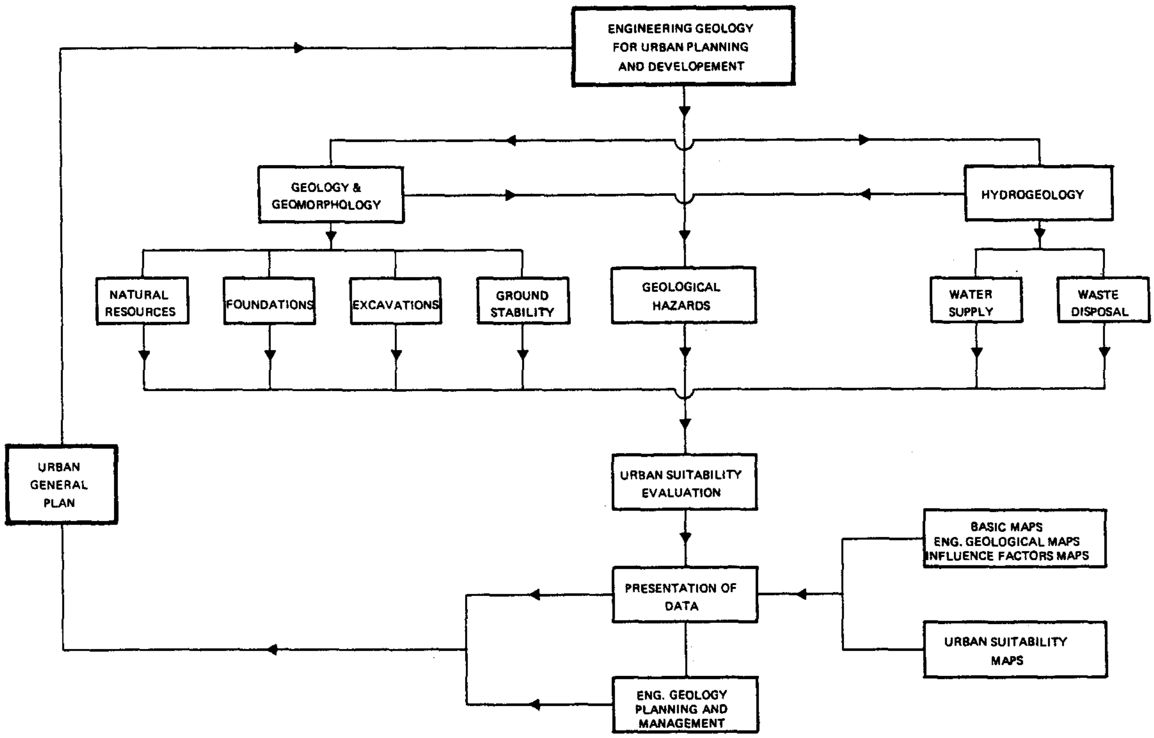


Fig. 6 : Engineering geology assesstment for urban planning and development

a) to evaluate in a first category those geological hazards which involve loss of life, and property loss and damage.
b) to establish a second category considering those factors which can severely affect environmental conditions.
c) to evaluate the remaining factors in economic terms when they do not substantially affect environmental conditions.

Engineering geological investigations should be carried out in the early stages of planning and during all the development and design stages. These investigations are particulary important for new towns, the peripheral expansion of existing towns and re-development. The "flow-chart" shown in Fig. 6 is a summary of the main stages of engineering geology for urban planning as discussed in this paper.

An engineering geology plan should always try to achieve the following goals:

- To optimize the whole environment
- To get the most economical solution for the urban plan.

Emphasis is laid on the importance of two aspects that need closer investigation and which should be included in all engineering geological investigations for urban planning:

I. The investigation of trends of engineering properties, and the degree of confidence in extrapolation of geotechnical data.
II. The changes, interferences or alterations that urbanization can produce on the geological environment.

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