SLOPE FAILURE IN CARACAS, VENEZUELA:
THE INFLUENCE OF SQUATTER SETTLEMENT

by

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ABSTRACT

In Caracas, Venezuela, landslides have become an increasing problem frequently associated with the rainy season and the creation of more vulnerable areas by the urbanization process. Their effects have been particularly evident in the squatter settlements or *barrios* in the hillsides surrounding Caracas. The purpose of this research is to examine the incidence of slope failure in the *barrios.* An account of the urban growth of Caracas is given in order to illustrate how population has been progressively occupying the valley and its hillsides. A data set of 205 slope failures which occurred over a six year period is set up. The slope failures in the Metropolitan Area are analyzed both spatially and over time in order to elucidate some of the factors responsible for their incidence. Besides location and date of occurrence, the data set incorporates rainfall seasonality and cumulative totals, lithology, slope angle, type of mass movement, and location within the urban context. The role of the rainfall as a triggering factor for the slope failures is examined. Cumulative rainfall values are considered for 10, 30 days and seasonally. With the help of a sequence of aerial photographs, the evolution of slope failure in *barrio El Ciprés* is used to examine the links between the settlement process and the evolution of the local geomorphology. A Landslide Susceptibility Map is then produced.

The research shows that rainfall plays an important role in the incidence of slope failures, but its influence in *barrios* is also compounded by other factors such as enhanced infiltration and the changes in slope produced by the settlements process. In this connection improvements in services and the consolidation of the *barrio* may add to the problem if they are not carefully planned.

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ACRONYMS USED IN THE TEXT

C.A.N.T.V.	Compañía Anónima Nacional, Telefonos de Venezuela
CECODAP	Centros Comunitarios de Aprendizaje
C.S.B	Centro Simon Bolívar
FUNDACOMUN	Fundación para el Desarrollo de la Comunidad y Fomento Municipal
FUNVISIS	Fundación Venezolana de Investigaciones Sismológicas
G.D.F	Gobernación del Distrito Federal
IMAU	Instituto Municipal de Aseo Urbano
INAVI	Instituto Nacional de la Vivienda
I.N.O.S	Instituto Nacional de Obras Sanitarias
M.A.R.N.R	Ministerio del Ambiente y de los Recursos Naturales Renovables
M.E.M	Ministerio de Energía y Minas
MINDUR	Ministerio de Desarrollo Urbano
M.O.P	Ministerio de Obras Públicas
MSAS	Ministerio de Sanidad y Asistencia Social
MTC	Ministerio de Transporte y Comunicaciones
O.C.E.I.	Oficina Central de Estadística e Informática
O.M.P.U	Oficina Metropolitana de Planeamiento Urbano
ORCOPLAN, R.C.	Oficina Regional de Cordinación y Planificación
UCV	Universidad Central de Venezuela

CHAPTER I

INTRODUCTION

1.1 SLOPE HAZARDS IN LATIN AMERICA

Housing the urban poor in the crowded cities of Latin America is already a complex task without the sudden demand caused by so-called 'natural disasters'. When these events occur, loss of lives and the level of disruption reveal the lack of preparedness in each country to deal with problems of such magnitude. This might also be the case for a developed country but the degree of vulnerability in the first case makes the overall effect worse.

A relatively recent disaster that stands out because of the magnitude of the losses it occasioned, particularly in terms of lives, is the volcanic eruption of Nevado del Ruiz in Colombia, during November 1985, in which 23,000 people were killed. Even more recently Hurricanes Gilbert and Hugo affected a large part of the Caribbean population, in 1988 and 1989 respectively.

In the Mexico City earthquake of September 1985 (7.8 on the Richter scale), approximately 10,000 people were killed and the estimated damage was 4,000 million US$. In the October 1989 earthquake in San Francisco (7.1 on Richter scale) 63 people were killed, "...many in the San Francisco Bay area where parts of the interstate 880 bridge collapsed" (Degg, 1992), and the damage was calculated at US$ 7,000 million. Although the estimated material loss seems higher for the second case, it is important to emphasise that the damage was also overwhelming to the properties of the urban inhabitants in Mexico, and therefore had a major impact on people's lives. The real values and meaning of property are different between different societies and could not be compared purely in monetary terms.

As Cannon (1992) states, there is in the literature "...a perception of disasters as having little impact in terms of deaths in industrialised countries but much material damage (in physical and value terms), while in the Third World the situation is seen as the opposite. This is based on a crude and ill-informed understanding of the value of a great deal of property in Third World countries for the actual users."

High magnitude-low frequency events such as earthquakes can obviously cause major disruptions and many have led to disasters. Although landslides are not considered to be as severe, they have also endangered the lives and properties of the inhabitants on many different occasions. Brabb and Harrod (1989) recognized that "...the extent and economic impact of landslides in the world are considerable, though not well known". He ascribes part of the difficulty in recognizing the scope of the problem to the fact that much landslide damage is masked by its association with other events. Here are some examples.

According to Cuny (1987: p.16), in the October 1986 earthquake in San Salvador

> "... a large percentage of the victims were squatters who, prior to the earthquake, were residing on marginal sites, such as the banks of steep ravines; along railroad tracks; and on public lands and or other sites that had been occupied illegally. Most of the houses were made of light-weight materials such as corrugated iron sheeting, cardboard, and wooden timbers. The majority of damages in this group, however, were not from the collapse of housing, but from landslides.(A large number of the victims were displaced persons who had moved to the city to escape the violence of the civil war in the countryside.)"

In northern Ecuador, March 1987, "The earthquake occurring at the end of the rainy season resulted in colossal mud slides that swept away 40 Kms of oil pipeline. Ecuador's economy is dependent on oil and as the pipeline was the only link between the oil fields and the ports the whole economy was brought to its knees" (Dudley, 1987: p.62). The following month, heavy rainfall triggered several landslides and approximately 100 people were killed (The Guardian, April 1987).

In May 1970, during an earthquake at Chimbote in Peru, "...50,000 people were killed, four-fifths in the landslide that engulfed the town of Yungay..." (Oliver, 1987: p.126). In the Guatemala earthquake (7.5 on Richter scale) of February 1976, landslides were also triggered (UNDRO, 1984: p.53).

In addition to being triggered by earthquakes, landslides have occurred as a result of more frequent events such as rainfall. They can be considered small dimension disasters, mainly but not only affecting communities located on the slopes, and in many cases they are an annual occurrence. Even so many cities still do not have the level of preparedness required to cope with such events.

In Brazil, in February 1988, as a result of heavy rainfall, landslides in Rio de Janeiro destroyed 500 homes and killed 94 people (Leite, 1988). The same source reports that the Civil Defence coordination assists an average of 200 accident occurrences per year, of which 21% refers to building collapses and 30% to landslides. Another 40% of assistance was for the *favelas* in cases where the shack collapsed from lack of technical or financial resources for the construction of safe and rain-resistant housing.

Early this year, another landslide was reported[1] in Teresópolis (Rio de Janeiro). This time a Civil Defence worker warned the household about the risk at 17.30 hours the evening before, but they refused to abandon their home. At 06.30 hours, after a night of rain, the landslide occurred. The seven members of the family were reported dead.

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[1] Jornal do Brasil, 6 January, 1992.

In Villa Tina, a shanty town in Medellin, Colombia, approximately 120 people were killed in a landslide that followed heavy rain in the area.[2] In October 1991, a landslide in Veracruz, Mexico, triggered by torrential rain killed 13 people, destroyed several homes and left 10 people missing.[3]

Other landslides that have occurred in Central and South America are: Mendoza, Las Cuevas (1965); Santos, Brazil (1956); Ceara, Brazil (1974); Sao Tome, Brazil (1974); Rio de Janeiro, Brazil (1966, 1967, 1983, 1987, 1988, 1992); Riñihue, Chile (1960); San Joseito, Colombia (1972); San Antonio de Prado, Colombia (1973); Quebrada Blanca, Colombia (1974); Medellín, Colombia (1974); Manizales, Colombia (1965, 1977); Bogota, Colombia (1983); La Piragua, Colombia (1985); Esmeraldas, Ecuador (1976); Morelia, Mexico (1969); Manzanillo, Mexico (1982); Huascarán, Peru (1962, 1970); Huaraz, Peru (1941); Mantaro River, Peru (1971); Chungar, Peru (1971); Yanacocha, Peru (1981); Yacitan and Cashipampa, Peru (1983) and Lima, Peru (1986).

In 1987, the United Nations declared the 1990s as the "International Decade for Natural Disaster Reduction". Special attention is focused in developing countries and as stated in the UN resolution (A/Res/42/169), the aim is to reduce, through concerted international action, loss of life, property damage and social and economic disruption caused by 'natural disasters'.

This is not an easy task in the already densely populated and still expanding cities of Latin America. Cities have often spread into the worst locations in terms of physical stability, such as hillsides prone to landslides and land subject to flooding. As Hardoy and Satterthwaite (1990: p.234) state, without changed policies "Cities will increasingly be made up settlements built on dangerous sites, continuing the long-established trends...". A consequence of the

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[2]Reported in The Guardian 29 September, 1987.

[3]Reported in The Guardian, 4 October 1991.

alteration of the natural characteristics of the environment is that morphogenetic processes have become a risk to the communities. As Cooke (1984: p. 35) states about Los Angeles: "Directly, urban growth is responsible for transforming geomorphological processes into community hazards".

1.2 ON THE DOWNWARD SLOPE: SQUATTER SETTLEMENTS AND LANDSLIDES IN CARACAS

In Caracas, Venezuela, landslides have become an increasing problem frequently associated with the rainy season and the creation of more vulnerable areas by the urbanization process. Their effects have been particularly evident in the squatter settlements or *barrios* in the hillsides surrounding Caracas, but no studies have looked closely at the problem.

1.2.1 A word of definition: *barrios*

The *tugurios* of Costa Rica, *vecindarios* of El Salvador, *favelas* of Brazil, *poblaciones callampas* of Chile, *villas miseria* of Argentina, *cantegriles* of Uruguay, *pueblos jovenes* in Peru, etc., are all shanty towns, but it is necessary to make clear that they may all refer to different standards in the different countries.

In the case of Venezuela, squatter settlement presents a wide spectrum of housing conditions, as seen in plate 1, ranging from precarious shelter to consolidated houses. Each shelter in the *barrio* is called a '*rancho*'. It is originally built of waste material or non-durable, non-perishable material. The author shares the view of Briceño (1986: p.77) that "...not all the houses in the *barrio* are *ranchos*...". He believes that the definition should not be based on the quality of the houses, or the quality of the basic services (sewage, water supply, electricity, etc). The criterion is "...the illegality or spontaneity or unpredictability of the way in which the

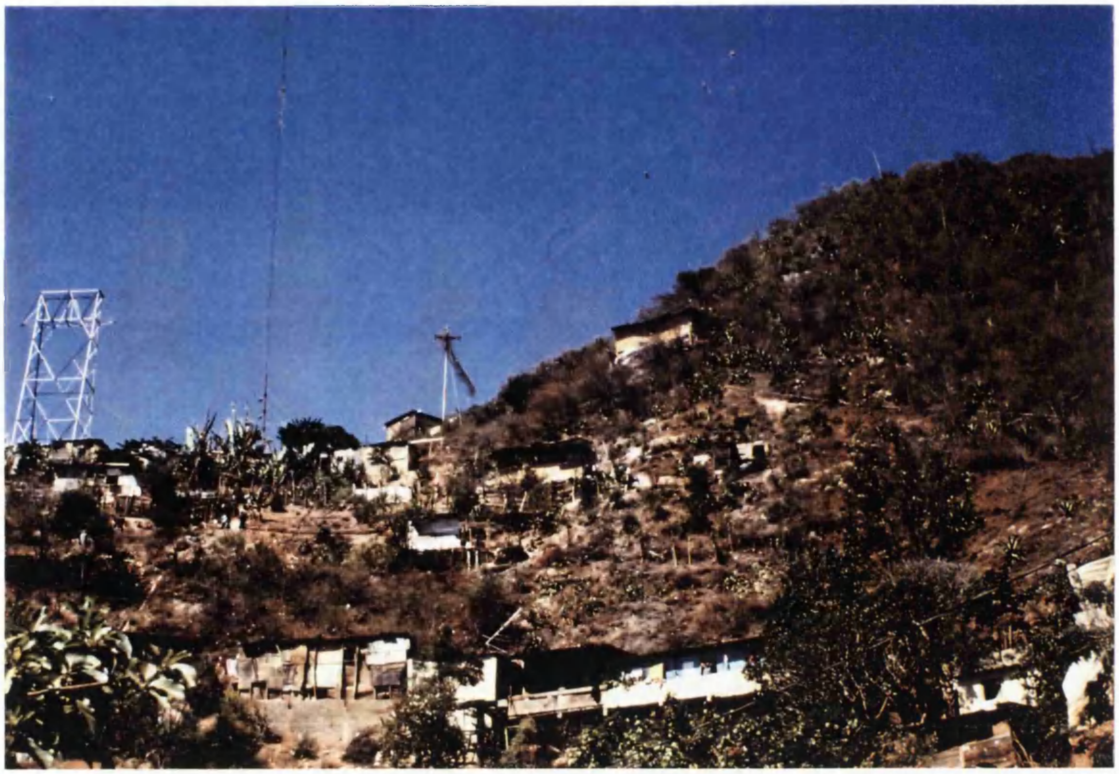


Plate 1: From shelters to consolidated houses

land is occupied, and the singular way of construction by which it evolves into an established urban area."

1.2.2 The incidence of slope failure

Table 1-1 shows slope failure events that have been reported between 1800 and 1988 in Caracas. It discriminates between slope failures that occurred in *barrios* from those that occurred in other urban locations except for those between 1980 and 1988. For this last period, such information is partial: data between 1980 and 1982 only consisted of the total number of slope failures; there were very few records for 1983 and 1984 (but those registered were mainly in *barrios*); and data from 1985 until 1988 were collected from the archives and files of the *Defensa Civil* (whose main records are from cases in *barrios*). It would be premature to conclude that most of the slope failures were in *barrios*, although that may well be the case.

In general, very few of the landslides in Caracas can be considered natural. The incidence of slope failures in Caracas has been partly a result of the establishment of urban areas that have been 'planned' without taking into account the stability of the terrain (plate 2). Frequently it is the case that slope failures occur in *barrios*, not only because of the already unstable natural conditions (as seen in plate 3), but also as a result of man-made changes to the slopes. A public statement was given by *Sociedad Venezolana de Geólogos* in 1988 which stated that only 40% of the Capital region presented an "...acceptable degree of safety."[4]

1.2.3 The rapid expansion of the *barrios*

The rapid growth of the *barrios* in the Metropolitan Area of Caracas would make difficult an attempt to plan or to determine the areas likely to be occupied. Bolívar (1988: p.6), using data from FUNDACONSTRUCCION and FUNDACOMUN, estimated that "...between 1978 and

[4]El Universal, 15 February, 1988.

Table 1-1: SLOPE FAILURES REPORTED IN CARACAS, VENEZUELA (1800-1988)

PERIOD	BARRIOS	OTHERS*	TOTAL
1800-1899	0	7	7
1900-1940	2	25	27**
1941-1950	2	1	3
1951-1960	2	5	7
1961-1970	7	5	12
1971-1979	122	99	221
1980-1988	-	-	266

Source: Inventario Nacional de Riesgos Geológicos (FUNVISIS)
Archives of Geotechnical Department (MEM)
Archives of Geomorphology and Soils laboratory (UCV)
Archives of Defensa Civil (GDF)
* : Roads and residential areas other than *barrios*
** : 21 landslides associated to the October earthquake of 1900 that affected the railway line Caracas-La Guaira.

Table 1-2: BUILT-UP AREA - METROPOLITAN CARACAS

LAND USE	SURFACE (ha)	%
Residential	3,700	23.7
Residential *barrios*	3,719	23.8
Commerce	2,500	16.0
Education	750	4.8
Government	450	2.8
Recreation	439	2.8
Industry	1,164	7.4
Military	340	2.1
Road	2,550	16.3
TOTAL	15,612*	100.0

Source: Diagnóstico Ambiental del Area Metropolitana de Caracas, in Ambiente (N.5, Año 6, 1982).

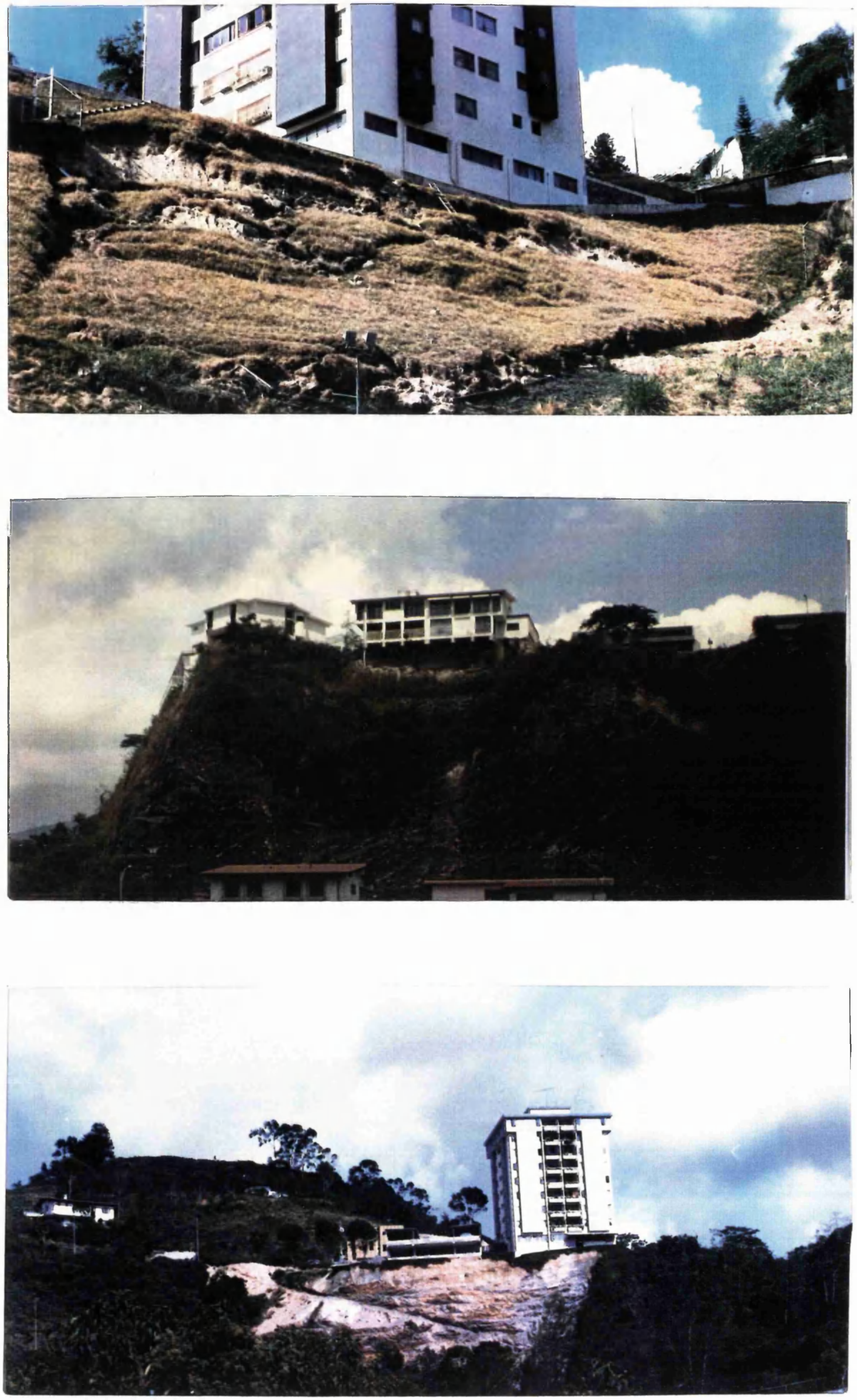


Plate 2: Evidence of instability in the more affluent areas of Caracas

Plate 3: Evidence of slope instability before the settlement process

Plate 4: Site for relocation of people made homeless

1985, the annual average of housing construction with planning permission was 37%, whereas the average of construction of *ranchos* in the same period was 63%."

To have an idea of the actual problem, it is necessary to mention that by 1985, 61% of the population of the Metropolitan Area of Caracas and Departamento Vargas was living in *barrio* settlements. Data about the area they occupy vary according to the source. Table 1-2 shows that by 1982 they occupied 24% of the total built-up area of the Metropolitan Area of Caracas. In 1990, according to the *División de Estadística e Informática* of FUNDACOMUN, the population in *barrios* formed 77.58% of the total population of the Metropolitan Area of Caracas (Soc. Xiomara Alemán, *pers. comm.*). An example of the physical growth of a *barrio* over a period of 19 years is given in plate 5 (p.29).

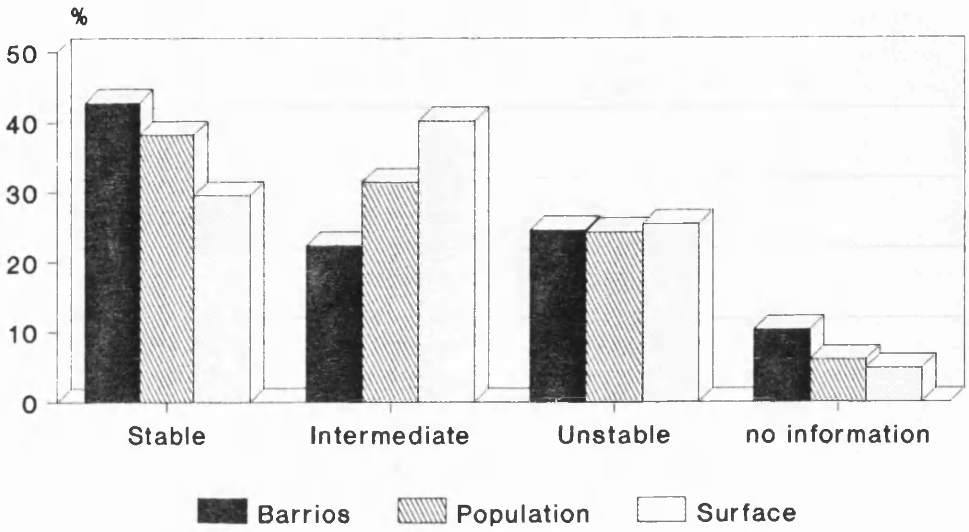
1.2.4 An argument for eviction

The argument of instability of terrains has been used to justify eviction of 67% of the total area occupied by *barrios* (Baldó and Bolívar, 1989: p.4). 573,949 inhabitants would be affected. This corresponds to 53% of the total *barrios* population considered for the study Barrios Urbanos del Area Metropolitana de Caracas[5] in 1984. This study classifies the *barrios* according to geotechnical conditions (figure 1.1). It is based partly on the Estudio Geotécnico del Area Metropolitana de Caracas. Sector Central, and reports and general information from the inventory of *barrios* published in 1978. The *barrios* are classified on a map according to the following grid categories for the purpose of geotechnical information: 'stable', 'intermediate', 'unstable' and 'without information'; and, for the purpose of governmental programmes in 'consolidated', 'to be consolidated' and 'no information'.

If the map is mainly based on the Estudio Geotécnico del Area Metropolitana de Caracas-Sector Central, it is important to note that such study is only for the purpose of

[5] Gobernación del Dtto. Federal, ORCOPLAN R.C., MINDUR, FUNDACOMUN, O.M.P.U.

Figure 1.1: *Barrios* classified according to geotechnical conditions



Source: 'Barrios Urbanos, Area Metropolitana de Caracas',1984.GDF-ORCOPLAN-OMPU MINDUR-FUNDACOMUN; Baldó & Bolívar,1989 geotechnical orientation. The scale of the study is 1:10,000, and at such a scale a very small area covered by a *barrio* shown on the map could include hundreds of houses. As the same study states (Feliziani *et al.*, 1985: p.4614) "Any professional decision to be taken in assessing geotechnical risk at detailed level has to be supported by studies of greater detail; it has to be based on the behaviour of the sub-units of each site, which the present study does not cover". In this case the resulting map which shows the supposed instability of the *barrios* in question might not be accurate (not for the study itself, but because the former will need greater detail). It follows that the grounds for eviction need to be revised (see Chapter 7, p.177). The subject was already mentioned in 1980: "It is necessary to eliminate eviction unless the security of the dwellers makes it necessary" Bolívar (1980: p.91).

As Baldó and Bolívar (1989) pointed out in a document issued to discuss the subject[6], the riot that occurred in February 1989[7] showed that the *barrios* dwellers might not be willing to accept this argument for eviction.

1.2.5 Who the land belongs to

An important aspect to be considered within the expansion of *barrios* settlements in Caracas is that, according to data published in 1984 by *Gobernación del Distrito Federal* (in Camacho and Bolívar,1987: p.8), 49% of the total area occupied by *barrios* settlements belonged to the State; 15% was private property; 19% mixed property (state and private sector). The ownership of the remaining 17% was not known.

Thus, according to this information nearly half of the *barrios* were settled on lands belonging to the State. When squatter settlements invade an area they are viewed with

[6] *La investigación de los terrenos como causal de desalojo de los barrios caraqueños, 1989* (The investigation of terrains as a cause for eviction in the *barrios* of Caracas).

[7] In February, 1989, there were riots in the main cities of the country as a result of popular discontent. The uprising led the government to declare a curfew and the suspension of constitutional safeguards. There were about 300 victims (or thousands, information differs depending on the source).

displeasure but, as the previous figure shows, the situation is often tolerated by the State. The complicity of the latter contributes to the production of *barrios* (Bolívar, 1988). The responsibility of course also lies with the leader of the initial occupation; the population occupying the land; and the public organization which represents the State (*op. cit.*: p. 12). The attitude of rejection is diminished partly because the political system is supported by popular votes. The settlement is later supported by the provision of the infrastructure and services necessary for the consolidation process (Camacho and Bolívar, 1987: p.10) as a populist way of getting support from the low-income communities. In some cases upgrading programmes to *barrios* are limited to the aesthetic aspects of housing (plate 6, p.33). The lack of continuity in the policies towards the *barrios* have contributed to the 'patchy' service supply they have. The investment and resources could have been more effectively allocated to social, legal and physical aspects of the problem. Physical conditions are considered only when landslides occur. Improvised locations for the homeless sometimes fail because land stability is not tackled (plate 4).

1.2.6 Who deals with the problem?

It was not until 1987 that the *Defensa Civil* drew up the Plan de Operaciones en Emergencias en Caso de Inundaciones y Derrumbes (Operational plan in the event of flooding and landslides).[8] The plan consist of a preventative and an operative phase.

The preventative stage proposes an inventory of all rivers and drainage lines and the cleaning, and maintenance of pipes for discharging water. A system of meteorological information is also proposed (especially forecasts for the following day). An inventory and relocation of houses located in areas at risk is also proposed. This first stage involves 14 government organizations.

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[8]As a result of the creation (*Instructivo Presidencial* N.5) in March 1986, of the *Comision Nacional para la Prevención Control y Defensa contra Inundaciones y otros Daños Producidos por las Lluvias* (National commission for prevention, control and defense against floods and other damages caused by the rain). The commission is formed by INOS, INAVI, Ministerio de Relaciones Interiores, Ministerio de la Defensa, MTC, MSAS, MINDUR, MARNR, OCEI, FUNDACOMUN. It also involves IMAU, Metro de Caracas, CANTV, Dirección de Obras Municipales (GDF), and CSB.

1959

1968

1978

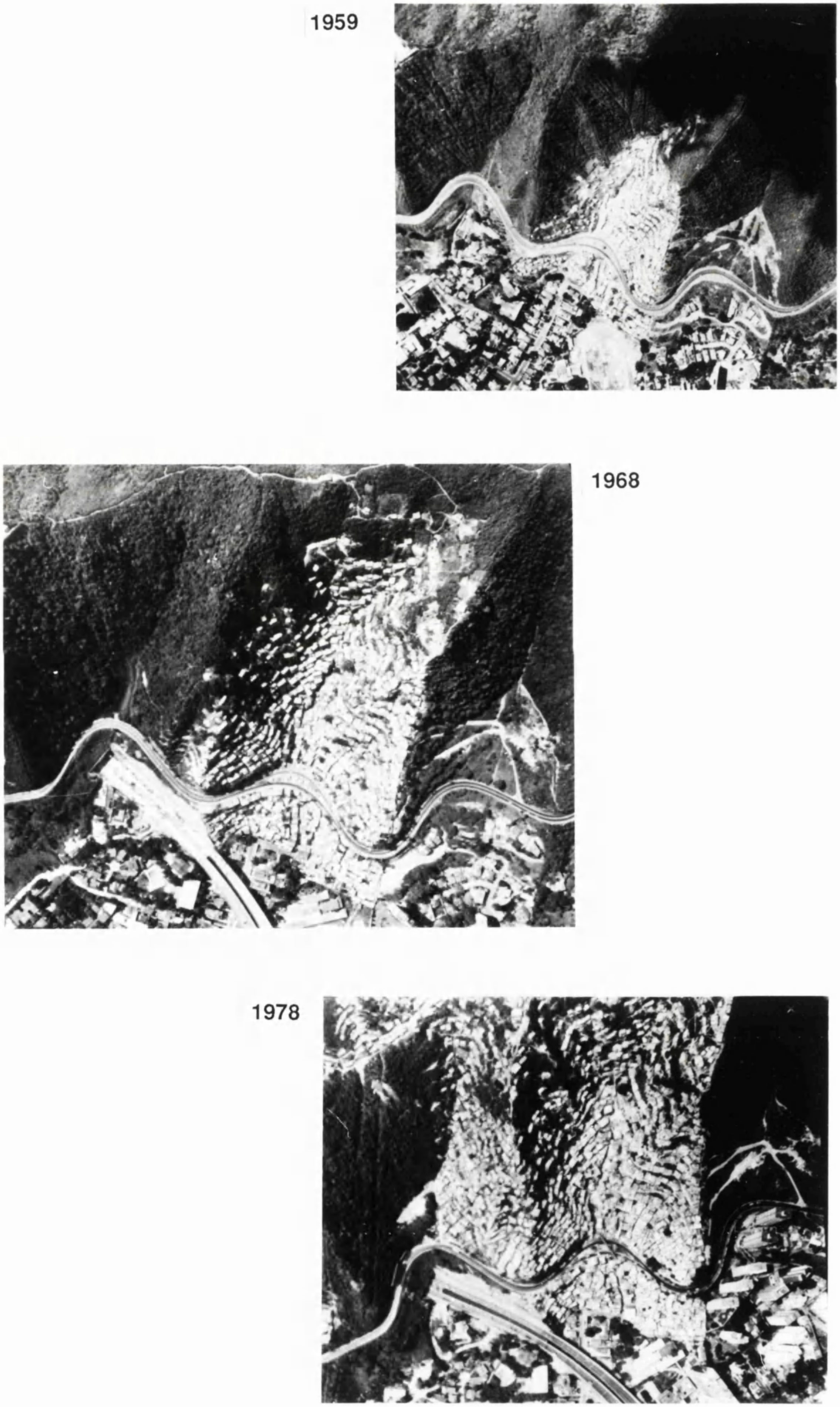

Plate 5: Physical expansion of *barrio Brisas del Paraiso*

The Operative phase involves various voluntary groups and organizations in the management of transport, accessibility and emergency services, and the restoration of public services affected as a result of the emergency. This second phase comprises 11 government organizations.

The plan also contains a schedule (procedimiento de trabajo) in the case of landslides and a list of *barrios* of low, medium and high risk (it does not give the source of information, or the procedure by which *barrios* are classified as such). This schedule outlines a not very precise set of actions to be taken in case of disasters, e.g. "...each group must go to the sites at issue at the beginning of a strong or violent rainfall..." (Defensa Civil, 1987: p.20) in order to evacuate the area promptly if there is a risk of landslides. The last section of the plan tries to assign responsibilities to each centre, group or individuals in the scene and it gives a set of instructions for communication between them but it does not specify any other action to be taken by them.

It is an attempt to deal with the problem, but unfortunately a *barrio* can occupy several hectares. In a city surrounded by 408 *barrios*, it is often difficult to be aware of the emergency situation that can arise almost anywhere. Without the means of identifying the unstable areas, with no warning system, and with the communication problems resulting from the heavy rainfall events (flooded streets, power failures, etc.) emergency planning becomes a difficult enterprise for the coordination body, in this case the *Defensa Civil*. The lack of resources is manifested as soon as the *Defensa Civil* visits locations where the inhabitants have reported unstable areas. *Defensa Civil* can propose the evacuation of the house or houses, but alternative housing is not available.

If it is to cope with the emergency the *Defensa Civil* needs to be allocated the necessary resources, personnel and information. Its response cannot be confined to the moment when the disaster occurs. It needs to include a prevention stage, actions during and after the disasters, and the provision of shelter as a long-term solution. Hundreds of homeless are provided for by 'provisional solutions' sometimes for periods of four years or more, as in the case quoted by Brumlik (1984) or as in Nueva Tacagua where the 'provisional' shelters in '*barracas*' (ravine and trailers) have been occupied for more than 14 years[9].

1.2.6 Risk assessment

On 20 August 1989, the 'disappearance' of *barrio 19 de Abril*[10], located in the north-west area of the city, was reported. According to the report, it included approximately 1,000 families, one primary school, and a Metropolitan Police Station.

The same source reports that, because of problems of instability, a containing wall worth 8 million Bolivars was built over a period of five months. Witnesses stated that a few days after the work had finished the road protected by the new wall started deteriorating and cracking until it collapsed completely. As the movement was progressing, the school and some houses were evacuated. The remaining families were sheltered by relatives and neighbours in the adjacent areas. The *Defensa Civil* used a tractor to open a 'hole' to drain the water coming from the houses located in the upper part of the *barrio*. Apparently it was known from the beginning that the construction of the containing wall had not taken into account the leakage of both sewage and clean water from the upper sectors.

Four years earlier, in July 1984, a study[11] of 16 barrios located in the area had anticipated the risk of this and other similar problems in the *barrios* (Jiménez *et al.*, 1984). The

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[9] Ultimas Noticias, 12 July 1988, p.32.

[10] El Nacional, 20 August, 1988.

[11] Implicaciones físicas, sociales y legales del proceso de ocupación del sector comprendido entre Blandín y Ojo de Agua (carretera vieja Caracas-La Guaira). Physical, social and legal implications of the occupation process in the area Blandín-Ojo de Agua

barrio in question had been founded in 1952. The *barrio* has 3,664[12] inhabitants or 1,804[13] depending on the source; 621 houses, and a density of 399 inhabitants per ha. The percentage of the *barrio* covered by aqueducts and sewage pipes according to the First Inventory of *Barrios* (FUNDACOMUN, 1978) was 98% and 90% respectively, but fieldwork showed that they were in very precarious conditions.

As regards the physical environment, the dominant slope angles exceed 50% (27°), the bedrock consists of quartz mica schist and regolith, and the main geomorphological processes are sheetwash (*escurrimiento difuso sin arrastre significativo de material*) and soil creep. About 31.9% of the area was found to be unstable; 63.6% of the area was potentially unstable; and 4.5% was moderately stable. From the 16 barrios studied, it was the only one that did not have any stable areas at all.

The condition of the *barrio* was summarised as "It presents a high percentage of potentially unstable areas, which means that any sudden modification could accelerate the morphodynamic processes taking place in the area. The inadequate maintenance of the basic services is one of the more negative factors and the one that gives the area its critical condition" (matrix N.2, column: *Condición actual del barrio*).

Six days after the newspaper report on the *barrio* in 1989, the then Director of the *Defensa Civil* commented "there is every chance that a calamity will take place tomorrow, within a month, next year or never" (in *Caracas Ciudad de Pre-damnificados*[14]). The spokesman here is the person who directs the institution responsible for coordinating action during disasters. A better approach than this has to be possible.

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[12]FUNDACOMUN- Fundación para el Desarrollo de la Comunidad y Fomento Municipal.

[13]OCEI- Oficina Central de Estadística e Informática.

[14]El Nacional, 26 August, 1989. c.1

"Toma aérea Hornos de Cal, Caracas"
Photograph taken from Briceño-León (1986)
Reproduced with permission from the author

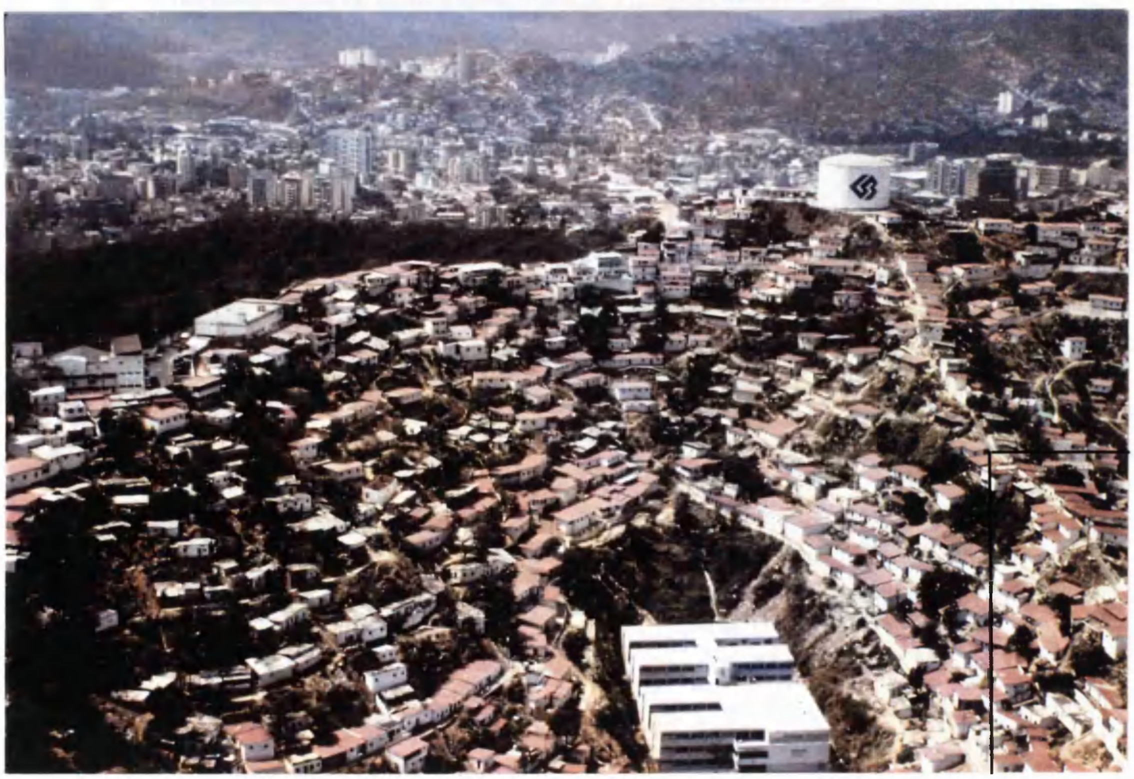


Plate 6 : Upgrading programme. *La Charneca-Hornos de Cal*, Caracas

1.3 PREVIOUS STUDIES

Although no studies were found regarding landslides directly related to squatter settlements, some ideas were drawn from previous work in applied geomorphology specifically concerned with urban development and slope instability. In a number of studies by Cooke (1984), for example, the role of the characteristics of the physical environment as 'predetermining conditions', the importance of the rainfall events as 'dynamics of change', and the consideration of the urban development were all combined to explain geomorphological hazards in Los Angeles.

In trying to understand the mechanism related to slope failure and the human impact, particularly valuable were Slope Instability (Brunsden and Prior, 1984); Hillslope Stability and Land Use by Sidle *et al.* (1985); Landslides: Causes, Consequences and Environment (Crozier, 1986); Slope Stability (Anderson and Richards, 1987); Geomorphology in Environmental Management (Cooke and Doornkamp, 1984); and Relative Slope Stability and Land Use Planning (Nilsen *et al.*, 1979), among others later mentioned in the text.

The absence of studies relating both subjects (i.e. slope instability and squatter settlements), led to the search for an explanation of the processes involved in the incidence of slope failures in Caracas. Studies of landslide hazard assessment in the Metropolitan Area of Caracas are mentioned in Chapter two when explaining the growth of the city. Although some work has been carried out on slope instability, its purpose is usually corrective engineering in which the cost tends to be deemed unjustified when squatter settlements are at issue. Investments are only undertaken when new residential areas or roads are being planned.

For the case study of the *barrio El Ciprés*, physical characteristics are assessed to produce a relative hazard map showing susceptibility to landslide processes within the selected area. An extensive review of methods for preparing landslide susceptibility maps has been outlined by Hansen (1984). Some studies consider only slope, bedrock and surficial geologic units, and landslide deposits, such as the study at a scale of 1:125,000 of the entire San Francisco Bay region Nilsen *et al.* (1979). Others employ Geographical Information Systems, including that by Carrara *et al.* (1991: p.434) which includes a data set in which "...each slope unit was associated with 40 morphological, geological and vegetational attributes." and which, after processing, was able to discriminate between stable and unstable slope units.

Landslides as slope processes are considered to be external expressions of geology, soils, climate, slope angles, vegetation and geomorphology. These parameters have been called 'internal causes' (Terzaghi and Peck, 1967), 'predetermining conditions' (Cooke, 1984), or 'preparatory factors' (Crozier, 1986). In the case of Caracas precipitation has been shown to be an important triggering factor in unstable areas.

To explain the combination of factors that can cause movement, a quantitative comparison can be made using the Coulomb-Terzaghi failure equation (Terzaghi and Peck, 1967) and "limiting equilibrium analysis". Here strength is represented as:

$$S = c + \sigma \cdot \tan \phi$$

where,

S= shear strength

c= cohesion with respect to effective normal stress

σ= total normal stress

ϕ= angle of internal friction (shearing resistance)

The effect of water in the slope is represented in the equation by adding u (pore-water pressure) which acts to reduce the normal stress. Thus the equation becomes:

$$S = c + (\sigma - u) \cdot \tan \phi$$

This equation represents specific conditions at one point of the slope; its application depends on the homogeneity of conditions (Crozier, 1986), which is not always found when considering natural slopes. Nevertheless, the relation is a useful theoretical tool to explain the influence of the active factors.

The following assumptions attempt to give an explanation of the mechanism whereby characteristics of *barrio* settlements could influence slope instability:

i) Variation in pore-water pressure towards a positive value. This can be developed as a result of increasing the amount of water in the slope by sewage or waste waters and drains. This accumulation of water, in many cases resulting from a lack of basic services, could also increase porosity by the promotion of weathering and, therefore, by decreasing rock strength. The depth reached by water as well as its effect on subsurface soil needs to be considered, as well as the modification of the natural lines of drainage. Broken sewage pipes might focus the effect of water accumulation and weathering at any point in the slope exacerbating the situation.

ii) Changes in unit weight as a consequence of settlement processes (including the replacement of cardboard for bricks), could alter the stability of the slopes depending on the characteristics of the slope-forming material. This is so in the case of cohesive slopes in which the factor of safety is reduced when surcharge occurs. In fine textured soils, surcharge has two different effects: an increase in strength as a result of internal friction (inverse relation) and the development of positive water pressure when reducing pore spaces. A worse situation is the presence of groundwater within the area of surcharge, making the overall effect dependent on drainage conditions.

iii) Variations of slope height as a result of excavation and cuts for houses and roads. This can lead to an increase in weight over a potential shear stress plane, as well as a lack of lateral support of the slope when the modification occurs at the base of the slope.

Modification within a slope seems to play a major role in the slope failures. As Sidle *et al.* (1985: p.84), observed:

> "Residential development of hillslopes (exclusive of road construction can decrease stability of terrain in the following ways: (1) removal of support by excavation, (2) mechanical overloading by fill placement, (3) concentration of water on the site or introduction of additional water, and (4) extensive removal or conversion of vegetation."

iv) <u>Concentration of runoff</u> by pavement areas and modification of natural drainage in the slope.

The modified slopes become a difficult case to assess in terms of stability. Moreover particularly in the *barrios* the lack of adequate quality data is a major limitation.

As in the case of Los Angeles (Cooke, 1984, p.37) "...urban development changes geomorphological systems in ways that are both spatially and temporally variable, and it thus adds significantly to the constantly changing nature of geomorphological hazards"

1.4 AIMS AND SCOPE OF THE STUDY

This research focuses on physical aspects of the location of *barrios*. Its main purpose is to identify the relationship of *barrio* settlements to the incidence and severity of slope instability in Caracas.

In order to achieve this aim, the research deals both with slope instability and with the settlement processes of the *barrios*. The occurrence of landslides and their consequences could be minimized in *barrios* if the mechanisms by which these movements are accelerated were known. Therefore, the study tries to identify the effects on slope instability of those factors directly associated with housing conditions in *barrios*, namely drainage systems, sewage, and changes in slope geometry produced by building.

The research attempts to focus on the human/physical interface. According to Johnston (1986: p.450), "More work on the interface between the vernacular human and physical geography (as in Cooke, 1984) is desirable, for the area is academically underpopulated." Goudie (1986: p.458), observes that the fragmentation of human and physical geography reduces "...the contribution that geographers can make to the examination and solution of fundamental world problems brought about by the increasing human pressures on environment and resources" The fact that a wide range of techniques or methodologies is often required makes it difficult to preserve a unified view when trying to analyzed a practical problem, as it is difficult to master two or more disciplines at a satisfactory level. What the author considers more important is that all the factors bearing on the problem should be identified. As Graham (1986: p.465) states "There is a great difference between alleviating symptoms and understanding the disease well enough to effect a cure". The parallel with this piece of research might be that trying to understand the slope instability in the *barrios* one is seeking to identify the role of the different variables in order to define a better-founded cure. Many of the specific solutions for the symptoms are in the hands of specialists; no solutions are possible without interdisciplinary work, and the solutions may be political even though the problem is a physical one.

On the other hand, research makes it possible to look further into problems that could be considered priorities and that do not receive enough attention in developing countries for many reasons including inadequate resources and lack of awareness.

i) Outline of the thesis

The opening chapters present an overview of the characteristics of the physical environment of the Caracas area and of the rapid urbanization process that has characterized it over the last three decades. Within this framework slope failures in the Metropolitan Area of

Caracas are analyzed both spatially and over time in order to elucidate some of the factors responsible for their incidence.

The purpose of the chapters 3 to 5 is to assess the possible significance of rainfall in defining the distribution of slope failure. A dataset of 205 slope failures which occurred over a six year period is set up. Besides location and date of occurrence, it incorporates seasonality and cumulative rainfall values, lithology, slope angle, type of mass movement, location within the urban context, and year of foundation of the *barrios* in question. The relationship between services (notably water supply and sewage) and *barrios* in Caracas is also included as a first step in analyzing the relationship.

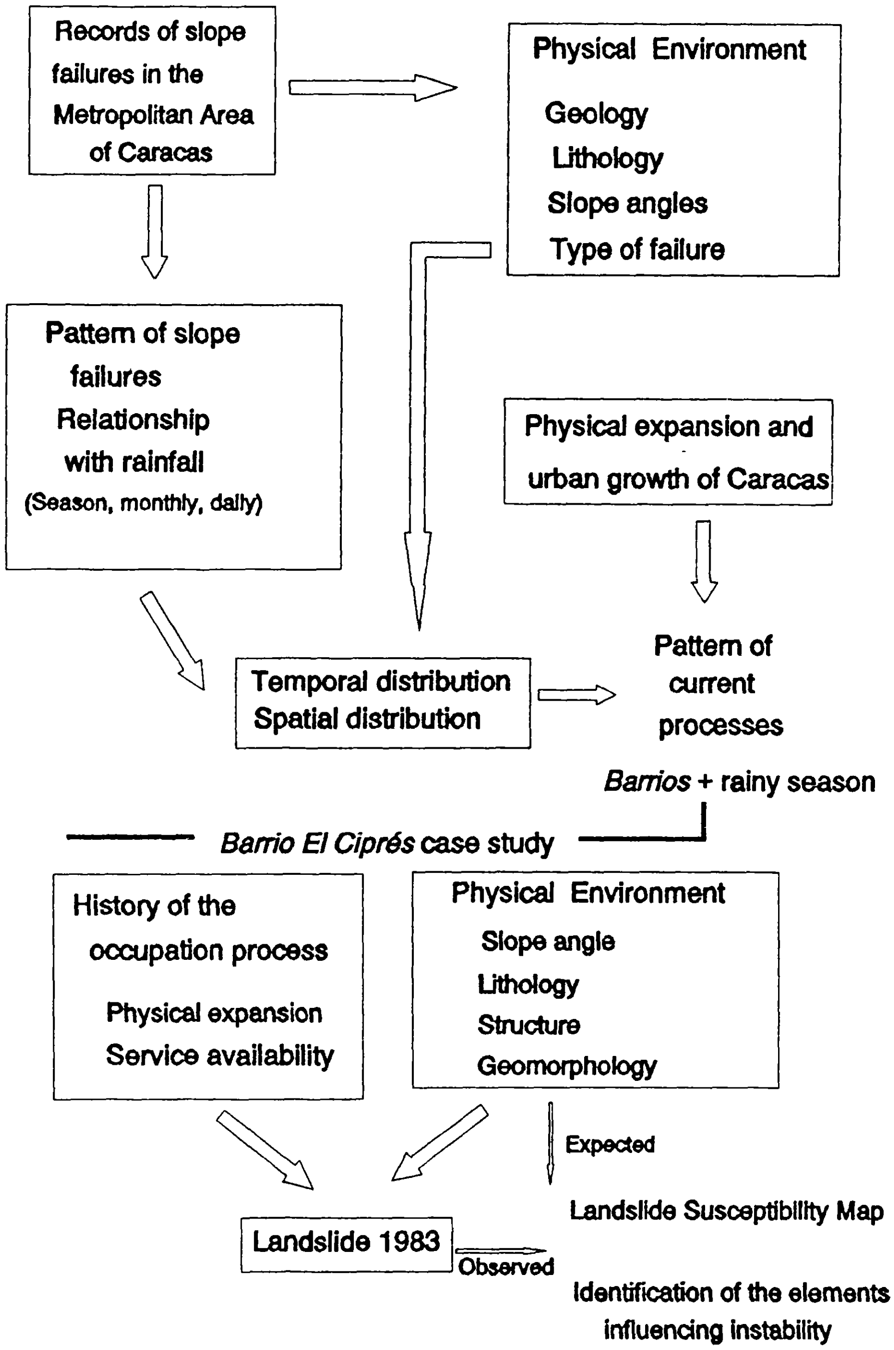
The final chapter 6 uses the *barrio El Ciprés* as a case study in order to relate the settlement process and the evolution of the local geomorphology using a sequence of aerial photographs. It illustrates the process from 1953 until 1983 which enables the identification at a more detailed scale of some elements influencing instability. A relative risk map is produced and recommendations are made about the actions that need to be taken to avoid major disasters. Figure 1.2 aims to show the pathways followed by the research.

ii) Methods

It was necessary to have a reference map of the general pattern of distribution and characteristics of the slope failures in Caracas. The role of rainfall was regarded as a major contributing factor needing to be considered.

According to Crozier (1986: p.171), if a climatic parameter is to provide some indications about thresholds, it "...should be specific to the hydrometeorological event itself but because such measurements are not always available, standard, calendar-defined meteorological parameters are most frequently used."

Figure 1.2: Research path



The same author mentions four different methods that can be used to determine thresholds: theoretical models, empirical tests, spatial and temporal correlation of landslides occurrence, and climatic events. He then notes:

> "The reliability of the thresholds established by any of these methods depends on the type of climatic parameter chosen, size (and therefore homogeneity) of the area under consideration, completeness of the data base, and the way in which mass movement is defined."

As Doornkamp (1982: p.215) comments: "... In many Third World countries a sufficient data set does not exist and alternative methods of predictions have to be found". The lack of data on squatter settlements, especially in terms of the physical environment, proved to be a major limitation when trying to find the factors that had led to previous landslides in these areas. As in the rest of Caracas, the place and date of occurrence were generally the only data available. In short, the experience gained from previous landslides has not been recorded in a way that assists subsequent analysis. The data thus had to be generated indirectly from maps (see § 4.2). In the case of the lack of hydrological data, precipitation (regarded as a major contributing factor) had to be taken as a guide to the amount of water in the slope, in the knowledge that such important factors as any dry intervals would thus be neglected.

The assessment for the case study *barrio El Ciprés* uses indirect mapping (Hansen, 1984). The characteristics of the physical environment reviewed include slope angle, geology (structure), lithology and geomorphology. The data acquisition and the methodology are explained in Chapter six. The study considers the methodology used in <u>Estudio Geotécnico del Area Metropolitana de Caracas. Sector Central</u> (Feliziani *et al.*, 1985). The evolution of geomorphological processes and the occupation processes of the *barrio* were traced with aerial photographs (1953, 1957, 1966, 1970, 1976, 1979 and 1983). In this way, a sequence of processes could be followed and present conditions better understood. The result is a relative susceptibility map showing four categories to define a range from stable to unstable zones.

CHAPTER II

CARACAS: A REGIONAL VIEW

2.1 INTRODUCTION

In searching for the factors that lead to slope instability in the Metropolitan Area of Caracas, the physical characteristics of the environment as well as man-made changes as a consequence of urban growth need to be considered.

This chapter attempts to give a regional overview of the characteristic of the physical environment and of the rapid urbanization process -mainly related to physical expansion- that has taken place in Caracas. This provides a framework in which slope failures will be analyzed both spatially and temporarily in order to establish the possible relations between the many factors that can operate in the complex process of slope failures.

2.2 CHARACTERISTICS OF THE PHYSICAL ENVIRONMENT

The Metropolitan Area of Caracas occupies one of the intramontane valleys of the *Cordillera de la Costa* (fig. 2.1), a tectonic belt parallel to the coast which belongs to the Caribbean Cordillera system.

The Caracas valley is located at 920 m above sea level. It is a graben clearly defined by *El Avila* fault system which runs east-west. The sediments of the valley were laid down in alluvial fans and consist of lacustrine and fluvial deposits. The thickness of this poorly sorted material varies according to the underlying topography. In general it is around 100 m but it

FIG. 2.1: METROPOLITAN AREA OF CARACAS

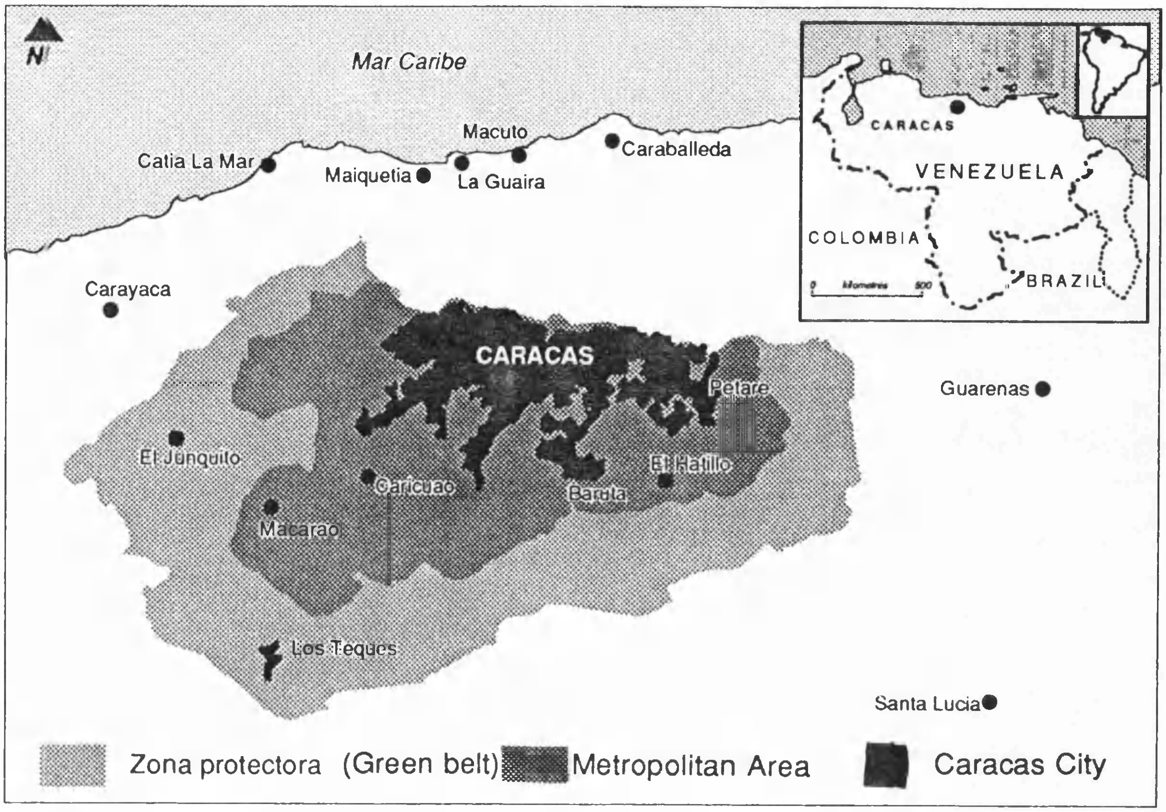
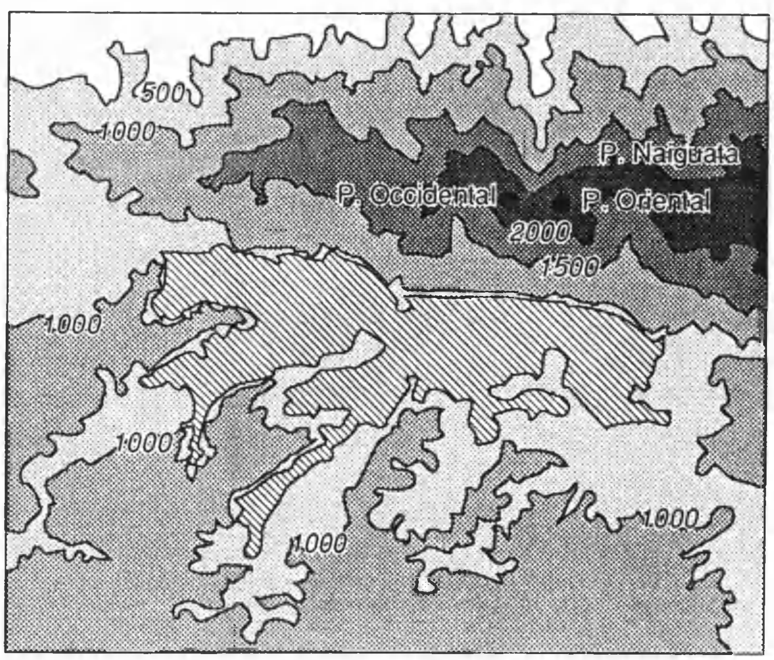


FIG. 2.2: CARACAS TOPOGRAPHY



attains 300 m in parts of the *Palos Grandes* depression *-cubeta de los Palos Grandes-* (Gonzales de Juana, 1980; Singer, 1977).

The northern boundary of this valley, *La Sierra del Avila*, is a large horst bounded by the fault system of the north coast and the *El Avila* fault system. The topography is varied (fig. 2.2). The highest peak, *Pico Naiguatá* (2.765 m), is less than 8 Km from the coast and *Pico Oriental* (2650 m) is a mere 5 Km away from Caracas (Gonzales de Juana, 1980). Consequently, the drainage systems in the northern part of the area consist of short torrents. A dendritic pattern dominates the rest of Caracas especially in the schist zones. The streams courses have been obscured and disturbed by the spread of urban settlement.

The vegetation cover has also been modified by occupation. It is typical of the tropophytic zone and comprises hill savannah (*sabanas de cerros*); deciduous upland woodland (*bosques deciduos montanos*) at altitudes lower than the *selva nublada* in *El Avila, Cotiza, Catuche y los Chorros*; and shrub vegetation (*matorral tropófilo*) especially on the hills around Caracas as it is a secondary community which replaces the original deciduous upland woodland destroyed by human activity.

The area is under the influence of the Trade Winds from the north-east and the Intertropical Convergence Zone. According to Koeppen's classification, it is considered a hot rainy isothermic climate of type A (Aw'i) (*clima cálido lluvioso tipo A*), with savanna (*herbazales*) and sub-humid tropophytic woodland (*bosques tropófitos*), and one annual rainfall maximum. There is a well-defined seasonal pattern of dry and wet periods during the year. The rainy season lasts until late November. The mean annual temperature in Caracas valley is 21.8°C.

The geology of Caracas has been studied mainly by Aguerrevere and Zuloaga (1937), Dengo (1951), and Wehrmann (1972). A comprehensive review of these studies and other regarding the geology of the area can be found in Gonzales de Juana (1980). For the purpose of this research the aspects to be taken into account are mainly structure and lithology as they strongly influence slope instability.

The main geological features are shown in fig. 2.3. Particularly noteworthy is the longitudinal system of faults (*El Avila*), striking east-west parallel to the coast and defining the border of the *El Avila* massif. Their dip varies between 40° and 60° N, and is locally vertical. The anticlines of *El Junquito* and *Baruta* whose approximate strike is N 70° E, and the syncline of *El Cementerio*, which separates them, are oblique to the fault system.

The area consists of a sequence of metamorphic rocks known as the *Caracas Group* which were deposited in a shelf environment at the beginning of the Andean Orogeny and folded when this reached its climax during the Eocene (Wehrmann, 1972). This metamorphic sequence of the late Jurassic-early Cretaceous is discordant over an igneous-metamorphic complex of the Palaeozoic Era (Silurian), the *Sebastopol Complex*. Table 2-1 shows the geological column of the Caracas Region.

The Caracas Group consists of five formations: *Peña de Mora*, *Las Brisas*, *Antímano*, *Las Mercedes* and *Tacagua*. The *Peña de Mora* Formation is an igneous-metamorphic complex, consisting of fine to medium grain-size gneiss, coarse and banded augengneiss, quartzite, quartz-muscovite schist, and occasionally amphibolite with local developments of thin marble. It outcrops in the northern part of Caracas where the predominant lithology consists of gneiss muscovite, composed of quartz (40%), feldspar (25%), muscovite (20%), chlorite (5%), epidote (10%), calcite (2.5%), and garnet (2.5%) (Wehrmann, 1972: p.2104).

The *Brisas* Formation is a sequence of meta-sediments from the Jurassic. It consists of quartz-feldspar-muscovite schist, and quartz-sericite-graphitic schists, and outcrops in the

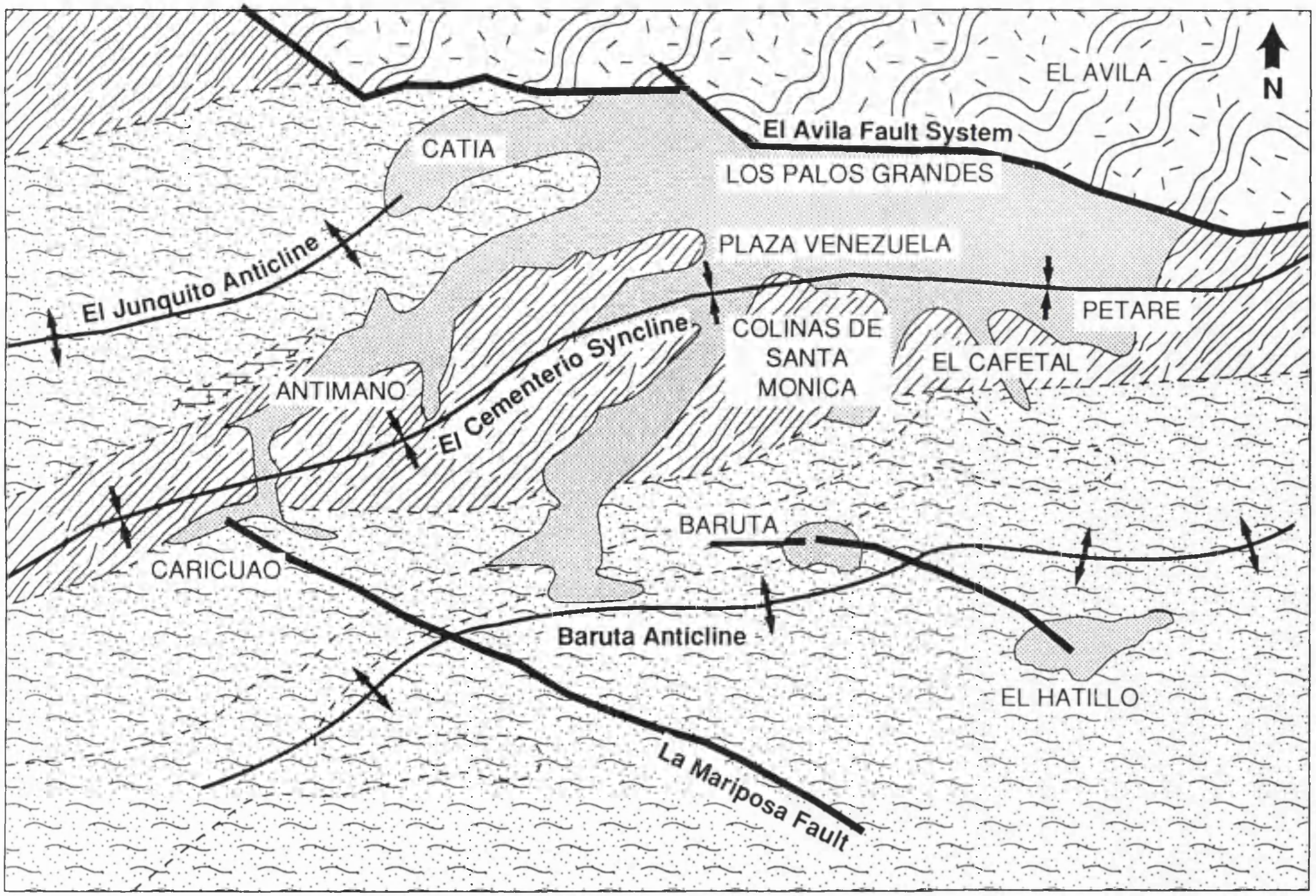


FIG. 2.3:
GEOLOGICAL MAP OF CARACAS
Main Features

LITHOLOGY

- Aluvium - Coluvium
- Calcareous Schists (KLM)
- Marble (KA)
- Quartz - Mica Schists (JLB)
- Gneiss - Pena de Mora (JPM)
- Lithological contact

STRUCTURE

- Fault
- Syncline
- Anticline

SOURCE: VI Congreso Geologico Venezolano excursion N.6 - Geologia Urbana de Caracas. Departmento de Geotecnia. - MEM.

TABLE 2.1: GEOLOGICAL COLUMN. CARACAS REGION

<table>
<tr><td rowspan="2">QUATERNARY</td><td>Holocene</td><td colspan="2">Aluvial</td></tr>
<tr><td>Pleistocene</td><td>Mare
Playa Grande</td><td rowspan="2">Grupo Cabo Blanco</td></tr>
<tr><td>CENOZOIC</td><td>Pliocene</td><td>Las Pailas</td></tr>
<tr><td rowspan="6">MESOZOIC</td><td rowspan="4">Cretaceous</td><td colspan="2">Chuspita</td></tr>
<tr><td>Tacagua</td><td rowspan="5">GRUPO CARACAS</td></tr>
<tr><td>Las Mercedes</td></tr>
<tr><td>Antímano</td></tr>
<tr><td rowspan="2">Jurassic</td><td>Las Brisas</td></tr>
<tr><td>Peña de Mora</td></tr>
<tr><td>PALEOZOIC</td><td></td><td colspan="2">Complejo de Sebastopol</td></tr>
</table>

Source: Mapa Geológico de Caracas, 1986

core of *El Junquito* and *Baruta* Anticlines. According to Gonzales de Juana (1980: p.312), its average mineralogical composition is quartz (25%), plagioclase (25%), muscovite (15%), biotite (5%), k-feldspar (5%), calcite (5%), chlorite (4%), epidote (2%) and small quantities of graphite, amphibole, tourmaline, garnet, titanate and pyrite.

The *Antímano* Limestones are defined as a series of marbles interbedded with mica-schist. Their composition is mainly calcite (90%) with small quantities of quartz, muscovite, pyrite and graphite. Quartz veins are frequent. The formation is exposed north of Antímano. Its probable age is mid-late Mesozoic.

The *Mercedes* Formation probably dates from the upper Jurassic Superior-Lower Cretaceous and consists mainly of graphite-calcareous schist and lenses of limestone, with quartz-muscovite-graphite-calcareous phyllite. It displays veins of quartz calcite and ankerite. The material is intensely folded. The average mineralogy consists of quartz (40%), muscovite (20%), calcite (23%), graphite (5%),iron oxides, epidote and plagioclase (Gonzales de Juana, 1980).

The *Tacagua* Formation consists of a sequence of sericite-schists intercalated with quartz-graphite-calcareous schists. It probably dates from the upper Jurassic Superior-Lower Cretaceous. It does not outcrop in the area of study.

2.3 METROPOLITAN AREA OF CARACAS

The Metropolitan Area of Caracas (AMC) has changed in extent since its creation in 1950. As a result, various documents and data refer to different areas, making the comparison of data between documents difficult. Hence in the account of urban growth that follows there will be no reference to the percentage of the area occupied by *barrios* at any one period. Instead, absolute figures for both population and area will be given.

The existing definition of the Metropolitan Area of Caracas is not based on natural boundaries and is purely administrative. When possible, the definition used in this study will be the one given in decree N.929 of April 5th, 1972, namely:

> "...para fines estadísticos y censales y para todos los efectos administrativos, se define como Area Metropolitana de Caracas el area comprendida por el Departamento Libertador y parte de la Parroquia Carayaca del Departamento Vargas del Distrito Federal, el Distrito Sucre y los municipios San Antonio, Carrizal y Cecilio Acosta del Dtto. Guaicaipuro del Edo Miranda."[1]

On the other hand the *Parroquia Carayaca* is left out of this account. According to Guevara Díaz (1980), in El concepto de Area Metropolitana de Caracas y sus cambios espaciales, that parish (758 inhabitants) is often omitted from population statistics for the Metropolitan Area of Caracas:

> "En los datos de población no se incluye a la población correspondiente a la parte de la Parroquia de Carayaca perteneciente al AMC como tampoco lo hacen las publicaciones censales y que para el año de 1971 era de 758 habitantes." (pag. 8, Síntesis Geográfica).

According to the same author, this definition (derived from the one given in 1969) has become the most commonly used and best known.

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[1]For statistical, census, and for all administrative purposes, the Metropolitan Area of Caracas is defined by the above mentioned parishes of Caracas and the adjoining municipalities of the *Estado Miranda*.

2.4 URBAN GROWTH AND PHYSICAL EXPANSION OF CARACAS

Although Caracas is a city more than four centuries old, it is only in this century, and in particular the last 40 years, that rapid population growth has become evident in terms of space.

The shape of the valley has played an important role in the process: the flat areas have facilitated continuous urbanization towards the east while the abrupt and steep areas of the north-west and south, known as *Terrenos baldíos* (waste land), have become the only available land for the low-income groups, unable to compete in the housing market. Associated with this, is the fact that the development of the city has been the result of a series of plans, some of them improvised, drawn up to satisfy different aims.

The following pages are devoted to tracing the physical expansion of the city in maps. The aim is to reveal some of the factors that may help to explain the vulnerability of some communities to the risk of slope failures in Caracas.

The layout of the city has gone through different stages. The early maps presented for this section are based mainly on the account of the city by Perna (1981). For the period of the last decades, the sequence will also include documents drawn from Atlas, government decrees, inventories, etc.

Since the *ordenanzas* of Felipe II, centralization has been the key to political and economic control of the population. The *ordenanzas* consisted of a set of comprehensive rules which specified the location and design criteria of the human settlements to be founded for the benefit of the Spanish administration (Brumlik, 1988; Perna, 1981). The documents also took into account the future expansion of the cities in an orderly way.

Caracas was founded in 1567. Figure 2.4 shows the *Primer Plano de Santiago de León de Caracas* in 1578 by the governor Juan de Pimentel and its equivalent area on a contour map (figure 2.5). According to the census taken by the colonial government in 1580, the city then had 2.000 inhabitants. The city initially grew south towards the *Guaire* river and west between the rivers *Caroata* and *Catuche*. It registered a very slow increase in the XVII century. Moreover, an earthquake in June 1641 struck the city claiming between 300 and 500 victims. There was damage to buildings and churches. The tremor was estimated at 6.3 on the Richter scale (FUNVISIS, 1981). A proposal to move the site of the city to the west was rejected by the Bishop. Fig. 2.5 shows the expansion of the city at the end of the century (Perna, 1981: p.37). Caracas now had 6,000 inhabitants. In the early 1600s the space between the streets (mainly those running north-south) was paved with stones, to reduce damage by runoff (Perna, 1981: p.31).

Partly as a consequence of the introduction of coffee growing in the valley, the city exhibited some growth between 1683 and 1789. The *Exato Mapa de la Ciudad de Caracas* by Don Juan de Bolívar y Ponte (fig. 2.6) provides a view of the city in 1772. Caracas by now had 20.000 inhabitants, 200 hundred years since the map drawn by Pimentel, but physical expansion is not much in evidence (fig. 2.7).

The *Plan de la Ville de Caracas*, was produced by Francisco Depons in 1801 (fig 2.7). Although he reported a population of 42.000 people, it shows almost no difference from the map produced in 1772. The lack of physical expansion seems to be explained by the higher density in existing '*solares*' or '*manzanas*'. Another map was produced in 1810, similar to that of Depons.

In March 1812, another earthquake estimated at 7.1 Richter scale struck the city. 10.000 people were affected, two thirds of the buildings were destroyed, and the rest suffered

PRIMER PLANO DE SANTIAGO DE LEÓN DE CARACAS - 1578

Source: *Caracas histórica. Atlas de Venezue*

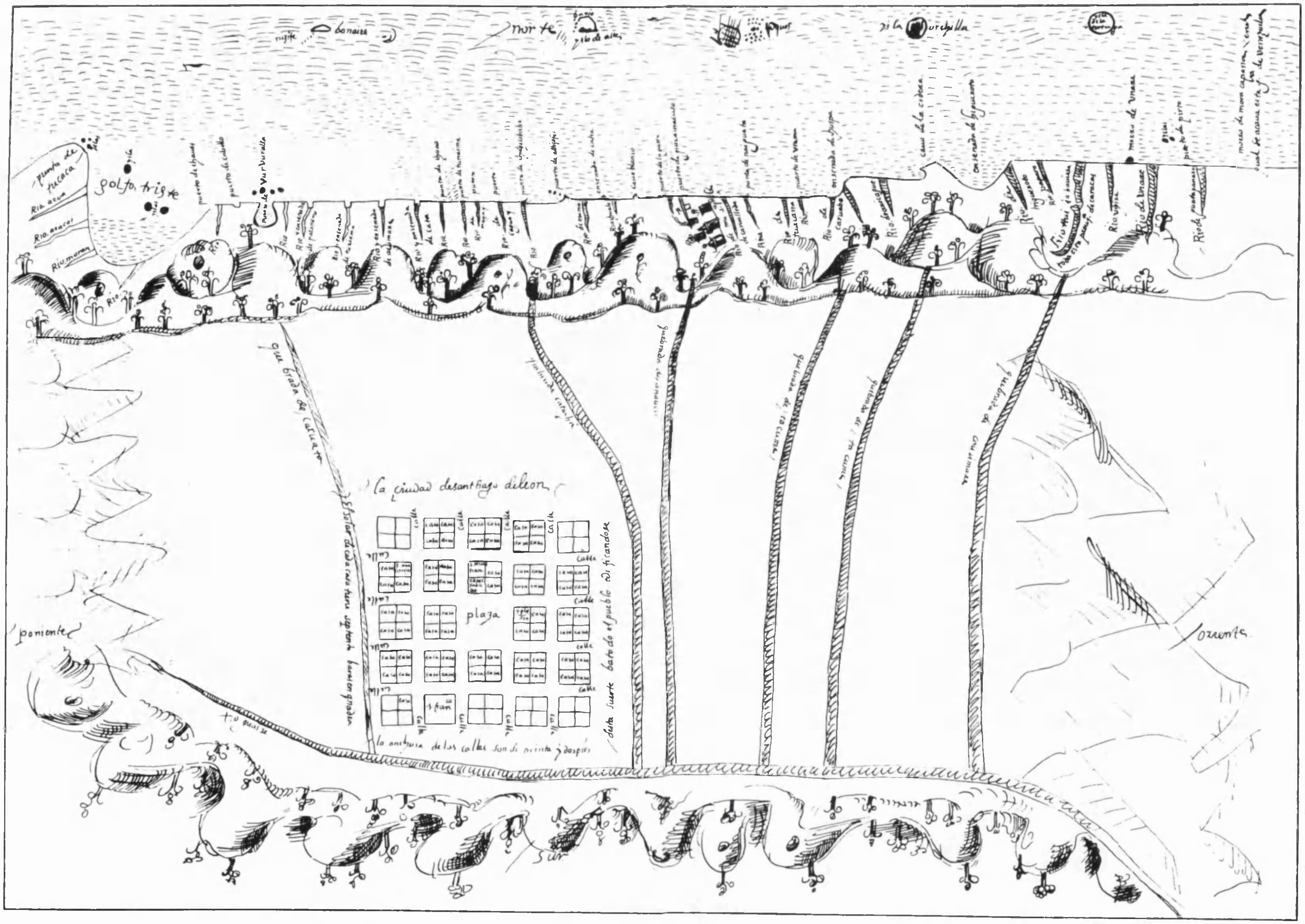


Figure 2.4: First map of *Santiago de León de Caracas*

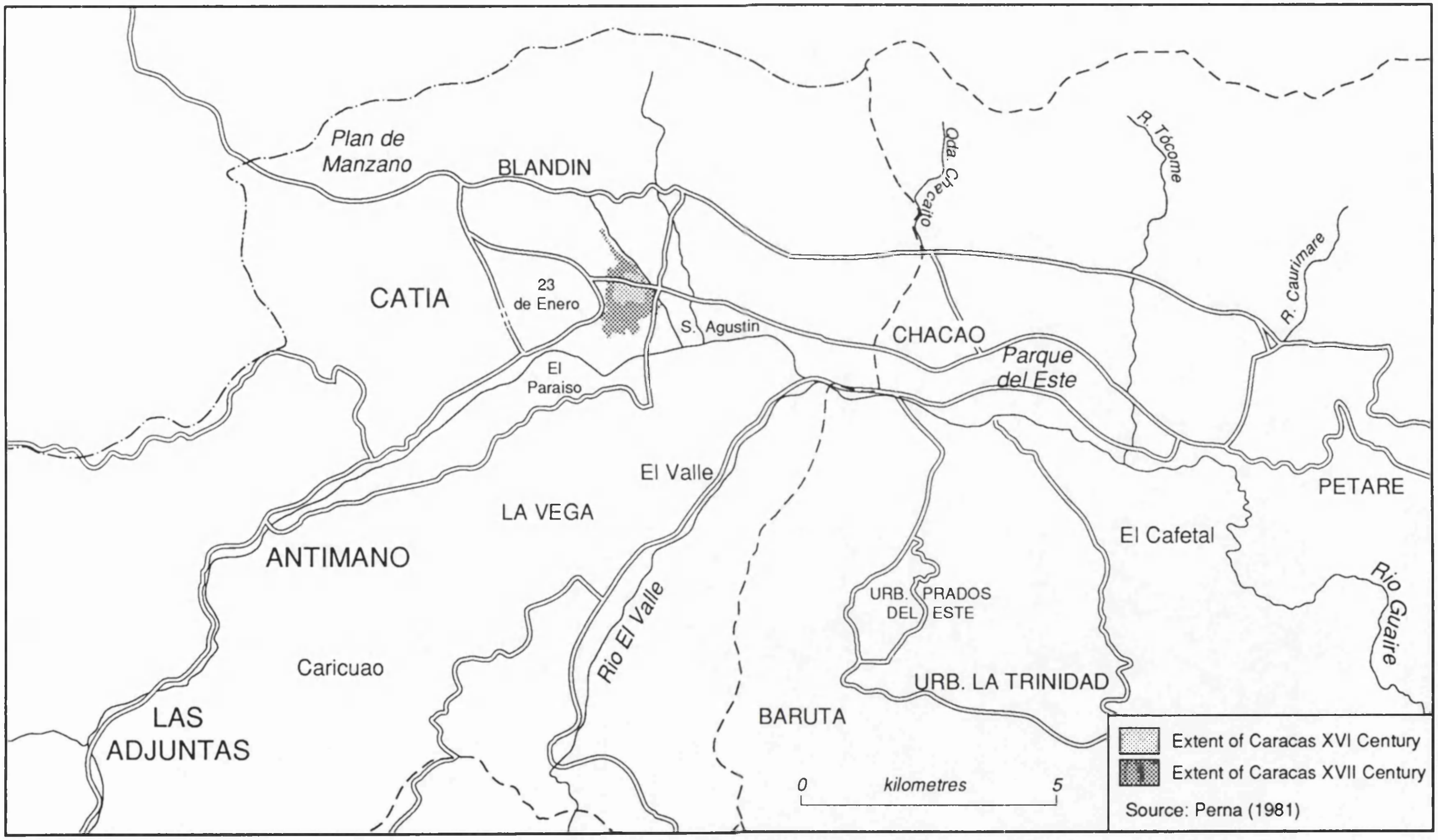


Fig. 2.5: Caracas XVI-XVII

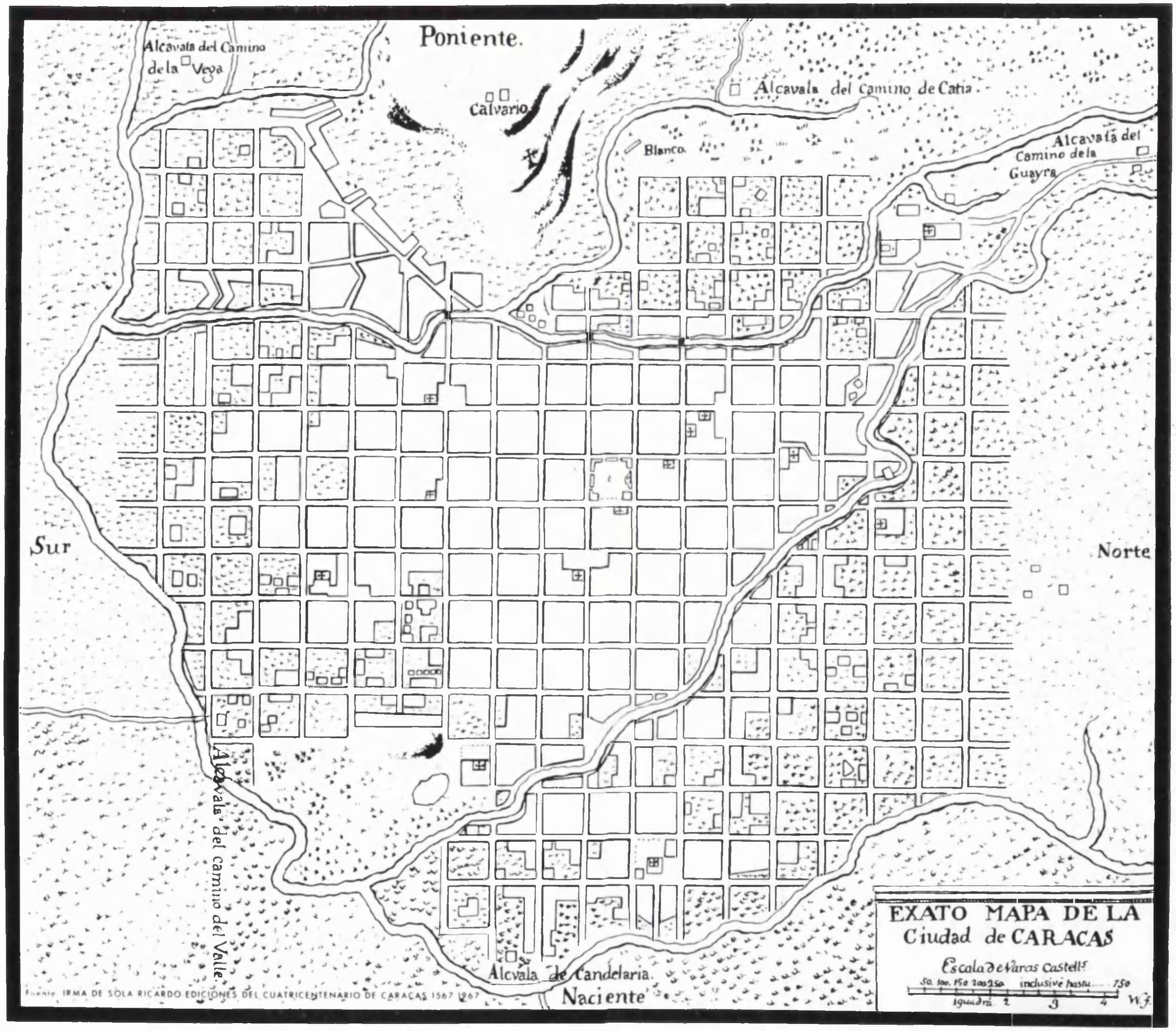


Figure 2.6: Caracas 1772

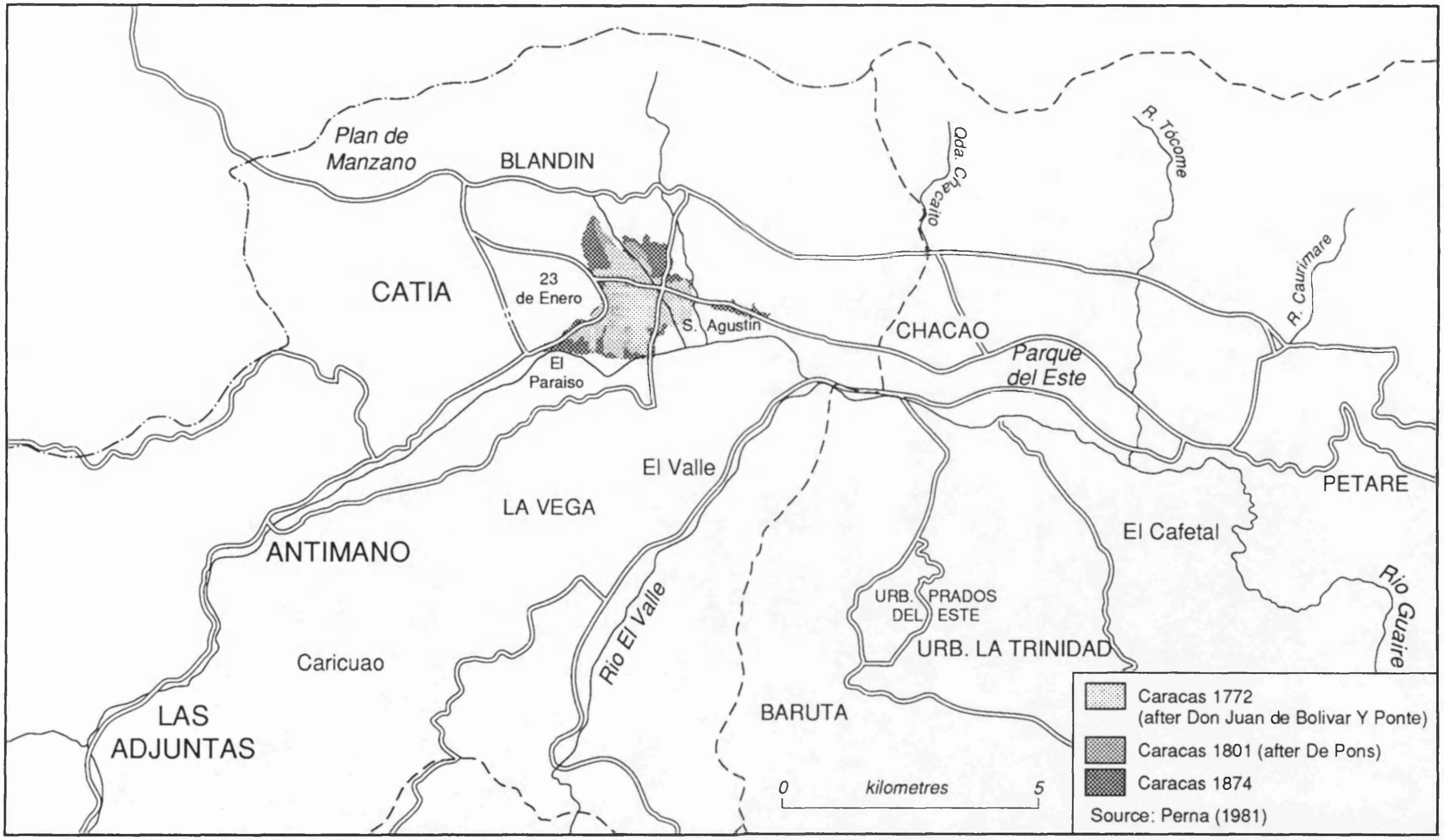


Fig. 2.7: Caracas 1700-1800.

cracking. In 1820 an *ordenanza* attempted to regulate the growth and structure of the city, but it was not put into practice. The only measure taken by the town council (*Concejo Municipal)* in 1821 was to name the streets and mark the houses.

After 1870, the dictatorial regime of Guzmán Blanco began to modify the city with the erection of museums, palaces, and the first aqueduct 46,037 m long. Fig 2.7 shows the expansion of the city by 1874. According to the census taken in 1883, Caracas had 70.509 inhabitants living in 9.224 houses. By the end of the century population growth had become evident with the construction of *El Paraíso*, an *urbanización* or housing state south of the *Guaire* river which replaced the old farms there.

The start of the XX century was marked by another earthquake, on 29 October 1900. Caracas had an urban space of 300 ha (Perna, 1981: p.104). The *Plano de Caracas* drawn by Ricardo Razzetti in 1906 (Fig. 2.8) shows that the city had expanded south of the river, a process facilitated by the construction of bridges. Around 1917, groups of people without titles to land started squatting in various parts of the city: *Potrerito* and *El Saman* near the centre of the city, and *La Hoyada* and *La Lareda* near *La Vega* towards the south of the city. These were the first *barrios*. The city remained much the same until the 1920s. During this decade, U.S. Standard Oil through the Creole Petroleum Co. began to control part of the oil activities in Venezuela with the support of the dictatorship. The inhabitants saw little of this income. In response to public protests and the activities of a variety of popular movements, the government set up an agricultural credit bank - the *Banco Agrícola y Pecuario*, and introduced legislation controlling working conditions (the *Ley del Trabajo*). Also in 1928, the *Banco Obrero* was created, the first official attempt to tackle the problem of housing for low income communities.

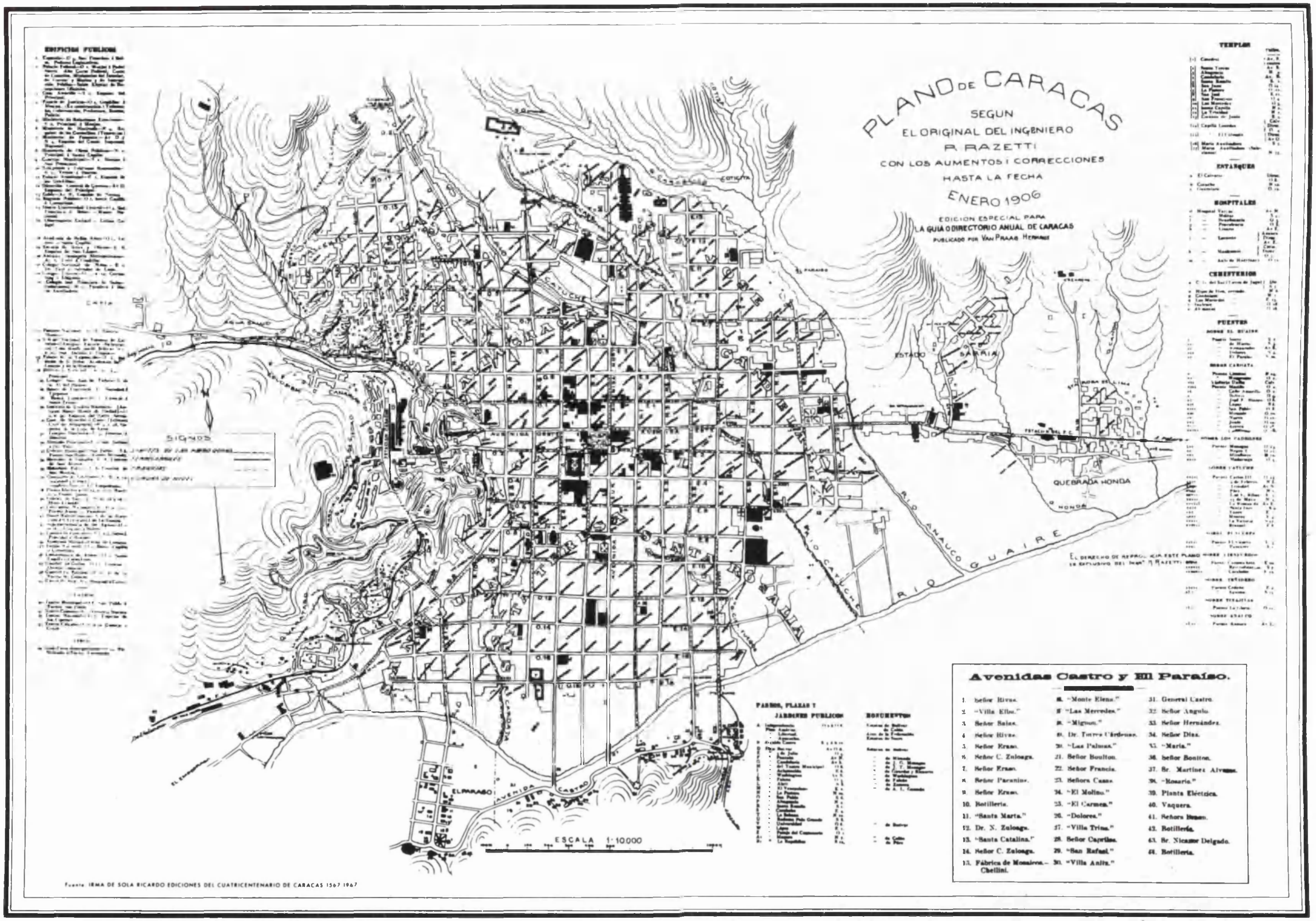


Figure 2.8: Caracas 1906, *Plano de Caracas*

At this time, and as an indirect consequence of the income from the oil activity in Venezuela, construction was stimulated. Thus the suburb of *San Agustín del Norte* was built in 1926. According to the population census in that year Caracas had 118.000 inhabitants and 750 ha of built-up area (Perna, 1981: p.110). The two main factors that promoted the concentration of population were the construction of roads to connect the city with the rest of the country, and a shift in the land use pattern from agriculture by urban. The later involved the displacement of the bourgeoisie towards the east of the city in new *urbanizaciones* which was facilitated by the construction of roads and infrastructure by the State. The valley consisted of farms (*haciendas*) and small villages linked to the city. Towards the west, the population started to settle near to the main roads.

By 1936 Caracas had become a city of 259.000 inhabitants. The second dictatorship ended and a strong migration process started. The peasants were no longer linked to the old system of '*fiches*', which for a long time hindered mobility between haciendas. Also in that year a second attempt was made to regulate the city by the *Plano Regulador de Caracas* with the aim of organizing roads and the administrative functions of the core of the city. More areas were built, namely *El Silencio, El Calvario* and the *Parque Los Caobos*. Westward development continued in 'patches', *La Florida, Mariperez, Las Delicias, Country Club*, etc, which gradually replaced the *haciendas*.

The census of 1941 showed that Caracas had a population of 269.030 people. The urban area measured 2.900 ha. The Second World War triggered an oil boom in Venezuela. More *urbanizaciones* were constructed. Fig 2.9, shows the expansion of the city at a time when private sector encouraged urban development. According to Perna (1981: p.120): "uncontrolled houses covered an area five times greater than in 1930". Fig 2.11 shows the *barrios* built up to 1948 in more detail. In 1950, a decree defined the Metropolitan Area of

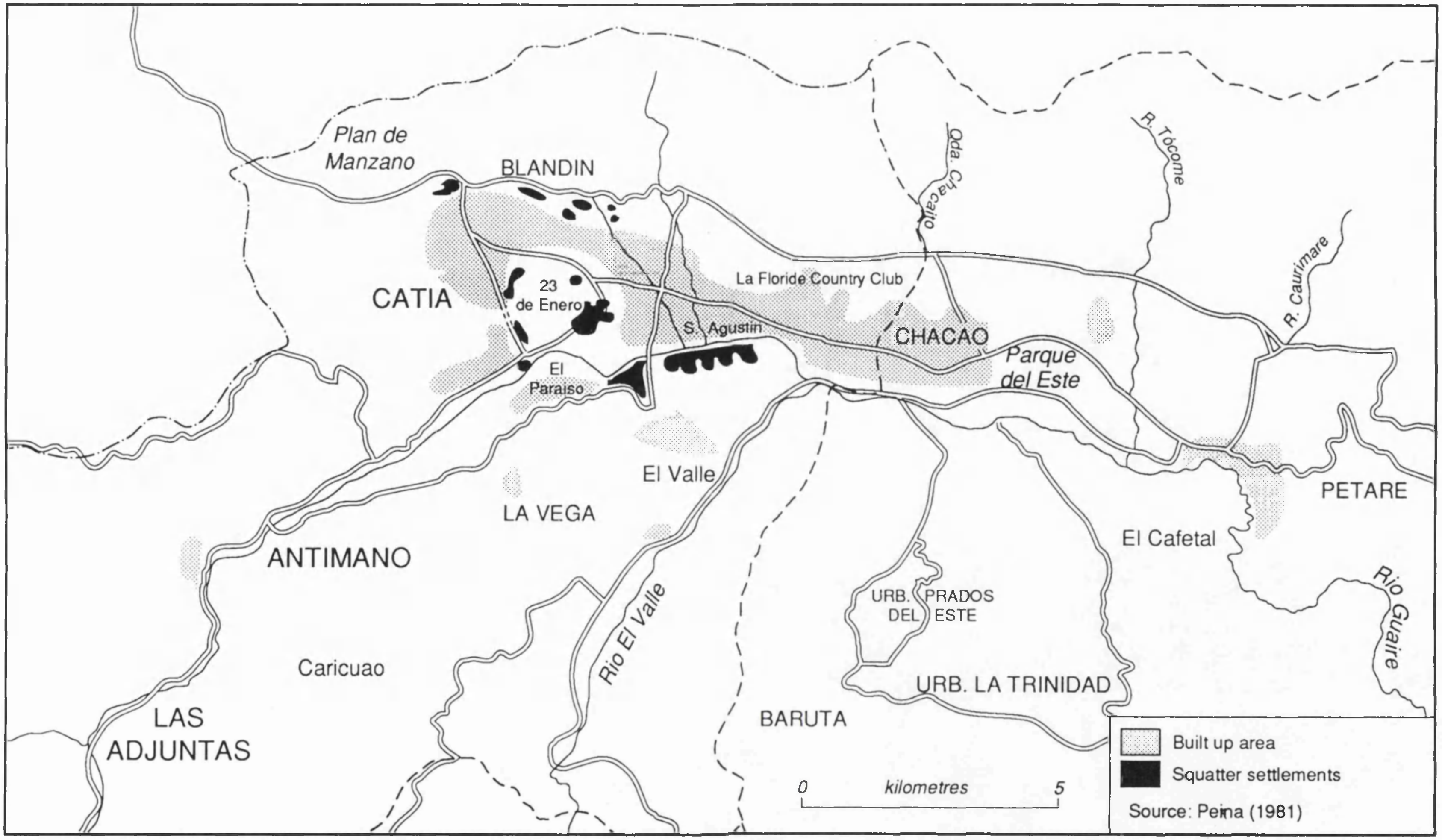


Fig. 2.9: Built up area of Caracas, 1940

Caracas but the boundaries were to change in response to growing links with the surrounding spaces. The decree was thus amended in 1969, 1972, 1975 and 1980.

The 1950s and the beginning of a new period of dictatorship reflected part of the income that the oil was bringing into the country. It allowed expenditure on agriculture and manufacturing and an emphasis on infrastructure including the *Avenida Bolívar, El Cafetal, Cumbres de Curumo, Prados del Este.* The *Concejos Municipales*, or local authorities, repeatedly changed zoning and land-use plans. Consequently, in some areas there is often a contrast between high buildings and modest houses which reflects the changes in density allowed at the time.

During the dictatorship, in the 1950s, the policies seemed well-defined: a 'war on the ranchos'. The main purpose of this policy was to relocate the evicted families in high storey buildings (Bolívar, 1988). In 1954, the *Banco Obrero* built the so-called '*super-bloques*' in an attempt to modify the city's skyline and to replace existing *barrios*. '*2 de Diciembre*' later renamed '*23 de Enero*', is one example: it housed 100.000 people in 38 buildings each of 15 floors and with a total of 150 flats (Brumlik, 1988). The provision of services was inadequate.

In 1958, a change in regime again changed the city's configuration: the areas that were 'controlled' by the dictatorship were invaded by the low income groups. The beginning of this decade was marked by unemployment and social tension. The provisional government's response to growing popular discontent was the *Plan de Emergencia*, which was administered through various governmental bodies such as the *Banco Obrero*, GDF, INOS, MOP. This plan made possible an improved infrastructure in some *barrios* of the city; including streets, stairs, drainage and schools, in some cases it included the construction and improvement of houses. This action intensified the movement of the rural population into the city in search of a better life. The population also invaded the natural streams within the areas which were already occupied by *barrios.*

The city had grown from an urban area of 4.000 ha in 1950 to 11.500 ha in 1966. The area occupied by *barrios* is approximately 1.000 ha (Perna 1981: p.156). Fig 2.10 shows the areas occupied up to 1966 and also include the *barrios* created by 1967. All flat areas have been occupied and the invasion of hillsides becomes more evident. In July 1967, another earthquake (m=5.6) struck the city leaving 234 victims (FUNVISIS, 1981).

In 1971 *barrios* occupied 2,973 ha. Between 1969 and 1973, the government set in motion another programme through The *Departamento de Urbanización y Equipamiento de Barrios* (1969-1974) of the *Banco Obrero.* It consisted of the provision of key services for *barrios* in the main cities of the country. A total of 100 *barrios* were selected, three of them in the Metropolitan Area of Caracas. Between 1974 and 1977 FUNDACOMUN continued this process in the consolidated *barrios* and sets up the *módulos de servicios* programme. By presidential decree is laid the basis of a national survey of *barrios* published in 1979 (I Inventario Nacional de Barrios). Urban growth led to more pressure on space. Landslides began to affect the population living on the hillsides. Fig. 2.11 shows the *barrios* founded between 1968 and 1977.

Differences between the maps (Fig.2.10 and 2.11) are due to reliance on two different sources as well as the greater detail of barrios shown in Fig.2.11. The *Programa de Consolidación de Barrios* of INAVI (Instituto Nacional de la Vivienda) was carried out in 1986.

In the last decade, the problems have been accentuated. The available services in the *barrios* are inadequate and furthermore they do not cover all the areas due to the continuing growth (Camacho and Bolívar 1987). Improvements are often very difficult to put into effect as the land is already occupied by other houses and the terrains is steep. The proper adjustment

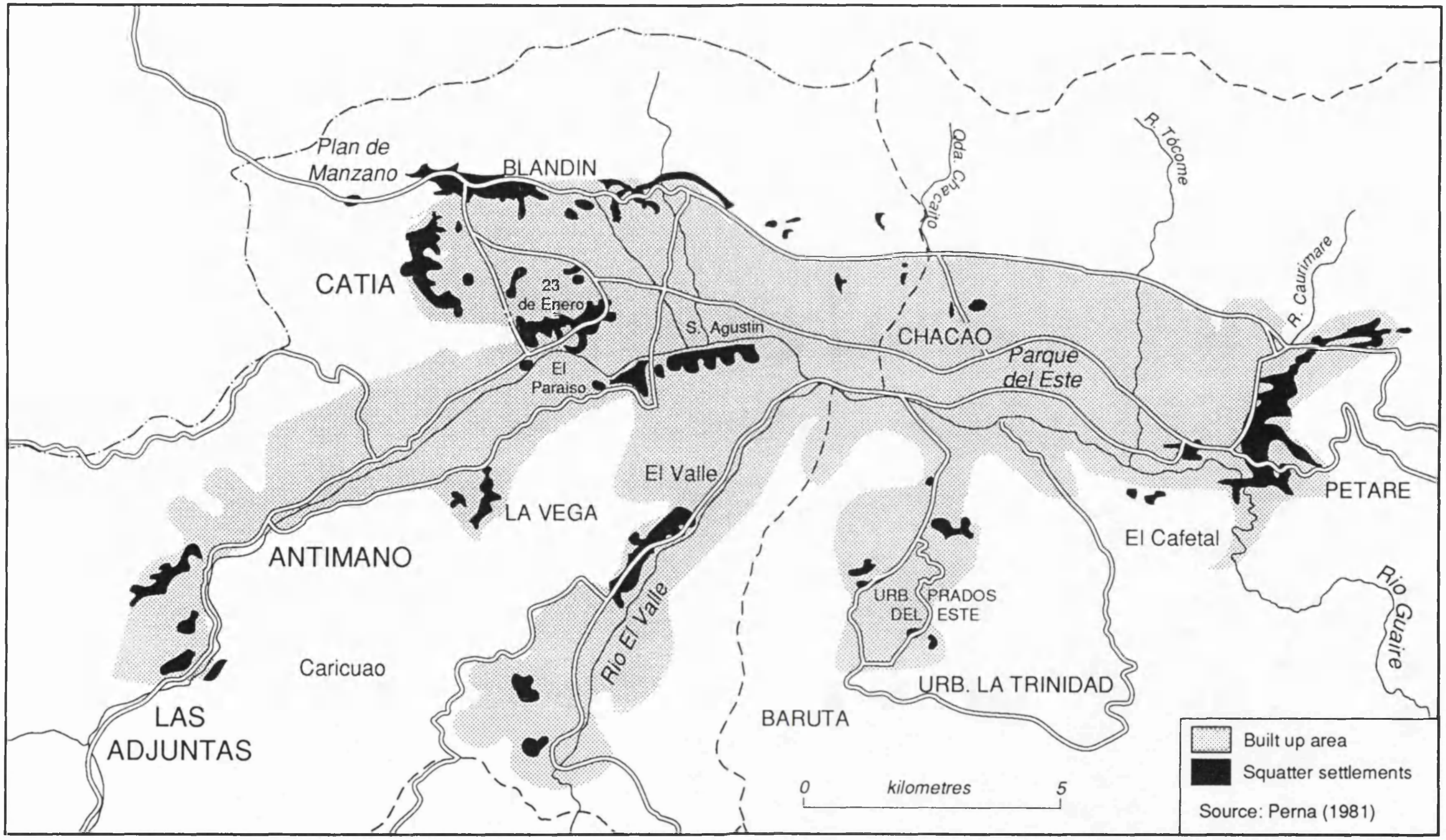


Fig. 2.10: Built up area of Caracas, 1966.

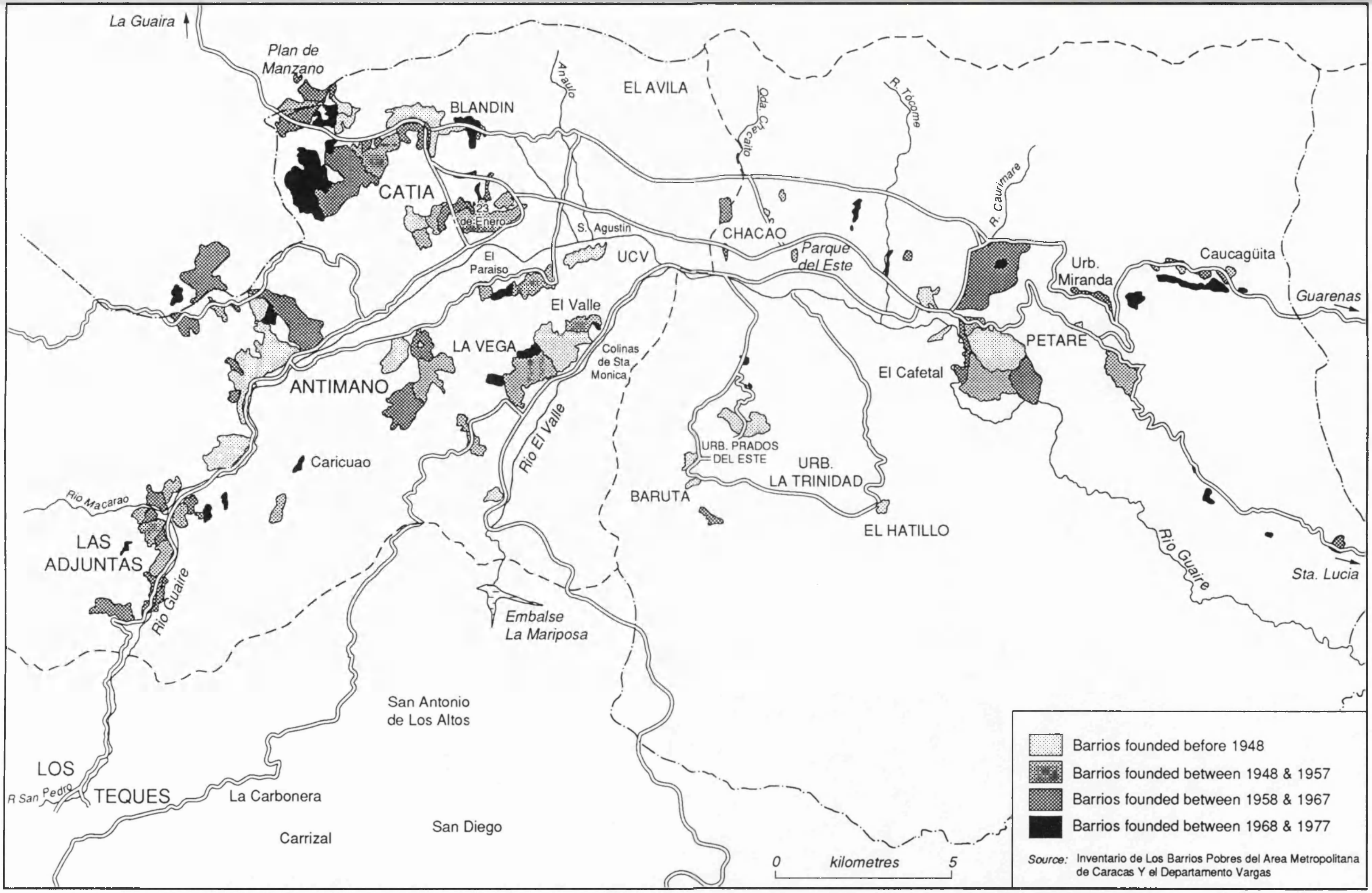


Fig. 2.11: Chronology of Barrio settlements.

of drainage and sewage pipes is equally problematic. Map 2.12, is based on a projection by OMPU (Caracas 2.000) of the areas occupied by *barrios* and of potential expansion in 1990.

The emergence of the earliest *barrios* in 1917 coincided with a document considered to be the first geotechnical map of Caracas (Singer and Feliziani, 1986). This anonymous map shows rock units, formations and terrains very accurately. It also recognized the existence of slope failures. In later years, the construction of roads, viaducts, aqueducts and reservoirs, stimulated the growth in understanding of the geology of the areas being developed. But no attempt was made to link this knowledge with that needed to plan the city.

The earthquake of 1967 focused attention on the physical environment of the city. Geophysical studies were carried out especially in the eastern part of the city. In 1972 FUNVISIS was created by governmental decree, in an effort to coordinate research on seismology, antiseismic engineering and the geology of the active faults in Venezuela. The problems of slope failure were still largely ignored, even though the city experienced numerous emergencies in the 1970s as a consequence of geotechnical problems.

In 1972 the *División de Geotecnia* was created at the same time as the *Oficina de Planeamiento Urbano del Distrito Federal* (founded in 1960) became OMPU (*Oficina Metropolitana de Planeamiento Urbano*). In the succeeding years were produced for the first time proposals for geotechnical zonation at scales of 1:10,000 and 1:5,000 in order to support urban plans and to tackle more specific geotechnical problems (Singer and Díaz, 1974; Marquez and Singer, 1977; Centeno and Rodriguez, 1980a, 1980b, 1982, 1983; Oliveros, 1977; Ferrer, 1981, 1984). An important contribution was made by the Estudio Geotécnico del Area Metropolitana de Caracas.Sector Central (Feliziani *et al.*, 1985), a document at 1:10,000 which aims to summarize geotechnical information on the city. Because of the small scale of

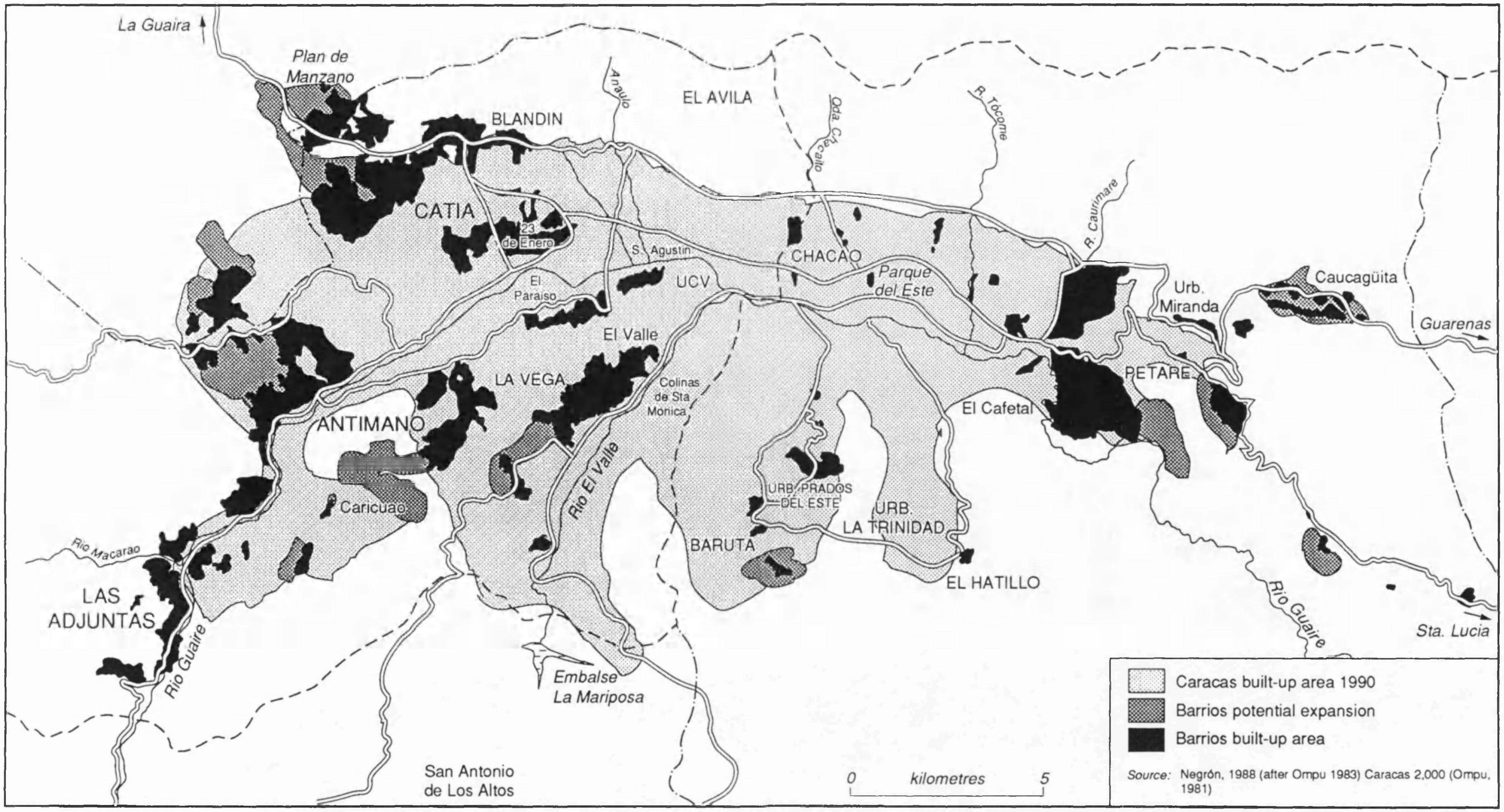


Fig. 2.12: Areas occupied by Barrios in 1983 and potential expansion.

the document, could be used only as a guide, and needed complementary information when detailed diagnosis was required.

By the end of the last decade, the government and people had started to realize the importance of the physical environment, its changes, and its role in the increased vulnerability of the city. In 1986, there was established by governmental decree the National Commission for prevention, control and defense against floods and other damages caused by the rain (see § 1.1). Multidisciplinary studies began to be carried out in order to fill the gaps and the lack of information which had for a long time dominated the topic. Since 1987, FUNDACOMUN has executed el *Sistema de Análisis de Información de Barrios* (SAIB), collecting and processing information on *barrios*. The aim is to supplement and update the information on *barrios* in three main areas: the characteristics of the physical environment, distribution of services and land use, and socio-economic aspects. FUNDACOMUN is also responsible for carrying out the *III Inventario Nacional de Barrios*, due to start in 1992.

Local groups, have begun to put pressure on the government to consider the relocation of settlements or improvements in areas under risk. Such was the case in *Nueva Tacagua*, where the community put forward a plan drawn up by the Faculty of Architecture at the Central University, to adapt development to the characteristics of the terrain as well as providing services, communal and green areas (El Universal, 4th July 1988).

Research institutions and Universities are also contributing to a better understanding of the problems and have produced valuable documents such as the study of the role of terrain in leading to the eviction of *barrios* in Caracas (*La investigación de los terrenos como causal de desalojo de los barrios caraqueños*, paper for discussion: Baldó and Bolívar, 1989). This paper also criticises the government's use of slope instability as a pretext for eviction.

By 1985, 61% of the total population of the Metropolitan Area of Caracas (including Departamento Vargas) lived in *barrios*. They occupied an area of 3.657 has in 1978 and of 4.157 ha in 1985. There had been also an increase in density (Briceño, 1986).

In 1990, FUNDACOMUN's division of Statistics and Informatics used the *II Inventario Nacional de Barrios* to estimate that 77.58% of the total population lives in 406 *barrios* (354,097 houses) in the Metropolitan Area of Caracas.

If growth continues at the pace of 1978-1985, by the year **2.000** 85% of the population will live in *barrios* (Bolívar *et al.*, 1989: p.13).

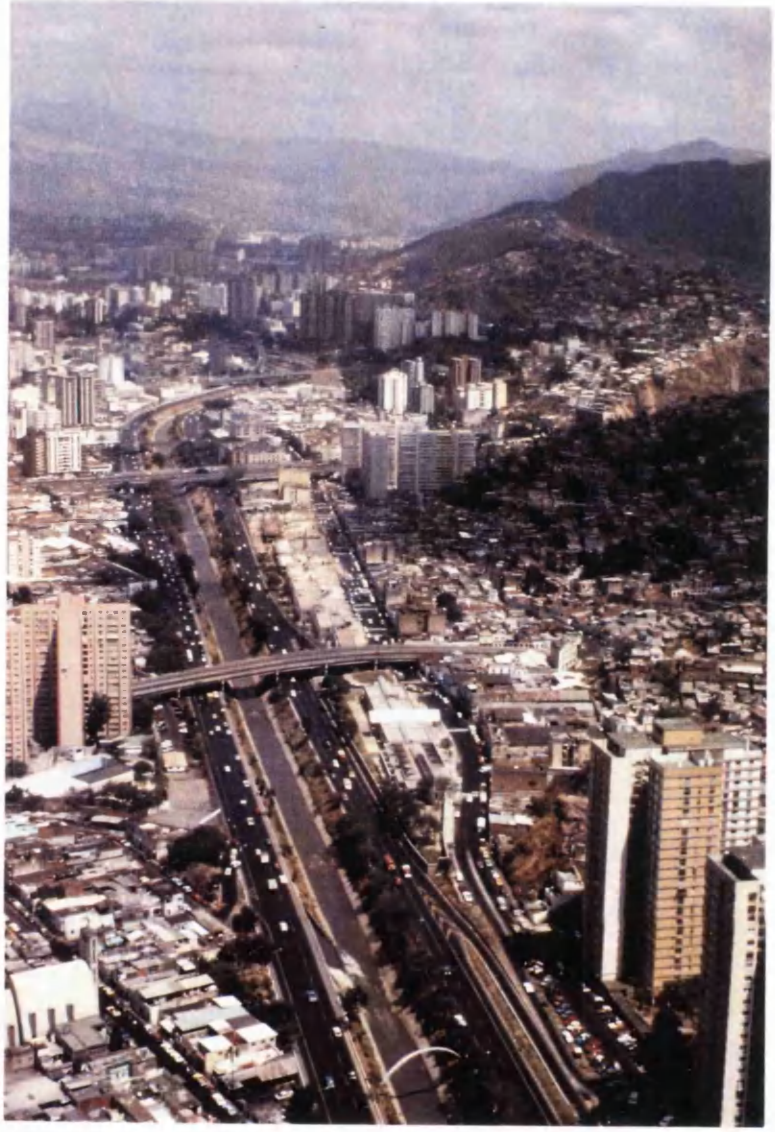
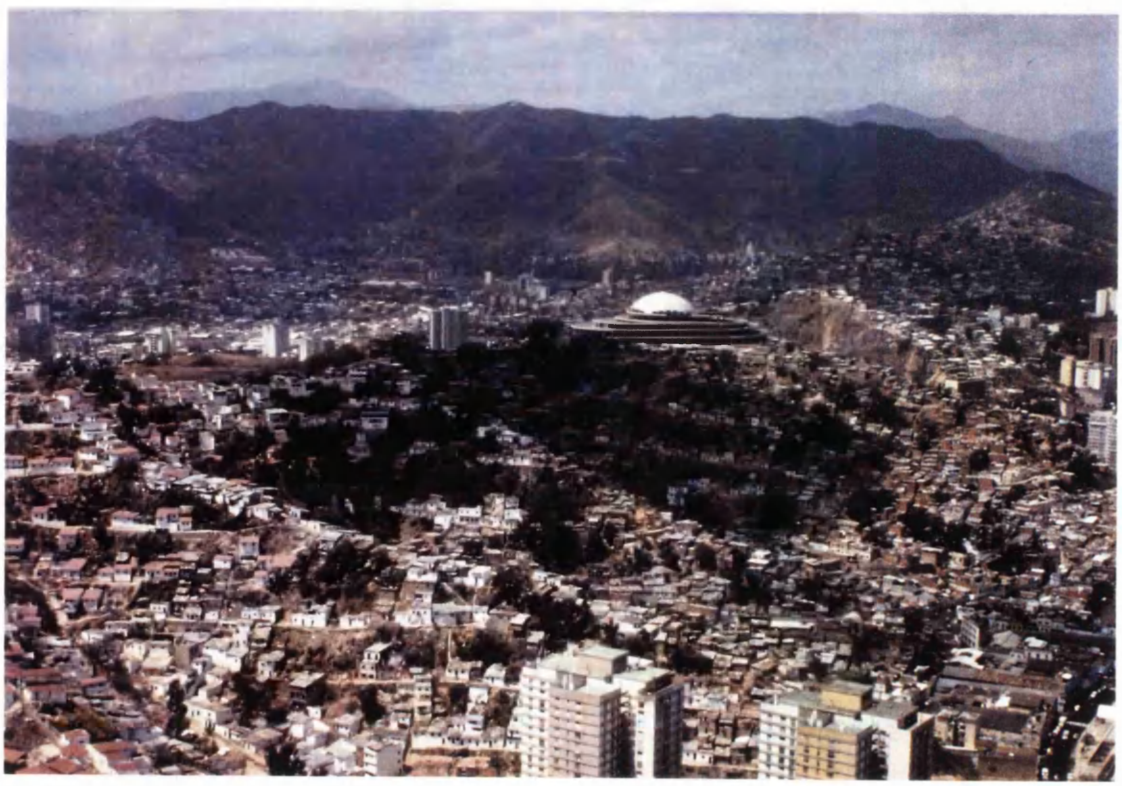


Plate 7:

Caracas 1990



CHAPTER III

TEMPORAL RELATIONSHIP BETWEEN SLOPE FAILURES AND PRECIPITATION

3.1 INTRODUCTION

Although pre-failure conditions may never be replicated, it is possible to assess a hazard-prone area and the characteristics that predetermined instability. To predict the occurrence of slope failures in terms of time then becomes a difficult task unless monitoring is carried out, but for some cases the mechanism that could either accelerate or trigger the instability process transforming it into a risk can be identified. In the case of precipitation, a threshold value based on calendar-defined meteorological parameters could provide the basis for potential predictability.

The purpose of this chapter is to determine a pattern of temporal distribution of slope failures in the Metropolitan Area of Caracas. Based on the occurrence of past mass movement, the aim is to try to identify a range of rainfall values which can be related to the occurrence of such slope failures.

According to Crozier (1986), four different methods can be used to determine triggering thresholds: theoretical models, empirical tests, and spatial and temporal correlation of landslide occurrence and climatic events. As far as data permit, approaches on both spatial and temporal correlations are used here to evaluate the occurrence of slope failure.

3.2 DATA

3.2.1 Records of slope failures

For the purpose of this section more than 250 records of events of mass movements have been gathered from different sources.

Particularly valuable was the Inventario Nacional de Riesgos Geológicos published in 1981 by FUNVISIS. It provides information on the date, location, links with seismicity and effect (where known), of events which have occurred since 1812. This information has been collected from catalogues of historic seismicity, written evidence of major destructive impact by eye-witnesses at the time, the archives of the administration, and press-cutting files.

For the period between 1980 to 1982, the files of the Geotechnical Department (MEM) provided data on the location and number of slope failures. For the subsequent years, the data are not fully complete, but from records kept by the Soil and Geomorphological Laboratory of the School of Geography (UCV) and from files of Defensa Civil (GDF) it has been possible to find the date, location and effect (where known) of events for the period between 1985 and 1988.

There has been a substantial growth in data collected in the last fifteen years, when awareness of the occurrence of mass movements increased as a greater number of people were affected. Although the information covers an extensive period, only data from the period 1974-1979 has been chosen in order to carry out a more detailed analysis of the relationship between rainfall and slope failure. This five year period benefits from consistent records mainly on slope failure from the same source. After 1979, the data on slope failure is dispersed and uneven thus the total number of slope failures in 1981 and 1982 is known but not the date of their occurrence. Apart from some press records, there are no data gathered for failures that occurred in 1983 and 1984.

Very few sources provide data bearing on the characteristics of the events such as magnitude, type of movement, morphology of deposited material and surface failure. Therefore, the data available are not suitable for purposes other than establishing any relationship between geographical location, timing and total number of events.

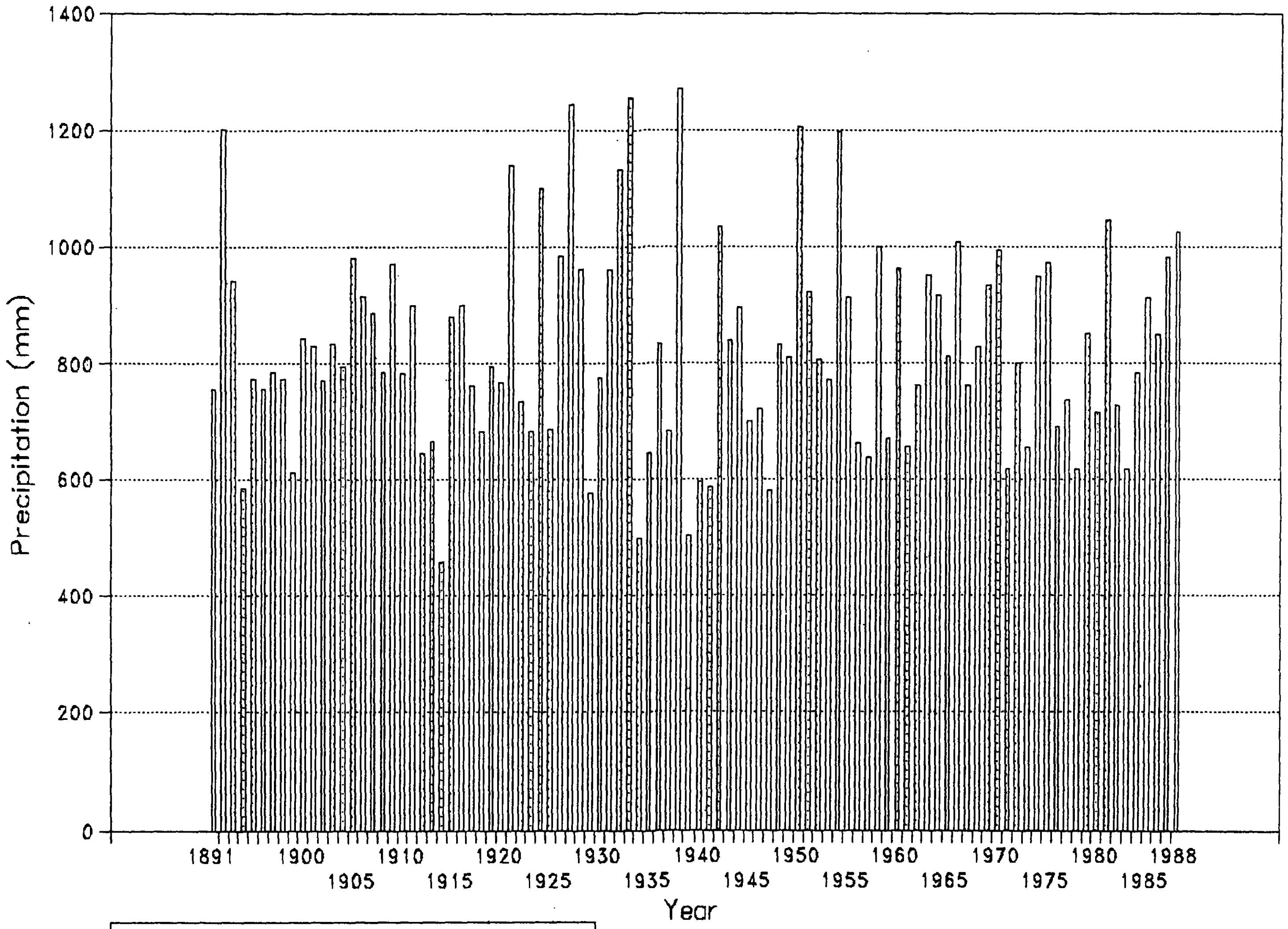
3.2.2 Records of precipitation

The data of daily, monthly and annual precipitation used here were derived from the "Observatorio Cagigal", the main meteorological station in Caracas, set up in 1891 and since then in operation almost without interruption. Although other stations exist in Caracas they are located towards the edges of the city and do not have concurrent records, or records of all relevant meteorological variables. Some stations have months when rainfall data has not been recorded, as is the case for parts of 1958 to 1963, 1981 and 1982 for "La Carlota" meteorological station. Nevertheless, a t-test was carried out on data from these two stations for the period when the relationship between slope failures and rainfall (monthly data 1974-79) was examined. The difference between the data was not significant at the α=0.05 level. This similarity meant that "Observatorio Cagigal" could be used to represent precipitation over the entire Metropolitan Area of Caracas. However it was still necessary to check each daily rainfall value against the hourly rainfall figure (1974 to 1979) since some discrepancy was found in the monthly data provided for the same office [1] in two different periods.

The "Observatorio Cagigal" meteorological station is located at 10° 30' 55" N and 66° 51' 15" W and at 1035 metres above sea level. Fig. 3.1 shows the annual rainfall figures since 1891 until 1988. There are well defined dry and wet periods, as 74.3% of the annual rainfall is concentrated between May and October.

[1] In the first period of fieldwork, data were obtained from the *Departamento de Procesos Automatizados* MARNR, and various conclusions were drawn from these data. However in the second period of fieldwork the data provided by the same office differed widely from the original data (over a period of six years, 38% of the figures for total monthly rainfall varied by up to 200 mm). Hourly data from Observatorio Cagigal enabled corrections to be made to precipitation data in order to verify the daily and therefore the monthly data before that information could be used again.

Figure 3.1
Annual Rainfall in Caracas 1891–1988



Data source: Observatorio Cagigal meteorological station

Within the period 1974-79, the maximum monthly rainfall registered was 214.8 mm (September 1975) and the maximum daily recorded was 70.1 mm (11 October 1976).

3.3 SUMMARY ACCOUNT OF THE ASSOCIATION BETWEEN SLOPE FAILURE AND RAINFALL. PRELIMINARY ANALYSIS OF RECORDS SINCE 1800s

Before the 1970s, most of the slope failures recorded in Caracas were related either to seismic activity or intense rainfall events. Indeed, to judge from the records Inventario Nacional de Riesgos Geológicos (FUNVISIS, 1983), of the only 7 recorded mass movements between 1800 and the end of the century, three were associated with the earthquake which occurred in August of 1812 and whose magnitude was estimated as 7.1 on the Richter scale. Between 1900 and 1939, 21 out of 27 mass movements registered in historical documents took place during the October earthquake of 1900, most of them along the old railway line *Caracas-La Guaira*. The event was estimated to have had a magnitude of 6.3 on the Richter scale. During February 1951, 224 mm rainfall apparently triggered 15 mass movements including 8 debris flows in different areas of Caracas. The event resulted in 26 deaths, various disappearances and a total of 139 houses damaged. Between 1961 and 1970 a total of 12 slope failures was recorded, 8 of which occurred on the 29th of July 1967 as a consequence of an earthquake of magnitude 5.6 on the Richter scale [2].

For the last 20 years similar recurrent events have affected life and property in many areas of Caracas. Although precipitation has been regarded a major contributing factor in the incidence of slope failures, proof of the relationship is lacking.

[2] Data of Richter Magnitudes for the above mentioned seismic events are taken from Mapa Sismico de Venezuela 1530-1980 (Observatorio Cagigal-MARNR-FUNVISIS).

The **annual rainfall** figures for Caracas together with the number of slope failures for the period of adequate records (1974 onwards) show a positive correlation (r_s= 0.525; r_{crit} α= 0.05). The highest annual landslide activity was in 1981, in which the rainfall was well above the average (figure 3.2).

Period 1974-1979

A closer look at **monthly rainfall** and the number of slope failures for a sequence of years 1974-79, suggests they are associated with prolonged wet periods and/or high monthly rainfall values.

In 1974, a total of 19 landslides were recorded in the Metropolitan Area of Caracas. According to the data, it seemed to be the beginning of a period of increasing landslide activity which is still continuing. A total of 949.4 mm of precipitation fell that year, 79.4% of which was concentrated in only four months (July to October). As can be seen in figure 3.3, slope failures occurred from August to November, during the rainy season. The sources do not indicate the magnitude of these landslides, but their effects resulted in 7 deaths, many injuries, 300 homeless, 72 family homes affected, and roads blocked.

In 1975, more than twice the amount of landslides as the previous year was recorded. Mass movements occurred mainly towards the end of the rainy season, during September; the highest monthly total precipitation for that year was 214.8 mm (Figure 3.4). October also registered high landslide activity. 20 of the 38 slope failures occurred in *barrios* resulting in a total of 10 deaths and more than 150 families homeless.

By the rainy season of 1976, and in spite of below average annual rainfall, a total of 33 landslides was recorded. July and October are the months with a concentration of landslides

Figure 3.2: Caracas
Annual rainfall and slope failures
1974-1988

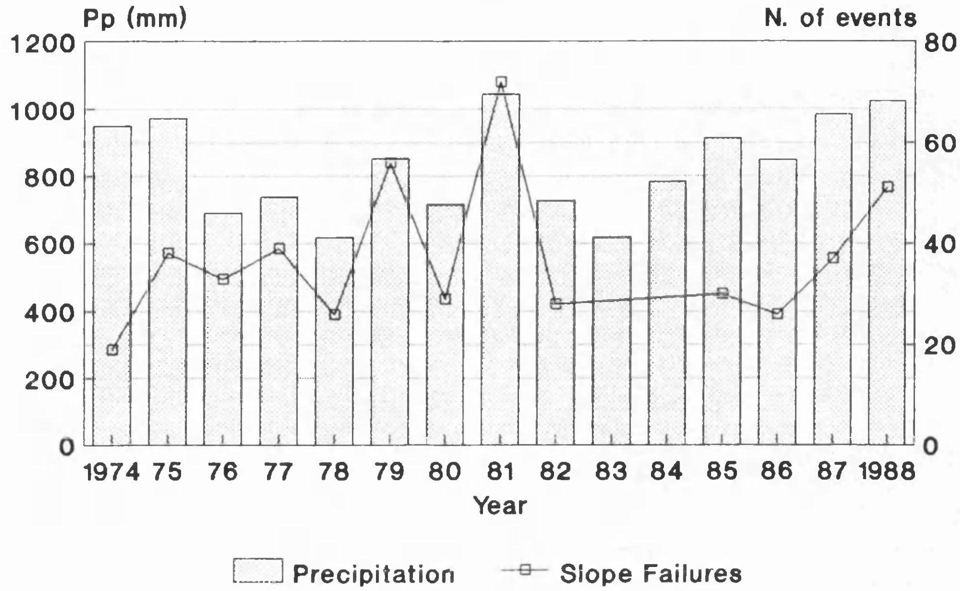


Figure 3.3:

Monthly rainfall and slope failures
1974

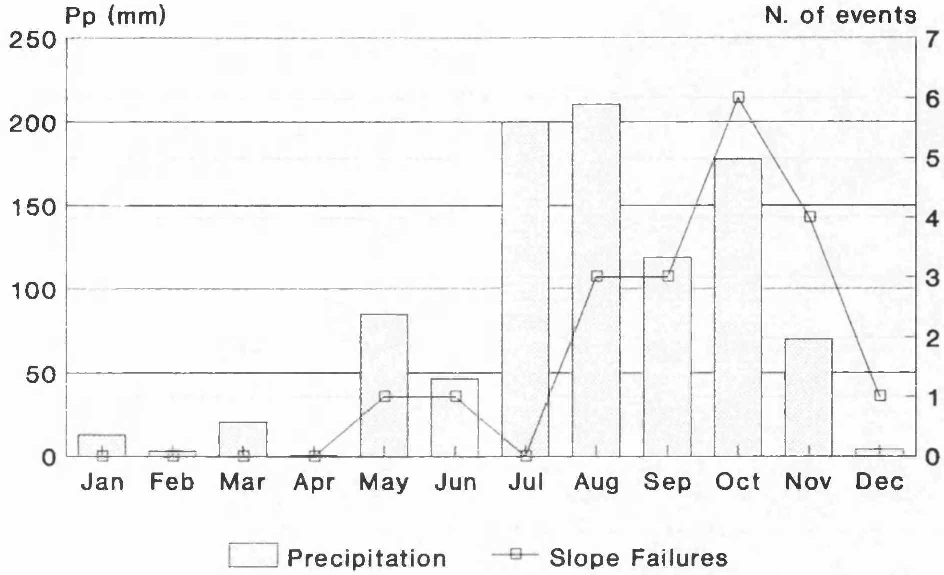
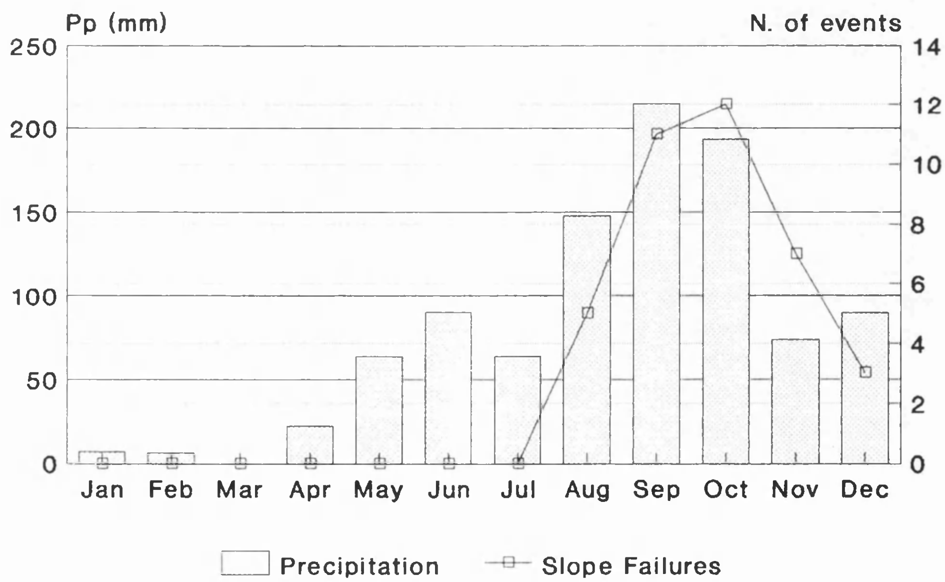


Figure 3.4:

Monthly rainfall and slope failures
1975



(Fig. 3.5). The consequences in *barrios* settlements were 10 deaths, 28 injured, more than 30 houses destroyed and another twelve damaged.

In August 1977, a monthly rainfall of 144.3 mm (after 306.6 mm in the preceding three months since the beginning of the rainy season) was apparently associated with most of the landslides that occurred on the 20th 21st of the month. The monthly precipitation of 131.5 mm in November also seems to have been associated with 10 landslides registered (Figure 3.6). Several houses were damaged and roads were blocked.

In 1978, 27 slope failures that occurred throughout the year were registered, 16 of them affecting *barrios.* This resulted in more than 560 homeless families and the destruction of 27 houses (fig. 3.7).

In 1979 slope failures occurred in almost every month, although the majority were concentrated in September (Fig. 3.8). There were 19 landslides after 395.7 mm of rain had fallen since the beginning of the rainy period in April. 37 slope failures occurred in *barrios* and this was the year in which more victims and damage were recorded than ever before.

The degree of association between monthly rainfall and slope failures was described by the correlation coefficient (r_s), shown to be positive and significant at the 0.01 level in most of the cases:

Figure 3.5:
Monthly rainfall and slope failures
1976

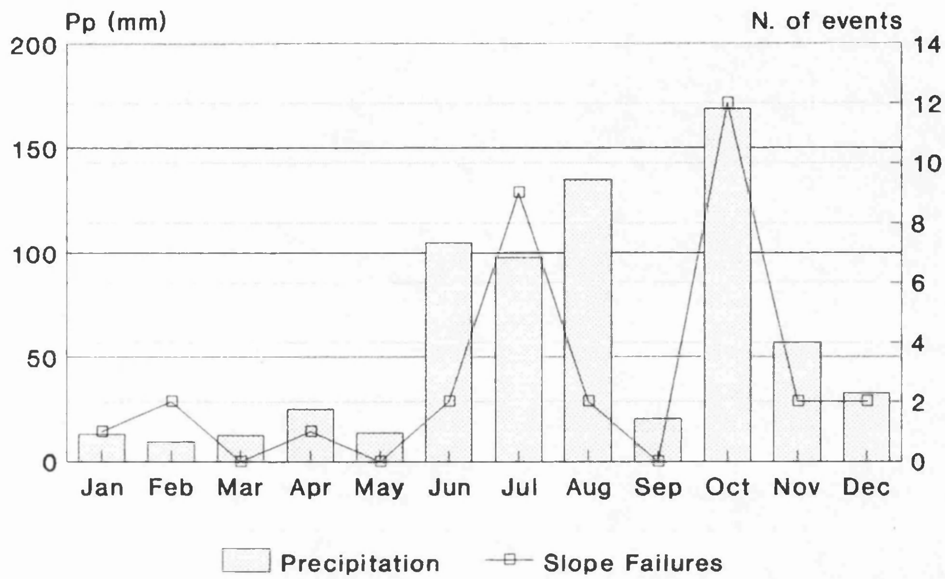


Figure 3.6:
Monthly rainfall and slope failures
1977

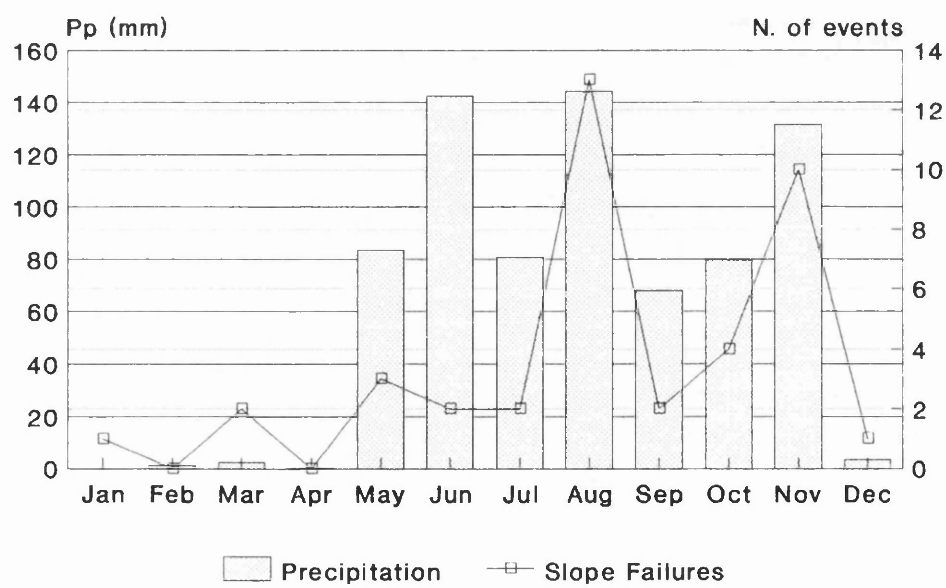


Figure 3.7:
Monthly rainfall and slope failures
1978

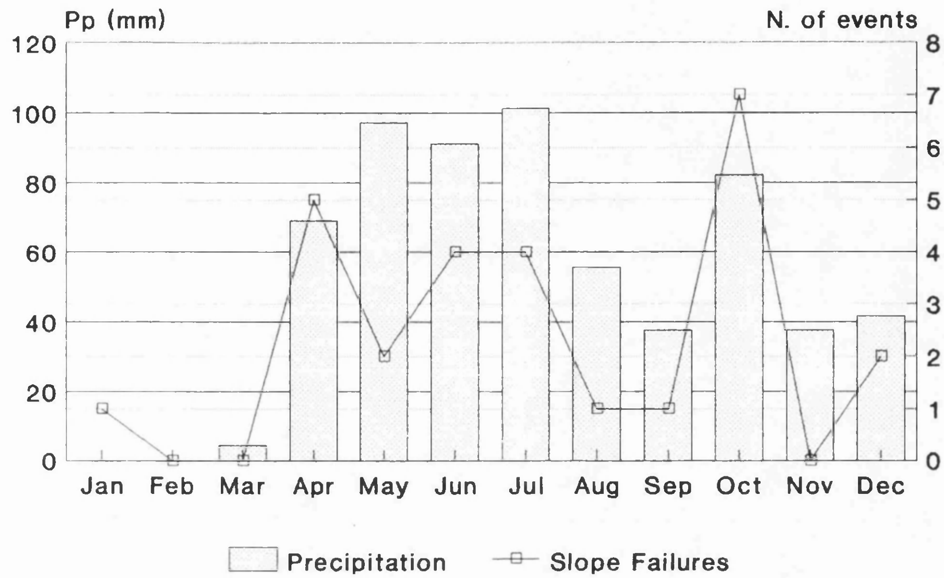


Figure 3.8:
Monthly rainfall and slope failures
1979

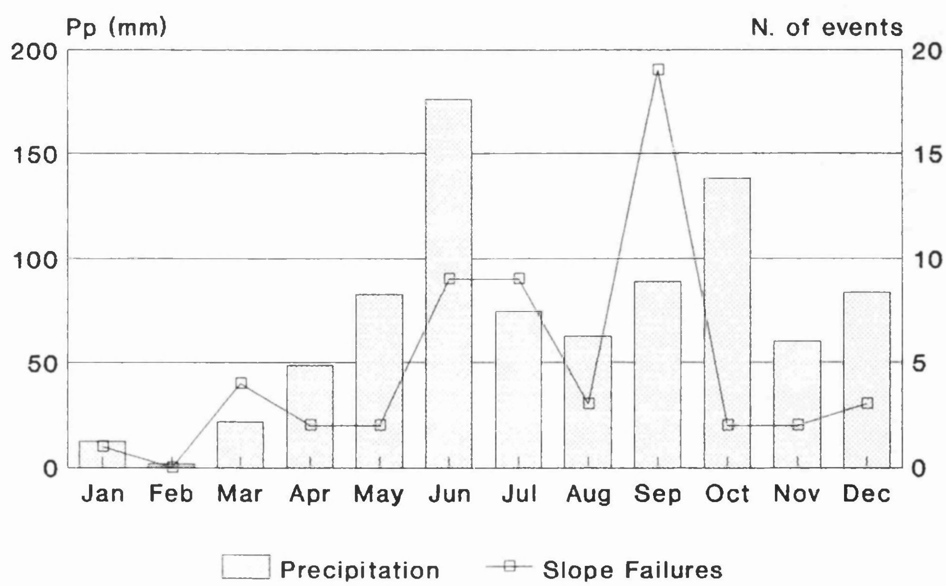


Table 3-1: MONTHLY RAINFALL AND SLOPE FAILURES

Spearman's Rank Correlation Coefficient (r_s)

Year	r_s
1974	0.567+
1975	0.788*
1976	0.692+
1977	0.822*
1978	0.784*
1979	0.593+

*: significant at $\alpha = 0.01$
+: significant at $\alpha = 0.05$

This correlation in time between the two is strongly supported by the **seasonal pattern** of distribution of slope failures (Figure 3.9) and leads to further consideration of the role of precipitation as a key factor or as the triggering factor for most of them. Taking this into account, different approaches were adopted to try and identify a threshold value of precipitation for slope failures between 1974 and 1979.

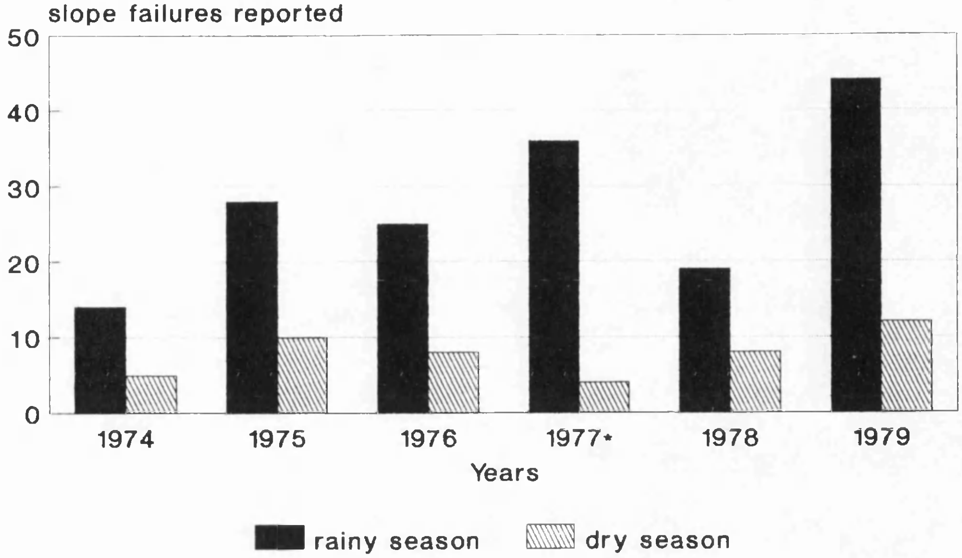
3.4 DETERMINATION OF THRESHOLD PRECIPITATION LEVELS FOR LANDSLIDES

The use of rainfall values to define the association between slope failures and precipitation has to be considered carefully since a wide range of values could seem to be related to the events.

Although daily rainfall values can obviously contribute to the mass movement, rainfall for 24 hours period can differ from 0 mm to 70.1 mm on days with events, as was the case in Caracas in the period considered (1974-1979). According to Crozier and Eyles(1980),

Figure 3.9:

Seasonal pattern of distribution of slope failures, 1974-1979



* In 1977, slope failures in November are included in the rainy season

"The inability of daily rainfall amounts to define a consistent triggering threshold has been attributed in general terms to the variability of pre-existing soil moisture conditions."

...but this element becomes a problem since rarely are the data available. Other indirect measurements are used, such as climatic water balance and antecedent rainfall. The aim is to find the approximate amount of water within an slope when the failures occurs.

3.4.1 Cumulative Rainfall

A series of graphs showing cumulative **monthly rainfall** were produced (see figures 3.10 and 3.11). For 1974, 1975 and 1977 an approximately similar range (300-400 mm) was reached before slope failures started to occur in a significant amount, whereas for 1976 and 1979 this value was lowered to less than 200 mm. The analysis of these two sets of years is presented in this section.

Daily data were examined for the rainy season and for 10 and 30 days before the events [3]. Graphs were produced only for the 10-day analysis as these could illustrate water conditions in the slope prior to each event and enable the resulting figure of cumulative rainfall comparable to the antecedent rainfall index as calculated by Crozier and Eyles for ten days (1980: p. 2-47). As regards intensities, the data on slope failure did not include the time of occurrence, thus making it impossible to assess the relationship between intensity and movement.

i) 1974, 1975 and 1977:

Before the events of August 1974, 349 mm of rainfall had fallen since the beginning of the rainy season in May, but in the 30 days immediately preceding the events experienced

[3] The daily rainfall value is conventionally the rainfall of the 24 hours preceding 08:00 on the day in question. The amount of rain that will fall on a particular day after 8 am will thus count as data for the following day. This fact evidently influences the way in which the data should be interpreted; in this thesis the data refers to the 24 hours in which the rain actually fell.

Figure 3.10:

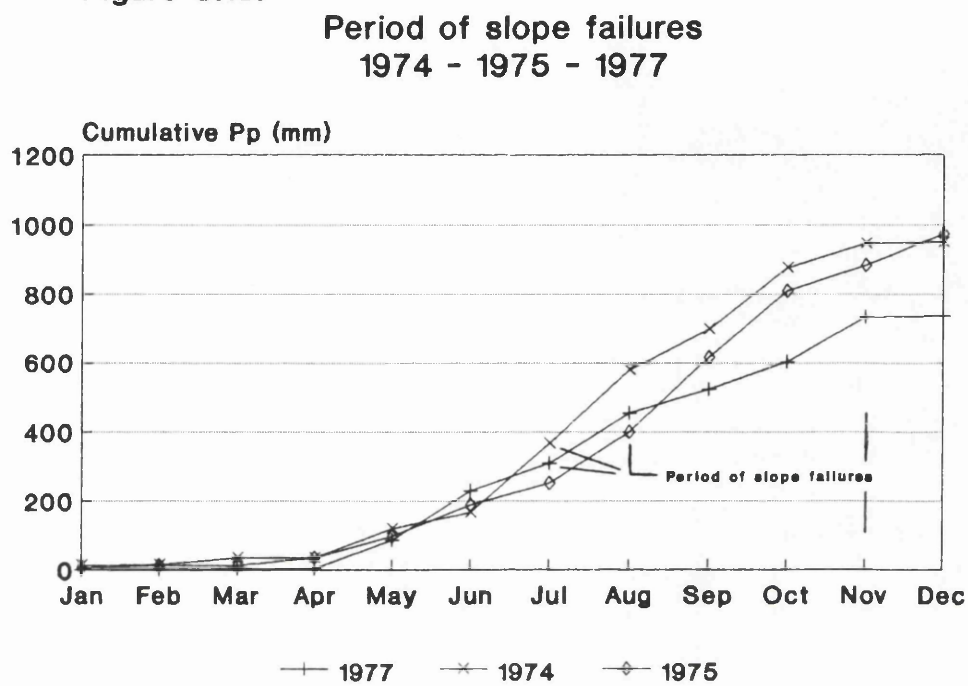
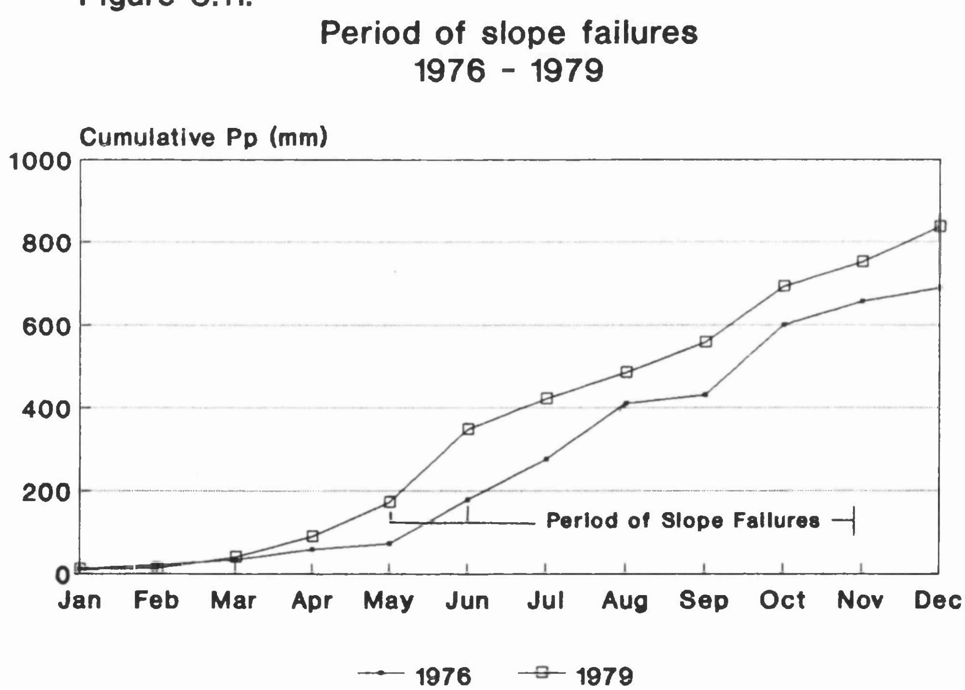


Figure 3.11:



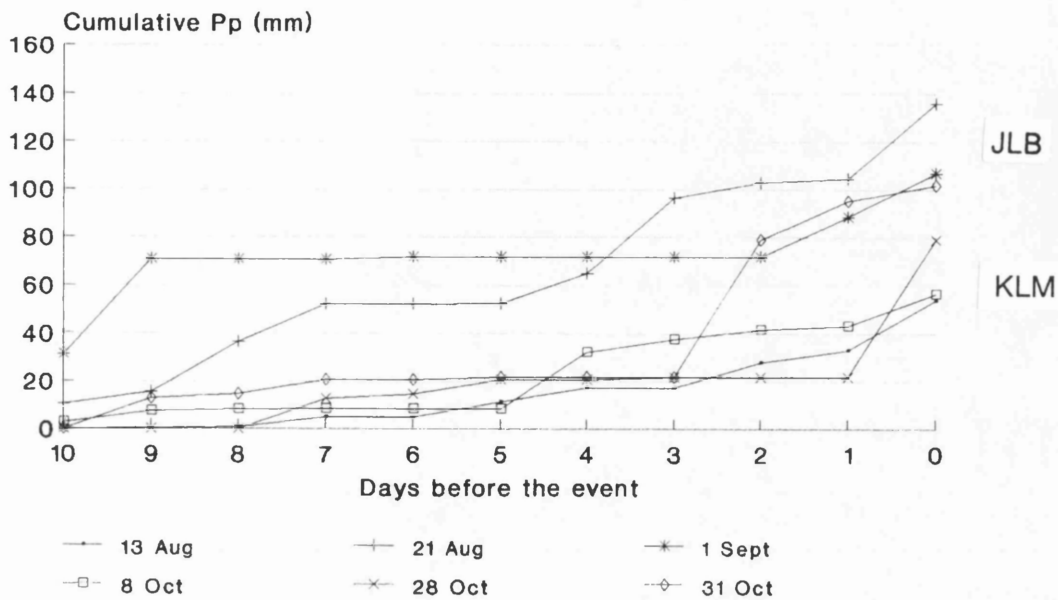
short dry periods and a mere 102 mm of rainfall were recorded to have accumulated in that period. For the events occurring from August to October the values in the graph in figure 3.12.a shows that slope failure in *barrios* built on calcareous schist (KLM) presented lower cumulative rainfall totals than those built on mica-schist (JLB). A certain amount of rainfall, 4-5 days before and within the 24 hours on the day of the event, may have triggered the mass movement. Figure 3.12.b shows slope failures in other areas (e.g. roads, planned housing developments, and residential areas other than *barrios*). These data are presented by *barrios* and lithology to show that in *barrios* the lithological factor might be of major importance. The events that occurred in November and December in areas other than *barrios* showed low values of cumulative rainfall in the preceding ten days and no rainfall on the day of the event.

The remaining years are presented in successive months to bring out the seasonal factor.

In 1975, 15 slope failures affected different places in the Metropolitan Area of Caracas in only three days during August and September. The first five of them on the 21st of August were preceded by 308.7 mm of seasonal rainfall. Approximately 60 mm of rainfall were accumulated in the preceding ten days for these events, and likewise for those that occurred on the 1st of September, in both *barrios* and roads. Values of rainfall on the day of the events were particularly high, namely 31.6 mm (21st August) and 53.6 (1st September). This rainfall almost certainly contributed to the slope failures that occurred on 4 September, raising the values of cumulative rainfall for the ten days previous to the events to nearly 140 mm (Fig. 3.13.a). Minimum values of 92 mm were accumulated within the 30 days before the events.

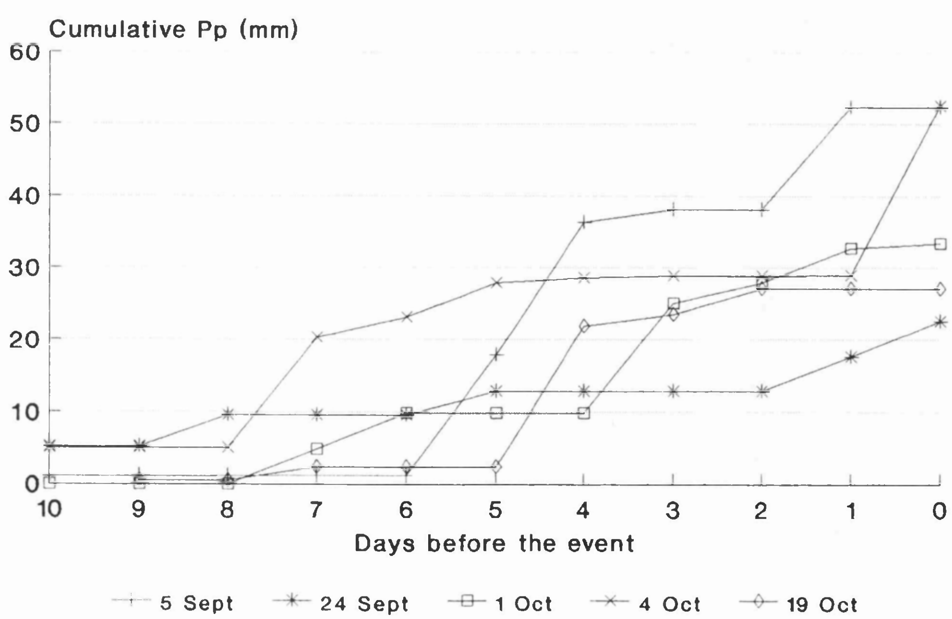
October was also a month of high slope failure activity. 9 out of 12 failures occurred in *barrios* and values of minimum cumulative rainfall of 40 mm in the previous 10 days before the event were needed (fig. 3.13.b).

Figure 3.12a: Cumulative rainfall prior to slope failures, 1974. *Barrios*



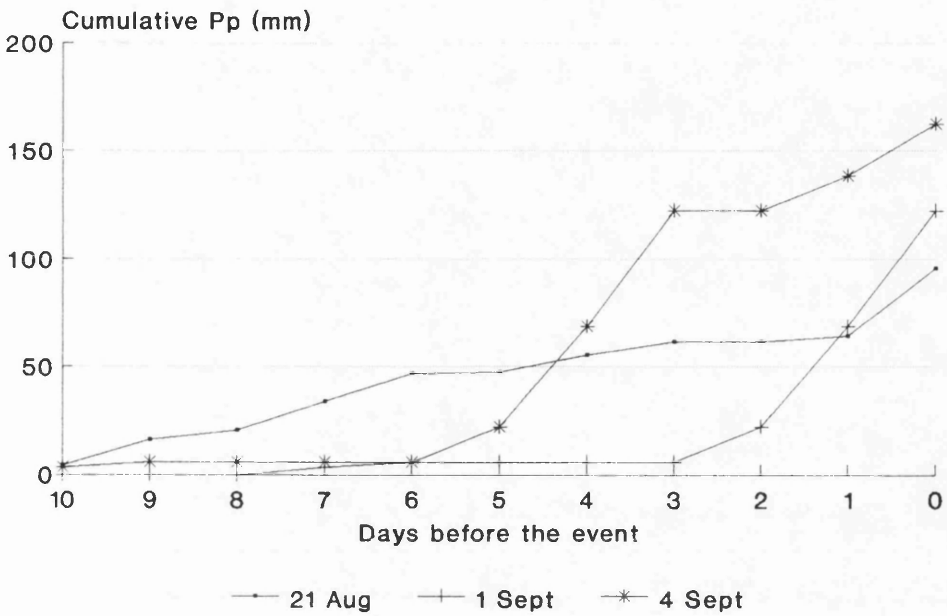
Day 0: day of the event

Figure 3.12b: Cumulative rainfall prior to slope failures, 1974



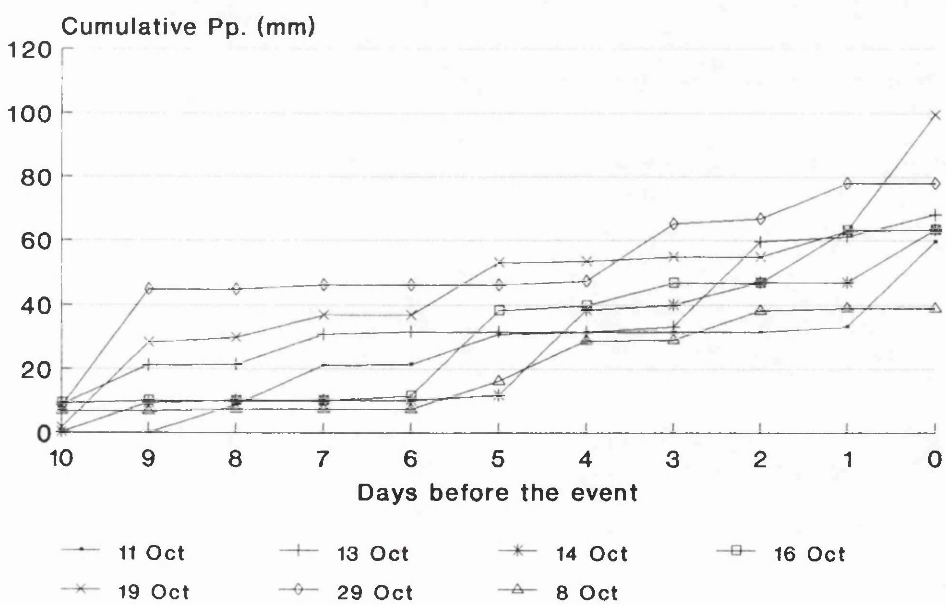
Day 0: Day of the event

Figure 3.13a: Cumulative rainfall prior to slope failures, Aug-Sept 1975



Day 0: day of the event

Figure 3.13b: Cumulative rainfall prior to slope failures, October 1975



Day 0: day of the event

Events in November and December do not seem to be related to any particular amount of rain accumulated during the previous few days. Most of them occurred in road-cuts. However, accumulated values from 30 days before the events were similar to those registered for the same period (30 days) in August and October.

During 1977, slope failures started to occur early in the year, in January, March and May, but these events occurred mainly in road-cuts.

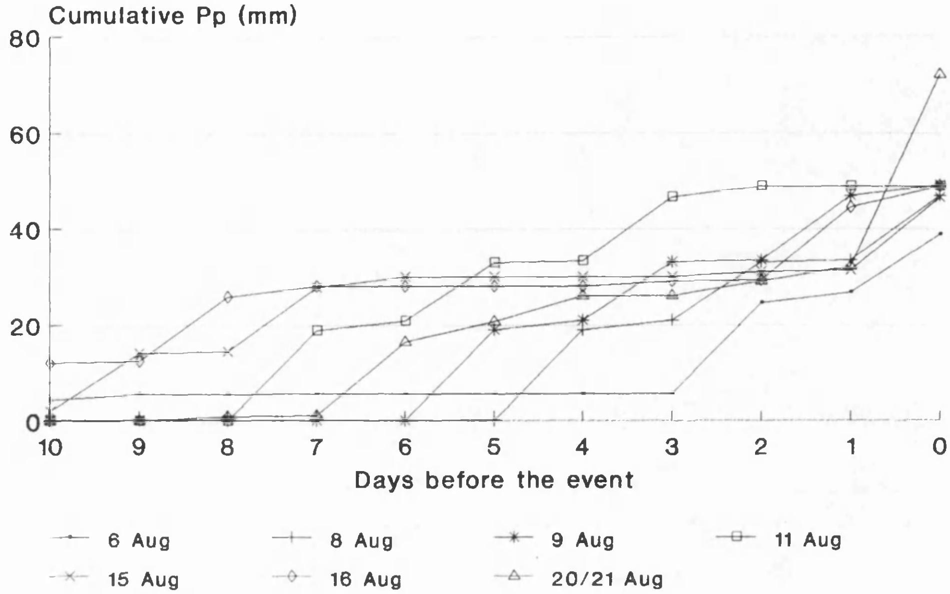
In June and July, 3 slope failures were reported in *barrios*. Cumulative rainfall for the 30 days before had reached 120 mm and precipitation values of more than 45 mm were accumulated in the preceding ten days.

327.5 mm of seasonal rainfall preceded 13 events which started to occur on 6 August. Five of them on August 20 may have been caused by 30.9 mm of rainfall in 3 hours on that day. Minimum accumulated values of 80 mm in 30 days and nearly 40 mm (fig. 3.14.a) within ten days prior to slope failures were needed.

The events reported in October occurred in road cuts. No rainfall was registered on the days of the events and very low values were registered within the previous days.

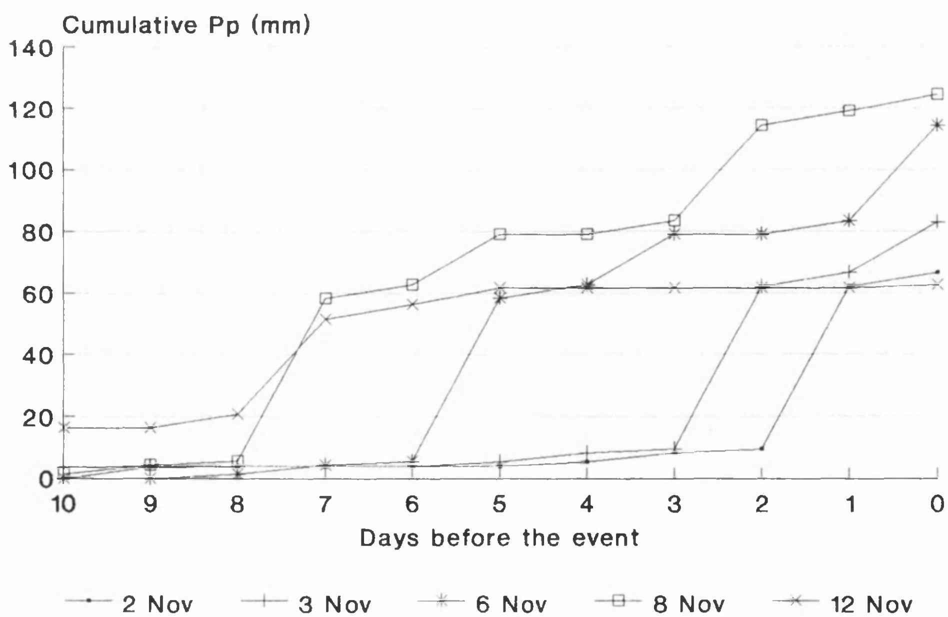
Ten events occurred in November. Very high values of cumulative rainfall in the previous ten days were recorded as an intensity of 40.3 mm/hr on the 31st of October raised the values to 60 mm and above for each event (Fig. 3.14.b).

Figure 3.14a: Cumulative rainfall prior to slope failures, August 1977



Day 0: day of the event

Figure 3.14b: Cumulative rainfall prior to slope failures, November 1977



Day 0: day of the event

ii) 1976 and 1979:

Two main periods of slope failure can be identified in 1976, in July and October. Some events occurred between January and June mainly in roads and they do not seem to have any association with rainfall.

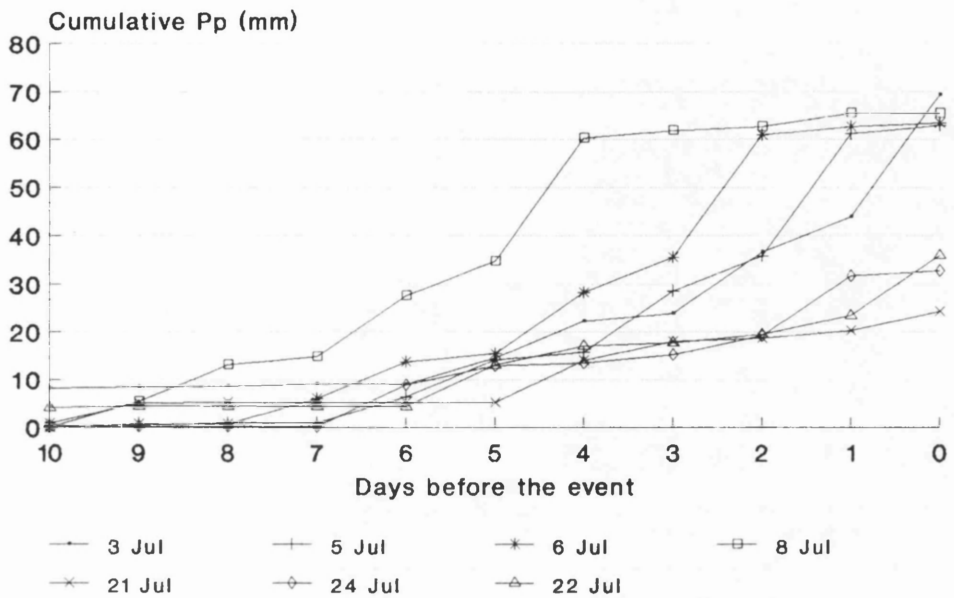
There were 132.8 mm of seasonal rainfall, 125.3 of it was accumulated 30 days before the events that started to occur on 3 July. All the slope failures occurred in *barrios*. The minimum cumulative rainfall for ten days prior to the first four events was approximately 25 mm (Fig. 3.15.a). Although the events that occurred later in July (21, 22, 24) showed low values of antecedent rainfall in the previous ten days, the threshold value might have been already exceeded with the rainfall earlier that month.

Slope failures that occurred in October were preceded by 371 mm of seasonal rainfall. On 11 October 70.1 mm of rainfall was the highest amount of daily rainfall recorded for the period 1974 - 1979. A total of 12 slope failures occurred (Fig. 3.15.b) and although the end of October shows low values of cumulative rainfall on the graph, the heavy rainfall of the 11th contributed to the amount accumulated and may explain the occurrence of some of the slope failures during that month.

The period of slope failures in 1979 started in June when 9 mass movements were recorded. Only 131.3 mm of rainfall were accumulated during the previous three months and 82.9 mm was the minimum value of accumulated rainfall within 30 days before the event. Values of at least 55 mm were needed in the preceding ten days (Fig. 3.16.a). Most of the slope failures occurred in *barrios*.

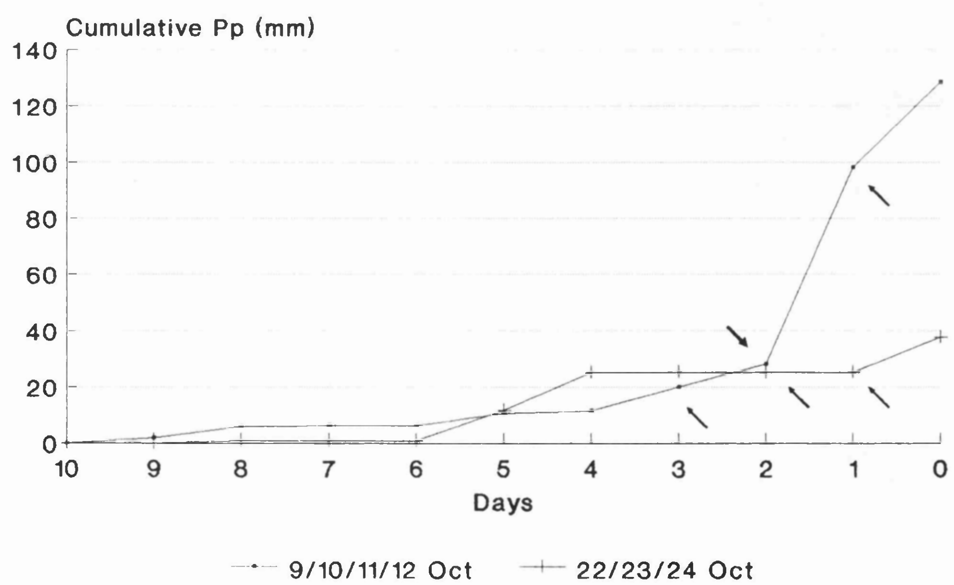
By July were accumulated 258 mm since the beginning of the rainy season in May and 175 mm within 30 days before. Graph 3.16.b shows that minimum cumulative rainfall of 60 mm

Figure 3.15a: Cumulative rainfall prior to slope failures, July 1976



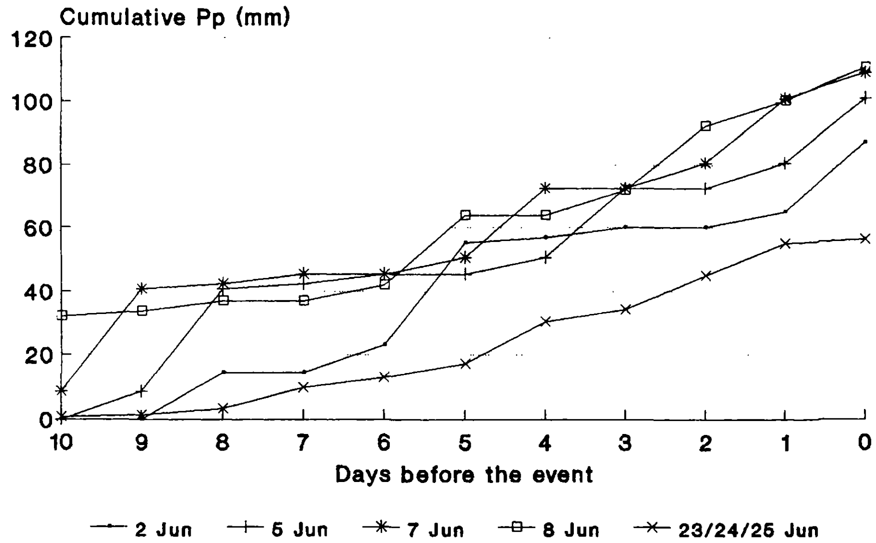
Day 0: day of the event

Figure 3.15b: Cumulative rainfall prior to slope failures, October 1976



Day 0: day of the event
Arrow indicates day in which slope failure occurred

Figure 3.16a: Cumulative rainfall prior to slope failures, June 1979



Day 0: day of the events

Figure 3.16b: Cumulative rainfall prior to slope failures, July 1979

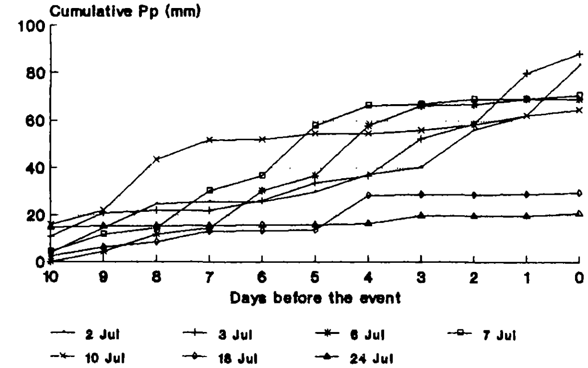
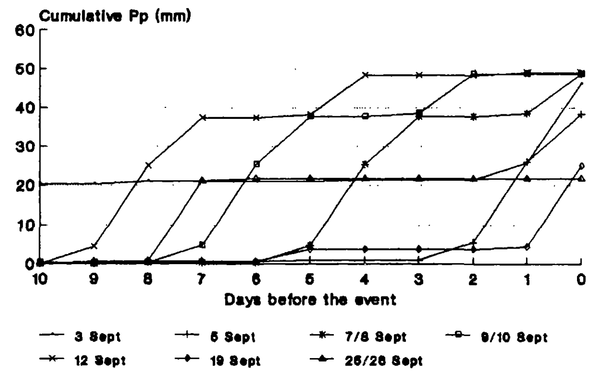


Figure 3.16c: Cumulative rainfall prior to slope failures, Sept. 1979



was needed in the preceding ten days. Although slope failures on 18 and 24 of July present lower values of cumulative rainfall, they were probably influenced by the rainfall at the beginning of that month. Six of the nine movements occurred in *barrios.*

September registered the highest amount of slope failures in 1979. Recorded seasonal rainfall was 395 mm. Values of cumulative rainfall in the preceding ten days were low but intense precipitation on the day of the events were associated with the majority of the slope failures (Fig.3.16.c).

Events in October and December were associated with high values of rainfall on the day on which they occurred.

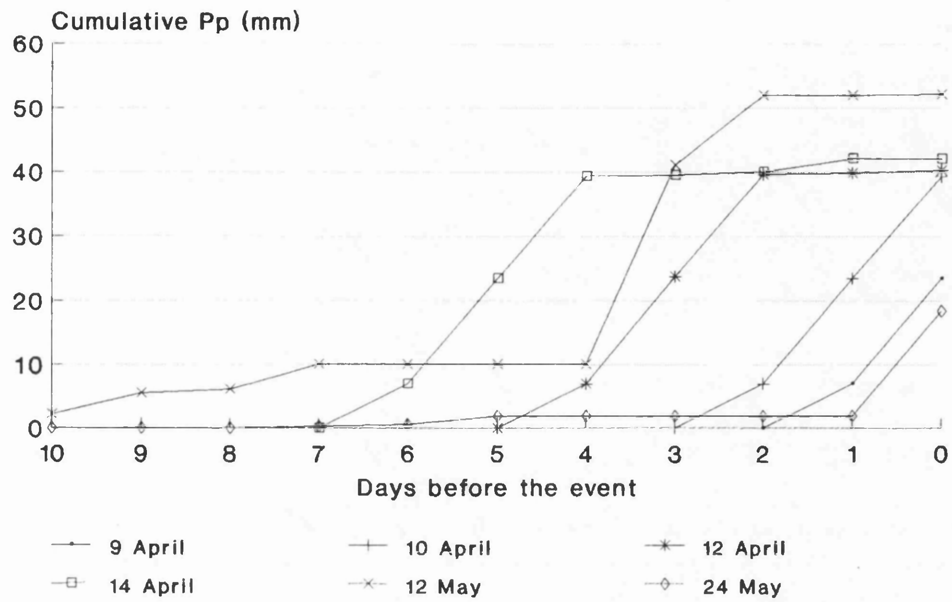
iii) 1978:

Slope failures in 1978 started to occur in April, and were generally associated with intense rainfall events (9-10 April, and 24 May) and cumulative rainfall for ten days of more than 40 mm (12-14 April and 12 May) (Fig.3.17.a).

In June, 4 events were reported, 3 of them in road-cuts, and rainfall within the 30 days before had reached minimum values of 103 mm.

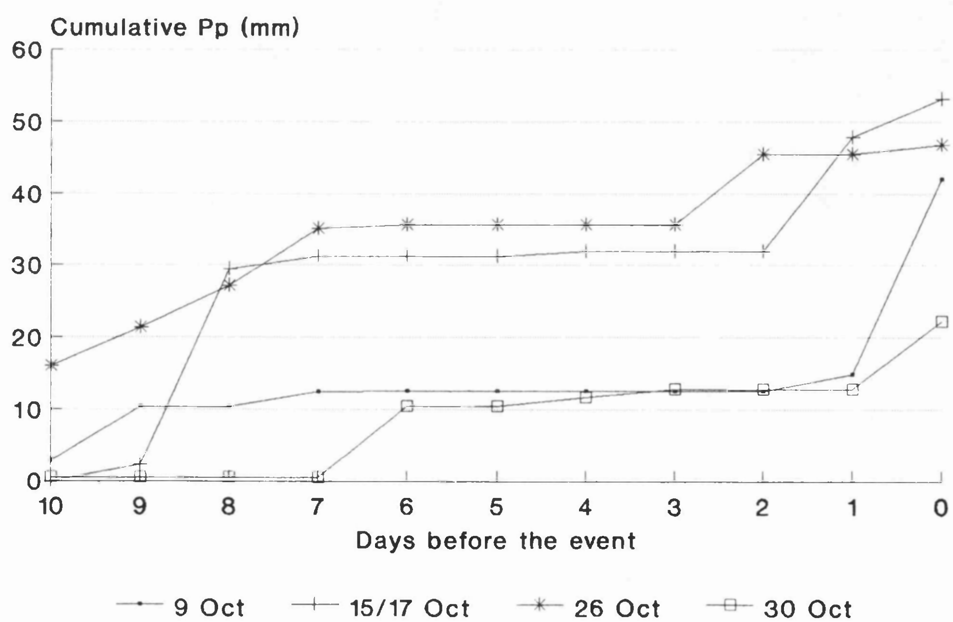
Seven slope failures occurred in October, five in *barrios*. They were associated with heavy rainfall on the day of the event as is the case for the 9 October, and with cumulative rainfall in the preceding ten days. Slope failures at the end of the month show lower values of cumulative rainfall in previous days, but these were probably influenced by the rain of the beginning of that month (Fig 3.17.b).

Figure 3.17a: Cumulative rainfall prior to slope failures, April-May 1978



Day 0: day of the event

Figure 3.17b: Cumulative rainfall prior to slope failures, October 1978



Day 0: day of the event

3.4.2 Antecedent Rainfall Index

An index of antecedent rainfall was developed based on Crozier's approach to triggering rainfall conditions by considering 10-day period immediately prior to the event (Crozier and Eyles, 1980).

This index was calculated for 3, 10, 30, 60 and 90 days previous to landslide occurrence in the above mentioned period in the Metropolitan Area of Caracas, using the following equation (Kohler and Linsley, 1951):

$$Pa_0 = K P_1 + K^2 P_2 + \ldots\ldots K^n P_n$$

Where:

Pa_0= antecedent daily rainfall for day 0

P_n = precipitation on the n'th day before day 0

K = 0.84.

The value 0.84 for k has been used here as in the original method, "...for its ability to delineate a threshold between landslide and non-landslide producing conditions" (Crozier, 1980). This value decays by an exponential function so that the rainfall value exerts progressively less influence on the index as time elapses.

The result does not give any specific value or range that can be related to define a threshold. For the case when 30, 60 and 90 days of antecedent rainfall were considered, there are no significant differences as the K factor obviously becomes a very small number after 30 days. Nevertheless looking at the graphs for 10 days of antecedent rainfall, slope failures in 1974, 1975, 1976 have low values of antecedent rainfall and very few events are associated with daily rainfall. Events in 1977 are associated with different values of daily rainfall and a range of 15 to 30 mm antecedent rainfall. In 1978 and 1979, both had different values.

3.5 DISCUSSION

A variety of studies have used rainfall values as thresholds to establish the relationship between mass movement and rainfall events. As an example, Crozier and Eyles (1980) showed in the case of the Otago Peninsula how progressively smaller amounts of rainfall were able to trigger landslides as the antecedent rainfall index increased. Campbell (1975) suggested that, for Los Angeles, a minimum total antecedent seasonal rainfall of 10 inches (250 mm) was necessary before an intensity of about 0.5 inch per hour (6.3 mm/hr) could provide the minimum conditions for failure. Hauser (1985) in a study of mudflows in the metropolitan region of Santiago, showed how values of 60 mm/24 hr were related to the events recorded in historical records. Jenkins *et al.* (1988) discuss the rainfall that initiated the failures in the steep slopes of the Ochil Hills, Scotland, in November 1984.

In the case of Caracas, the mechanism seems to be related to the building up of water in the regolith as a result of seasonal rainfall. The slope failures taken into account in constructing the graphs comprise 78% of the total of slope failures for the rainy seasons in the 6 years including April, 1978 and November, 1977 by virtue of their evident association with the rainfall. In only 22% of those failures the accumulated values were below 40 mm for the preceding ten days (i.e. 78% of the accumulated values were over 40 mm) but even then they always exceeded at least 20 mm. As regards the data for 30 days, 65% of the slope failures were above the 90-100 mm range and 50% above 100 mm. The remaining 35% was rarely below 40-50 mm.

According to the graphs, minimum values of approximately 40 mm within the 10 days prior to the failures were accumulated for the majority of slope failures between 1974 and 1979. The mean values calculated for all 205 slope failures were 43.4 mm for the preceding 10 days, and 108 mm for the preceding 30 days. This is of some predictive significance locally, for it can act as a warning that failures are imminent and local emergency services need to be activated.

Coefficients of variation[4] were calculated for the results given by the cumulative rainfall values and antecedent rainfall index for 3, 5, 10 and 30 days prior to the events, and for all the slope failures between 1974 and 1979. Since the former presents less variation (fig. 3.18), it could represent the association with a threshold more reliably. The relevance of cumulative effect in the long term is clearer, as the coefficient of variation declines: the threshold may be more closely associated with the rainfall accumulated in the season than with the rainfall that fell in the immediately preceding days of rainfall. Cumulative rainfall could be taken as indicative values for 10 and 30 days, depending on the characteristics of the slope failures, as will be shown in the ensuing chapters.

[4]An expression of variation (another way of indicating dispersion) obtained by converting the standard deviation to a percentage of the mean (Hammond and McCullagh, 1978).

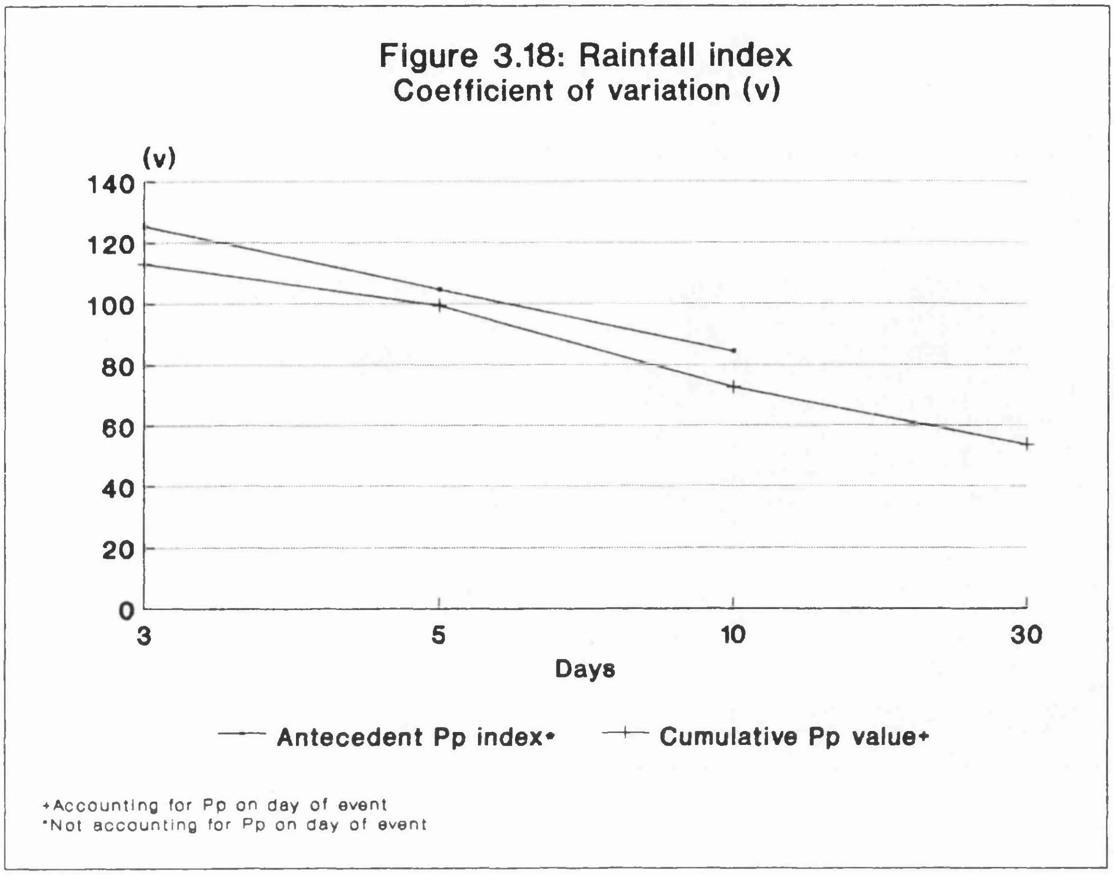


Figure 3.18: Rainfall index
Coefficient of variation (v)
(v)
140
120
100
80
60
40
20
0
3
5
10
30
Days
Antecedent Pp index•
Cumulative Pp value+
+Accounting for Pp on day of event
•Not accounting for Pp on day of event

CHAPTER IV

SPATIAL PATTERN OF LANDSLIDE OCCURRENCE IN CARACAS

4.1 INTRODUCTION

Cumulative rainfall values were considered in the previous section in an attempt to define a climatic threshold above which slope failures occur. Although a single threshold could not be defined, at least on the basis of rainfall values alone, the analysis of rainfall data showed approximate figures for minimum values of rain for 10 and 30 days prior to mass movement.

The fact that the threshold depends in part on other characteristics of the physical environment, such as rock type or its location within the urban context, provides the justification for considering other characteristics relevant to the spatial distribution of slope failure. They will be examined in order to identify the major contributing factors to landslide occurrence in the Metropolitan Area of Caracas and to discover whether, within such a contextual set of variables, rainfall can be viewed as the triggering factor.

4.2 THE DATA SET

In this section a sub-dataset of 205 slope failures for which location and date of occurrence were known was selected and other characteristics of the environment associated with the failures were recorded. As mentioned in section 3.2.1, very few sources provided data on the physical features of the movements. There is no standard procedure for gathering information of landslides in Caracas, which makes it more difficult to draw a clearer picture of the factors that are involved in the process. When an event occurs, the first-hand information comes from rescue workers, journalists, individuals concerned about the landslide and, for some cases, technical reports dealing with the site for specific enquiries such as insurance. The information here described was obtained by the author indirectly from several sources.

4.2.1 Location, Date of Event and Type of Failure

As explained in section 3.2.1, data available from the Inventario Nacional de Riesgos Geológicos (Singer *et al.*, 1981-FUNVISIS) include location within the Metropolitan Area of Caracas and date of occurrence. This dataset comprises most of the slope failures used in the previous chapter for failures that occurred between 1974 - 1979. Those for which location and/or date of occurrence were unknown have been excluded.

For location, place names were given by the same source (FUNVISIS) for each site of the event. They were plotted on a topographic map at a scale of 1:100,000 which allowed the subsequent identification of other variables also available from maps.

The FUNVISIS source also distinguishes two types of slope failures: *deslizamientos* and *derrumbes*. Both are included in the wider category of "...risk associated with gravitational forces". Although no definition of each type is given by the source , in practice the distinction is made in the field by the causes of movement related to soil moisture (largely as the direct result of rainfall), and the characteristics of the material moved.

Slope failures in which rainfall is believed to play a very important role in terms of the cause of movement, and where mainly regolith is involved, are collectively identified as '*deslizamientos*' (*deslizamientos* could be considered as the approximate equivalent of soil slips, except that they do not only cover small-scale failures). On the other hand, when the material includes primary bedrock and the movement has not necessarily been linked to the presence of water, the movement is referred as '*derrumbes*' (rock fall).

Within Caracas, other types of movement have also occurred. They include falls, toppling, landslides and flows. Nevertheless, landslides - represented by *deslizamientos* and *derrumbes* - are regarded as the commonest.

Feliziani *et al.* (1985), in Estudio Geotécnico del Area Metropolitana de Caracas, explains that owing to characteristic geological structures, weathering grade and human intervention, there are two common basic forms of landslide in Caracas: rotational slides and complex slides (indeed, they all seem to be referring to a particular type of mass movement, **landslides**). Although the classification given in Inventario Nacional de Riesgos Geológicos does not define slope failures precisely, it was felt necessary to use it in the following analysis since it was the only classification available.

4.2.2 Season

As stated in section 3.2.2, Caracas has a well-defined dry and wet seasons. Date of occurrence was used to classify the events within the appropriate season:

i) rainy season, for the events recorded between May and October

ii) dry season, for the events registered from November to April.

An exception was made for 1977, in which very high values of daily precipitation during November (monthly total of 131.5 mm) were associated with slope failures that occurred in that month.

4.2.3 Geology and Slope

i) A geological map of Caracas (scale 1:100,000) was used for locating each slope failure according to one of three formational groups: KLM (the *Las Mercedes* Formation of Cretaceous age) a lithological unit of mainly calcareous schist; JLB (*Las Brisas* Formation, of Jurassic age) principally a mica schist; and a third group which includes other rock types found in relatively small proportions of the area affected by slope failures including the *Peña de Mora* Formation, found in the *El Avila* National Park on the northern boundary of the valley and which presents very few signs of human interference and the *Antimano* limestones. The area occupied by the main formations, *Las Brisas* and *Las Mercedes*, were calculated from the geological maps of Caracas: the <u>Mapa Geológico de la Región Colonia Tovar-Guatire</u> (Wehrmann, 1969) and the <u>Mapa Geológico de Caracas</u> (MEM, 1986. hoja 6847). Within the boundaries of the Metropolitan Area of Caracas as defined in section 2.2 chapter II, the proportion is as follows: KLM 29.3% (177 Km^2); JLB 42.8% (259 Km^2); and others 27.8% (168 Km^2).

ii) Slope angle was measured directly on a topographic map at a scale of 1:100,000. The average slope angle for each site was calculated over distances of 500 m (0.5 mm on the map). It must be emphasized that the database only shows date and location (by the name of the site) and not the precise location of the failure on the slope. Slope was based on the standard formula S=VD/HD (where VD is the vertical difference between the contour lines and HD is the horizontal distance between the contour lines). Seven categories were considered: <24% ; 24-32% ; 32-40% ; 40-48% ; 48-56% ; 56-64% ; >64%. Most of the areas in which the landslides occur have probably been modified by human activity, particularly those associated with artificial cuts in roads and for structures and buildings. Consequently the slope angle is not necessarily represented here with the value at which the slope failure occurred. Nevertheless it gives a reasonable idea of the slope angle of the original topography, and of the minimum slope on which the failures occurred.

4.2.4 Urban Location

Each slope failure was classified in terms of the urban characteristics surrounding it that could have some influence on the occurrence of slope failure, as follows:

i) *Barrios* when slope failure occurred within the boundary of the barrio settlement or where the source reported damage in *ranchos*, a name given locally to the individual houses located in *barrios.*

ii) Other residential areas, including buildings, houses and housing estates provided with services such as water supply, drainage and sewage systems.

iii) Road-cuts and other artificial cuts. At such locations, it is likely that slopes have been oversteepened. Although the type of site is not specified, information relating to the damage is an indication of the use made of the site (e.g schools, parking places).

4.3 SPATIAL DISTRIBUTION OF SLOPE FAILURES IN CARACAS

Although the data set examined to define a pattern of slope failures has only taken into account six years (1974-1979), the slope failures reported since 1800 should not be ignored in seeking to define a pattern of distribution.

The location of the slope failures that have taken place since 1800s is shown in figure 4.1. The distribution of these failures gives some indication of the effect of population pressures on most of the hill sites in Caracas. The areas where the landslides occurred between 1800 and 1970 have been further affected during the 1970s and 1980s, as they coincide with the physical expansion of Caracas since 1960 shown in Chapter 2.

It could be argued that the process of urban growth has led to an increase of vulnerable areas by turning geomorphological processes into community hazards, as Cooke (1984) points out for Los Angeles.

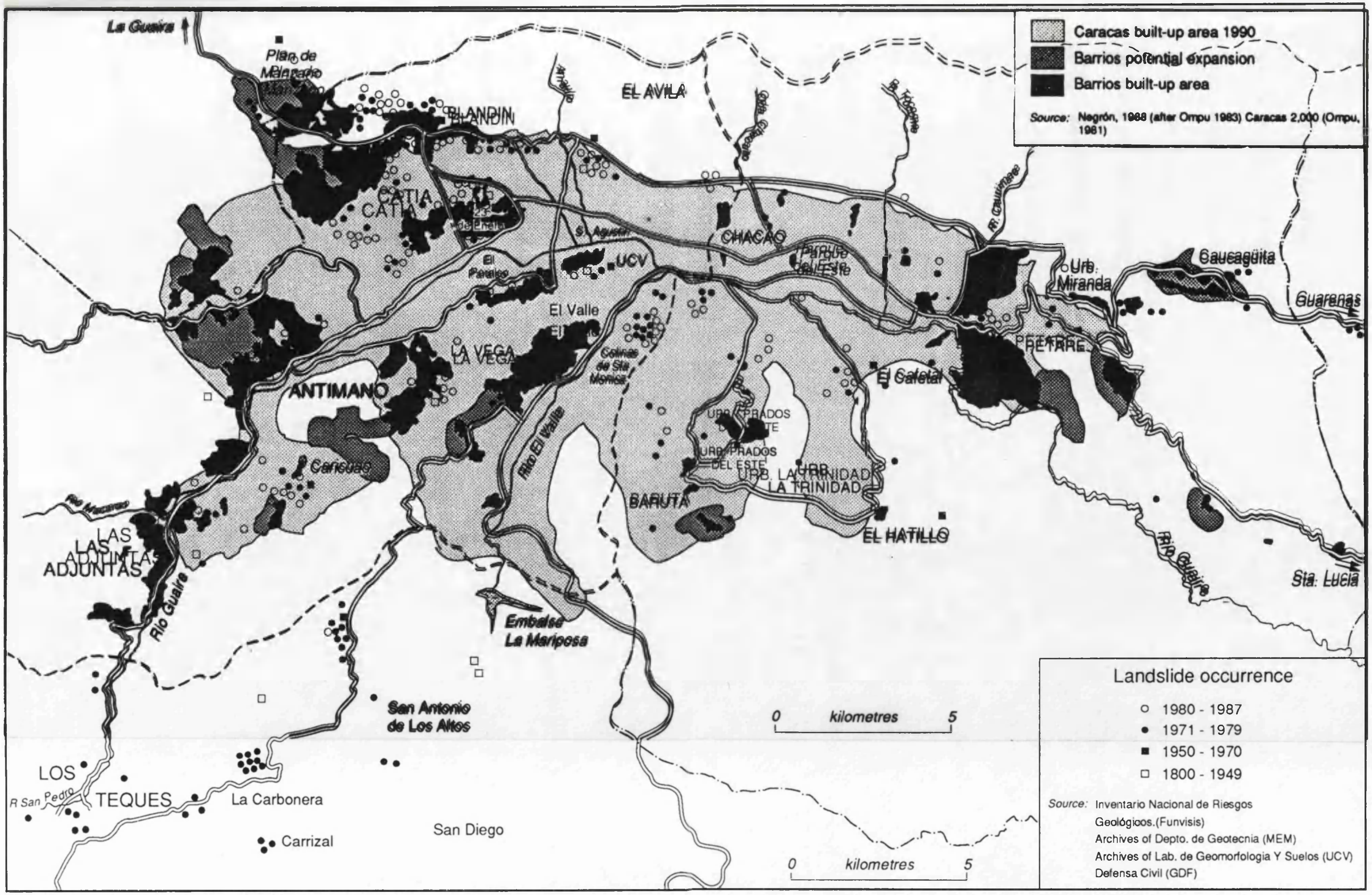


Fig. 4.1: Landslide occurrence in the metropolitan area of Caracas

The main areas continually affected by slope failures have been identified on figure 4.2, which shows areas where landslides are concentrated. More than 20 events for the period considered are found in *Petare*, *Carapita-Antímano*, and *Blandin-Gramoven*; from 15 to 20 events in *Santa Mónica* and *La Vega*; and at least 10 events in *El Cafetal, El Valle, San Agustin del Sur, Avenida Guzmán Blanco (Cota 905), Caricuao, Moran -Vista Alegre, Catia-Propatria-Casalta*. Apart from *Sta. Mónica* and *El Cafetal*, all other areas mentioned are occupied by *barrios*. The concentration of failures in *Santa Mónica* is a direct consequence of construction work.

The concentration is not so apparent elsewhere in Caracas. Therefore it seems possible that the areas of high slope failure incidence may have certain features in common. The period 1974-79 is accordingly examined to determine the physical characteristics associated with the landslides that occurred in that period.

4.4 CHARACTERISTICS OF SLOPE FAILURES IN CARACAS

a) Frequencies for all slope failures

For the period 1974-79, figure 4.3 shows the frequencies for the variables described in the previous section: season, lithology, type of failure and urban location. Figure 4.4 shows the analysis of slope angles. The results allow preliminary characterization of the failures in terms of the variables considered:

i) slope failures occurred mainly during the rainy season comprising 81.5% of all 205 slope failures that occurred in the period mentioned;

ii) The majority of failures (55.8%) were in barrios; the next largest proportion was associated with road cuts (20.1%);

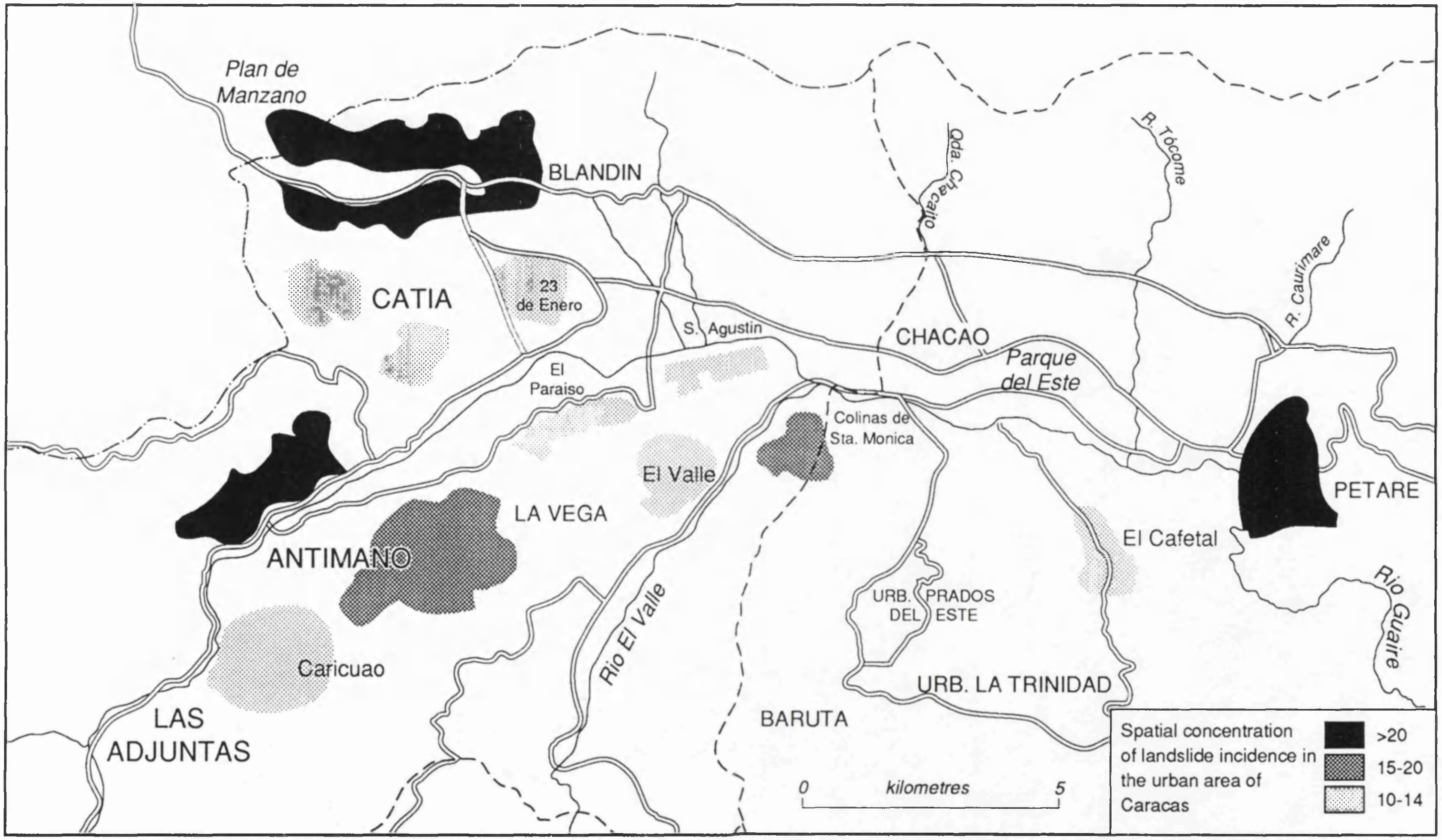
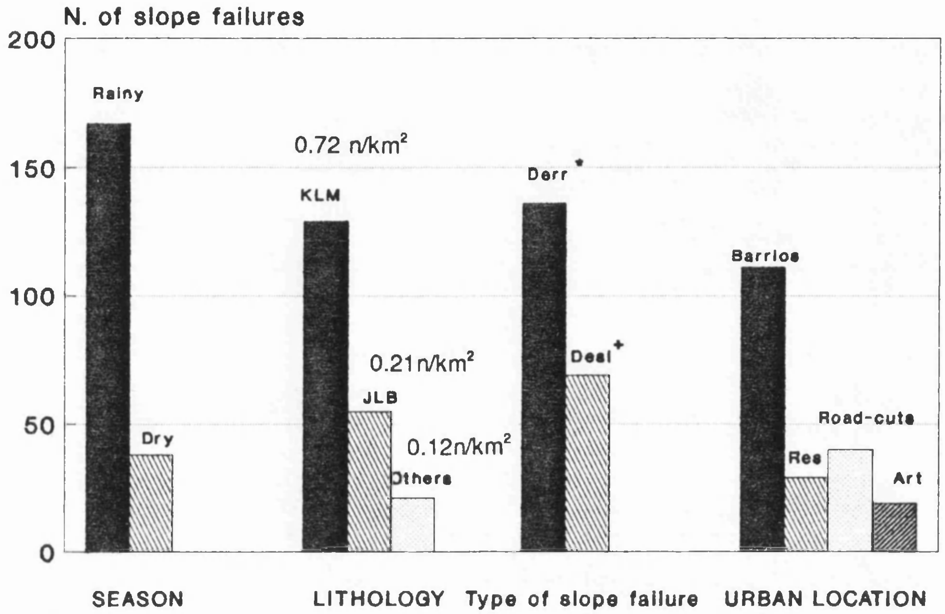

Plan de Manzano
BLANDIN
CATIA
23 de Enero
El Paraiso
S. Agustin
CHACAO
Parque del Este
Qda. Chacaito
R. Tócome
R. Caurimare
PETARE
Rio Guaire
El Cafetal
Colinas de Sta. Monica
El Valle
LA VEGA
ANTIMANO
Caricuao
LAS ADJUNTAS
Rio El Valle
URB. PRADOS DEL ESTE
URB. LA TRINIDAD
BARUTA
0 kilometres 5
Spatial concentration of landslide incidence in the urban area of Caracas
>20
15-20
10-14
Fig. 4.2

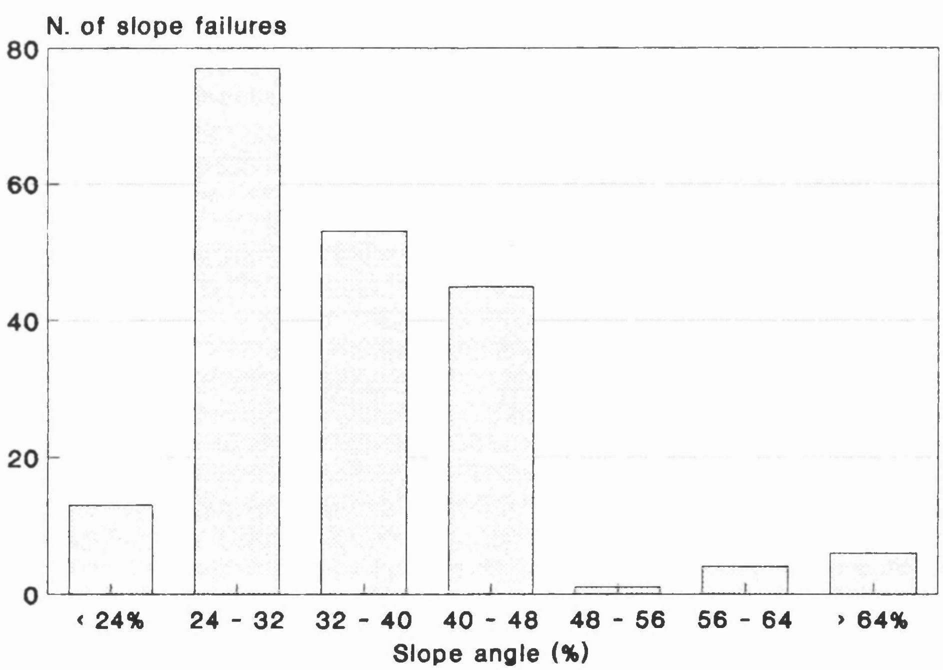
Figure 4.3: Characteristics of slope failures, 1974-1979



* *Derrumbes*
\+ *Deslizamientos*
Categories are explained in the text

Density (n. of slope failures/km^2)

Figure 4.4: Slope Angles *



* Frequencies for 205 slope failures occurred between 1974 and 1979

iii) More than 60% of the failures were related to the calcareous schist of the KLM-*Las Mercedes* formation. The relative area occupied by each lithological unit is given in p. 100. The relative densities of slope failures per unit area of *Las Mercedes* (KLM) and *Las Brisas* formations are as follows: 0.72/Km^2 for KLM; 0.21/Km^2 for JLB and 0.12/km^2 for others. These differences may be explained, as discussed further in chapter 5 (p.117), mainly by the presence of highly fractured and weathered material in the intensely folded *Las Mercedes* formation (KLM) when all other factors are held constant.

iv) '*derrumbes*' (rock falls) are the most common type of movement (66.3 %);

v) approximately 40% of the failures are associated with slope angles between 14-18° (24-32%).

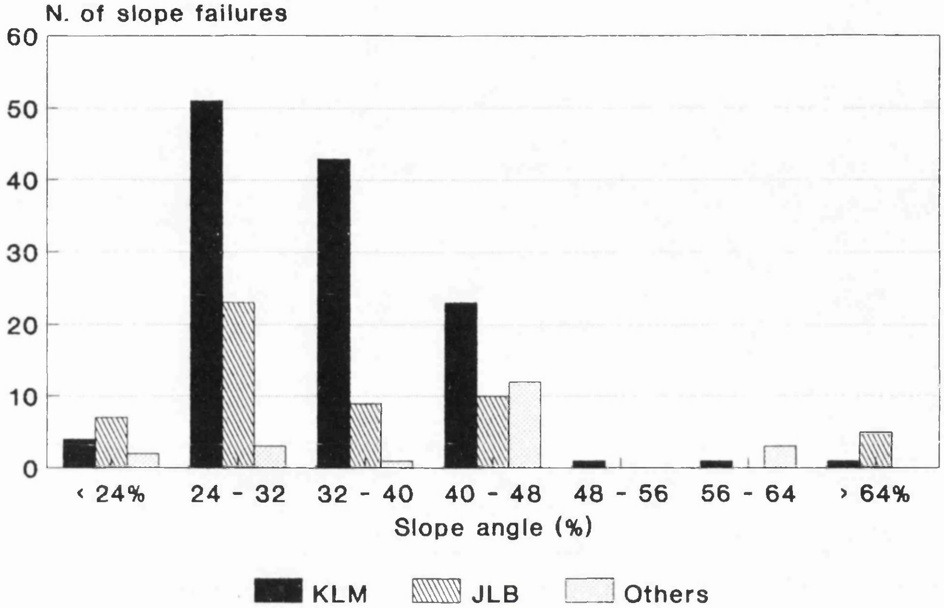
b) Cross-tabulation

Cross-tabulation of the variables was carried out in order to assess the relationship between them. The effect of lithology on the limiting slope angles as well as the association with the type of failure are examined below.

Figure 4.5 shows the relationship between slope angles and lithology. It indicates that slope failures in the *Las Brisas* Formation (JLB) were mainly associated with low slope angles 14-18°(24% - 32%), whereas the *Las Mercedes* Formation presents a significant proportion in other ranges. This is almost certainly due to the fact that the angle of internal shearing resistance for the micaceous lithologic unit (JLB) lies between 12° (21%) and 18° (32%) (Feliziani *et al.*, 1985), as well as being more deeply weathered than the calcareous schist (KLM). The latter has an average angle of internal shearing resistance of 18° (32%). Reductions in shear strength occur as a result of the weathering in the mica schist unit. A Chi square test conducted on expected versus observed frequencies of angle of slope failures upon the above lithologies confirmed this relationship at a significance level of 99.9%.

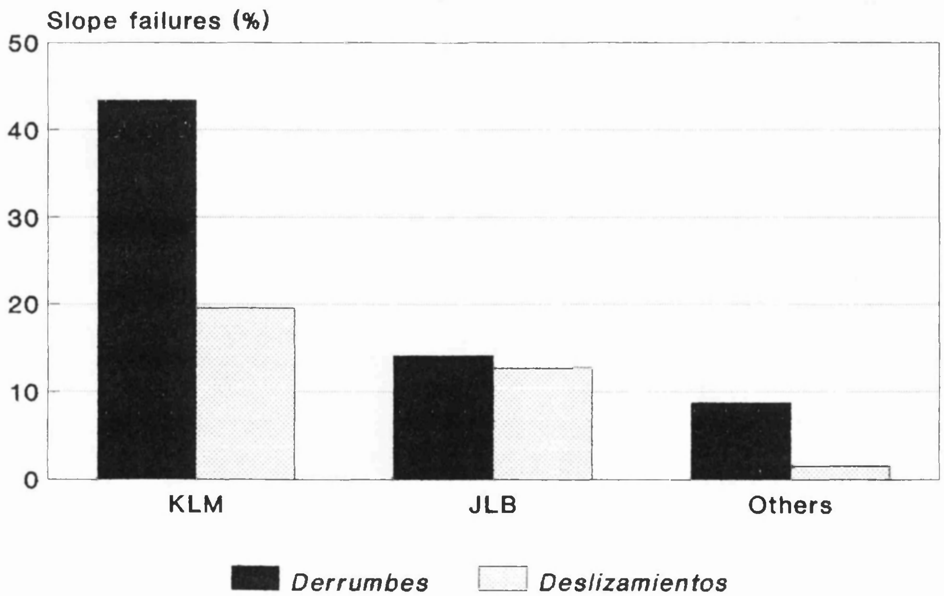
Figure 4.6 shows the proportion for each type of movement according to the lithological units in which they occurred: '*Derrumbes*', (failures in which bedrock is mainly involved), were

Figure 4.5: Lithology and slope angles *



* Frequencies for all slope failures
KLM: Calcareous schist
JLB: Quartz-mica schist

Figure 4.6: Type of slope failure and lithology



KLM: Calcareous schist
JLB: Quartz mica-schist

predominant in calcareous schist (KLM). Foliation is well-developed in this unit (Feliziani *et al.*, 1981). Movements which occur along the main foliation or along other planes of separation, as well as rotational slides, are most likely to be found in this lithological unit.

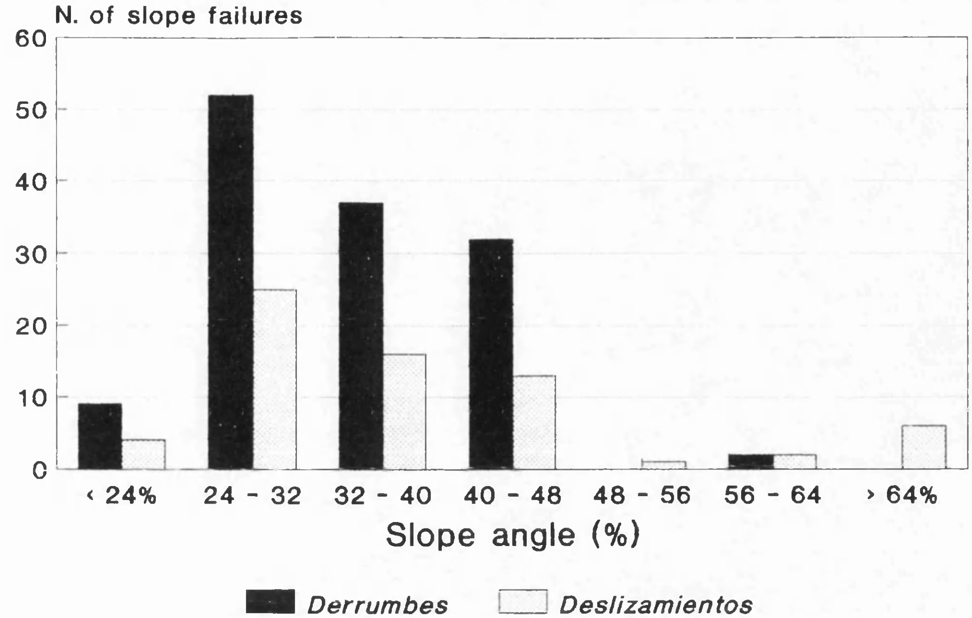
The difference in the proportion between the two types of failures is not so noticeable within the *Las Brisas* Formation (JLB). *'Deslizamientos'* (movements mostly within regolith) were found in the mica schist unit (JLB) as well as in the calcareous unit (KLM) in almost the same proportions. This is probably because the movements are chiefly determined (and classified) by the presence and thickness of regolith, the mica schist unit (JLB) being the one that exhibits the deeper weathering profiles (19-30 m). A Chi square test conducted on expected versus observed frequencies of type of slope failures upon the above lithologies, confirmed this relationship at a significance level of 95%.

Figure 4.7 shows the relationship between type of slope failure and slope angle. The relative proportion in *derrumbes* and *deslizamientos* are similar in each slope category. Since *deslizamientos* are related to the soil moisture and the movement of regolith, the expected case would be that they would be more common at the lower angles. A Chi square test conducted on expected versus observed frequencies of type of slope failures upon slope angles confirmed this relationship at a significance level of 95%.

c) Frequencies according to seasonality (rainy and dry)

Since the previous chapter has emphasized the role of precipitation in slope failures, Table 4-1 has been produced to show the relationship between season and the other variables considered.

Figure 4.7: Type of slope failure and slope angles *



* Frequencies for all slope failures

i) Slope angles were lower when failures occurred within the rainy season. The proportion was higher for failures in road-cuts, where 53.8% of all slope failures were concentrated in the range 40%-48% within the dry season.

ii) 64.7% of the failures during the rainy season occurred in calcareous schist (KLM, *Las Mercedes* Formation). The proportion of failures related to mica schist (JLB, *Las Brisas* Formation) was slightly higher for failures in the **dry season**. It is important to highlight that *Las Brisas* Formation has deeper weathering profiles than the calcareous schist.

iii) In relation to the type of movement, although '*derrumbes*' were predominant, the proportion of '*deslizamientos*' increased in the rainy season, reflecting the association of this type of failure with soil moisture.

Table 4-1: PHYSICAL CHARACTERISTICS OF SLOPE FAILURES ACCORDING TO SEASONALITY (%)

	TYPE OF SLOPE FAILURE		LITHOLOGY			PREDOMINANT SLOPE ANGLE (%)		
	Derr	Desl	KLM	JLB	other	24-32	32-40	40-48
RAINY	64.7	35.3	64.7	25.1	10.2	40.1	27.2	19.8
DRY	73.3	26.3	55.3	34.2	10.5	32.4	24.3	35.1

n= 205.

4.5 SOME CASES OF SLOPE FAILURES IN CARACAS

In order to correct the lack of information of physical characteristics on slope failures in Caracas, a detailed survey of seven recent events was carried out .

Table 4-2 illustrates some of the characteristics of slope failures in Caracas and gives an example of the way in which the data were collected. These failures comprise most of the frequent geotechnical problems encountered in the Metropolitan Area of Caracas: slope failure in residential areas, in road-cuts, and in other artificial cuts. The landslides in *barrios* are considered separately in subsequent chapter.

Table 4-2: SOME CASES OF SLOPE FAILURES IN CARACAS

LOCATION	DATE	TIMING	DEGREE OF ACTIVITY	APPROX. LIMITING ANGLE	TYPE AND SIZE OF MATERIAL MOVED	UNDERLYING GEOLOGY	TYPE OF MOVEMENT	VEGETATION	CAUSE OF MOVEMENT	MORPHOLOGY OF DEPOSITED MATERIAL AND OF FAILURE(m)
Sta. Rosa de Lima	13-12-86	end of rainy season	Inactive	40°	Bedrock + detritus	KLM	slide translational	scarce	rainfall	Ws=15 Ds=10 Wm=30Lm=30 HE=40 Vl=30
Colinas de Sta. Mónica	07-87	mid. rainy season	Active	40°	Bedrock	KLM	complex	none	geometrical changes + rainfall	Ws=25 Vl=30 *
Caurimare	19-11-87	end of rainy season	Active	34°	Bedrock + detritus + silt matrix	JLB	slide rotational	scarce	--	Ws=17 Ds=5 Lm=45 Wm=27 Dm=6 HE= 30 Vl=40
Urb. Miranda	12-87	end of rainy season	Active	38°	soil + debris	KLM/JLB	rotational cohesiveless grain flow	none	rainfall	Ws= 40 Wm= 70 HE= 50 Vl=50 *
Cerro Verde	12-87	end of rainy season	Active	35°	soil + detritus	JLB	slide rotational	none	geometrical changes + vibration	Ws=14 Ds=4 Lm=32 HE=35 Vl=25
Los Pomelos	7-01-88	dry season	Active	33°	Bedrock + detritus	JLB	slide planar/ translational	scarce	geometrical changes	Ws=15 Ds=5 Lm=40 Wm=24 Dm=8 HE=30 Vl=40
Colinas de Sta. Mónica	7-02-88	dry season	Active	55°	Bedrock	KLM	complex	scarce	--	Ws=57 Ds=5 HE=10 Vl=35

*: material removed

Figure 4.8: SLOPE FAILURE REPORT

<u>Slope failure report</u>

1. Date of Survey:

2. Record No:

3. Location:

4. Date of movement/time (24:00):

5. Degree of activity:

6. Limiting angle and mean slope angle:

7. Type and size of material moved:

8. Underlying geology:

9. Type of movement:

10. Water content:

11. Vegetation:

12. Causes of movement:

13. Timing

14. Morphology of deposited material and of slope surface:

Hillslope	Scar	Failed mass
slope length(Ls)	scar width (Ws)	maximum length (Lm)
	scar depth (Ds)	maximum width (Wm)
		maximum depth (Dm)

Horizontal equivalent of failed mass (HEm)

Vertical interval of failed mass (VIm)

Length of failure surface (Lf)

15. Damage:

Comments:

Reporter:

Some of the common problems are pointed out by Sidle *et al.* (1985): "In residential developments, the quantity of water introduced into the hillslope soil mantle can be greatly increased by irrigation, swimming pools, small artificial ponds, and septic drainage fields." The consequences of this added water can contribute to the failures.

The description was based on field observations (fieldwork November 1987 - February, 1988) on landslides which still displayed traces of the mechanism responsible for them. A checklist was previously drawn up (figure 4.8) to describe each event, using the criteria considered for landslide classification by different authors including Coates (1977), Varnes (1978), and Hansen (1984).

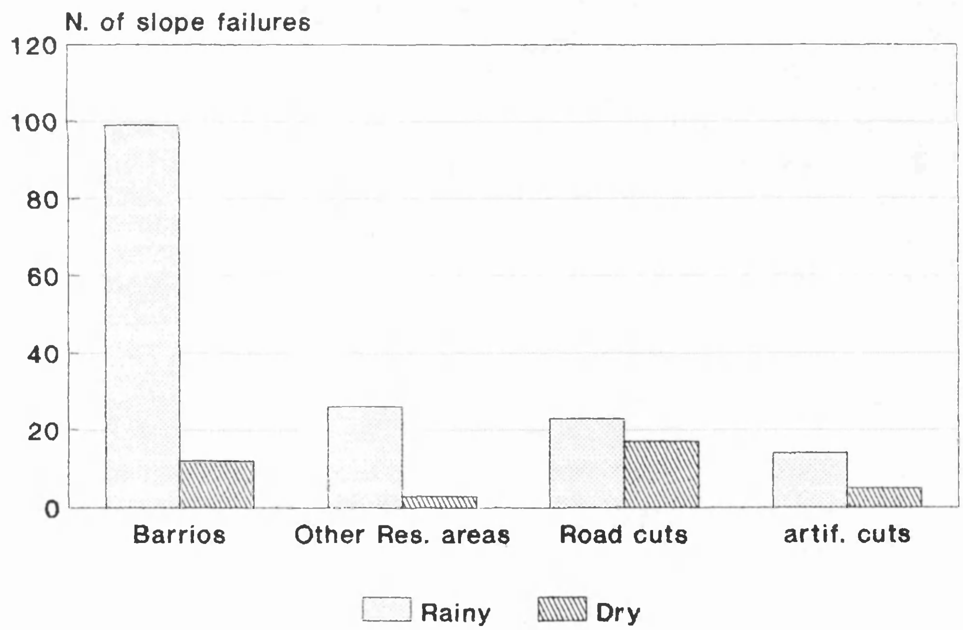
The resulting table (4-2) for the seven cases includes: location and date of movement, timing (if possible, time 24h in which slope failure occurred), degree of activity, limiting angle, type and size of material moved, underlying geology, type of movement, vegetation, causes of movement or triggering mechanism (where identified). Information about morphology of deposited material and of slope failure is also given.

4.6 CONCLUSIONS

The characteristics outlined in this chapter give some indication of the conditions for landslide occurrence in the Metropolitan Area of Caracas in relation to seasonality, type of failures, lithology and slope angles. A full evaluation of the factors involved requires further details regarding the type and size of material moved, water content, velocity of movement, geotechnical properties, and so forth.

Figure 4.9 illustrates the frequencies in relation to season of slope failure and urban context. It demonstrates the high incidence of slope failures in *barrios*. The following chapter develops this theme and also seeks to determine more clearly the role of the precipitation as a trigger for slope failure.

Figure 4.9: Slope failures in Caracas
Season and urban location



CHAPTER V

PATTERN OF SLOPE FAILURES IN BARRIOS

5.1 INTRODUCTION

The high incidence of slope failures during the rainy season in the *barrios* of Caracas has been demonstrated. This section seeks to identify the variables that characterized slope failures in *barrios* and to consider the role of rainfall in such movements. It also aims to illustrate a first step in assessing the relationship between the services in the *barrios* in the context of the incidence of slope failures in Caracas.

5.2 THE INCIDENCE OF SLOPE FAILURE IN *BARRIOS*: MAIN FEATURES

Figure 4.2 (chapter 4) showed the concentration of slope failures in the metropolitan Area of Caracas since 1800. All the areas with the exception of *Santa Mónica* and *El Cafetal* are occupied mainly by *barrio* settlements. Some common features in the areas of concentration of slope failure are as follow:

i) Vegetation:

The vegetation cover has been removed mainly through urban growth. Only patches of vegetation remain; isolated trees may even have an adverse effect on slope instability. Roots penetrate the thin regolith and enter the cracks and joints of the metamorphic rocks, reaching depths of 1.40 m. An example is shown in plate 8. According to Greenway (1987), roots and stems increase the roughness of the ground surface and the permeability of the soil, leading to increased infiltration capacity. So does depletion of soil moisture which may accentuate

Plate 8: Root penetration of isolated trees on metamorphic rocks

desiccation and hence cracking in the soil. In addition vegetation exposed to the wind transmits dynamic forces into the slope.

ii) Geology:

Geologically, these areas are located in the zone of influence of the *El Junquito* anticline and the *Baruta* syncline. The movements can be frequently controlled by structure and schistosity of the metamorphic rocks of the *Las Brisas* formation. Similarly, in the intensively folded *Las Mercedes* formation, movements are influenced by the bedding planes and highly fractured material in the man-modified slopes. Bare cuts (as a consequence of cut and fill) have a similar effect specifically in the area around *Colinas de Santa Mónica*. Moreover, percolation into the slope is encouraged.

iii) Lithology

Lithologically, the main concentration of landslides (more than 15) was found in the calcareous-graphite schist of the *Las Mercedes* formation. In fact, the percentage was higher than for Caracas as a whole (69.4%).

According to Feliziani *et al.* (1985), lenses of mica within the rock represent planes of weakness; deep weathering profiles; and the fractured nature of the material in the slopes highly modified by human intervention also contribute to the poor stability of the calcareous schist unit.

But the concentration of slope failures in *barrios* in this unit (KLM) requires additional explanation. One possibility is that waste water including sewage accelerates rock weathering. Salcedo (1991) regards the effect of the 'aguas negras' as very significant in limestones, schist and calcareous phyllites of the metamorphic sequences around Caracas. For instance, he argues that bacteria such as *Thiobacillus ferroxydans* promotes the alteration of pyrite, the resulting sulphuric acid dissolves the carbonates of calcareous rocks. But it is important to note that pyrite makes up only 2% or less of the *Las Brisas*, *Antímano* and *Peña de Mora* formations, so its effect is unlikely to be fundamental. According to Gonzales de Juana (1980: p. 317), the calcareous composition of the *Las Mercedes* formation favours chemical weathering, and so also mechanical weathering. Feliziani *et al.* (1985: p.4629), on the other hand, states that chemical weathering dissolves calcite with difficulty.

Petrographic analysis on samples from different areas of *Las Mercedes* formation in Caracas have shown that the mineralogical composition consists mainly of calcite, quartz, mica muscovite and carbonaceous material (Valle, 1965; Wehrmann, 1972; Salcedo 1984). The pH of the waste water (sewage) was measured in *barrios* at source, in the channels and at the point of deposition, the measured values ranged between 8.1 and 7.6, which suggests that the waste water has little effect on the dissolution of the calcareous rock through chemical weathering. Instead, as previously mentioned, bands of mica and graphite by providing planes of weakness could have a much more important influence on rock behaviour, and waste water has a purely mechanical effect by increasing pore water pressure or, if it does effect any dissolution, by increasing porosity and permeability.

iv) Types of slope failure

Although the predominant type of slope failure was *derrumbes*, the *barrios* during the rainy season displayed a higher incidence of *deslizamientos* in both formations than when considering slope failure for Caracas as a whole.

The movements were classified mainly according to the presence of water as well as regolith as the dominant deposited material. House construction in the squatter settlements often entails cut and fill, the result being the accumulation of unconsolidated material at different points on the slope. When the movement affects the *barrios* these areas become a significant source of material deposited downslope in the affected area.

v) Slope angles

In the *barrios* during the rainy season the hill sites failed at lower slope angles (24%-32% and 32%-40%) than when considering all slope failures for Caracas for the entire period.

vi) Urban location

Two kinds of urban location are recognized, both of them being artificially modified environments.

Table 5-1 shows the physical characteristics of the affected sites in relation to urban location. The *barrios* emerge as vulnerable in the following characteristics: lower slope angles, a higher frequency of slope failures in relation to the calcareous unit and a slightly higher incidence of *deslizamientos* than others types of failure. These characteristics are examined in the context of the rainfall values determined in chapter three.

Table 5-1: PHYSICAL CHARACTERISTICS OF SLOPE FAILURES ACCORDING TO URBAN LOCATION (%)

	TYPE OF SLOPE FAILURE		LITHOLOGY			PREDOMINANT SLOPE ANGLE (%)		
	Derr	Desl	KLM	JLB	other	24-32	32-40	40-48
BARRIOS	58.6	41.4	69.4	26.1	4.5	38.7	29.2	17
ROADCUTS	70	30	42.5	22.5	35	15.4	25.6	53.8

n (*barrios*)= 111
n (road cuts)= 40

5.3 THE ROLE OF RAINFALL IN THE EVENTS

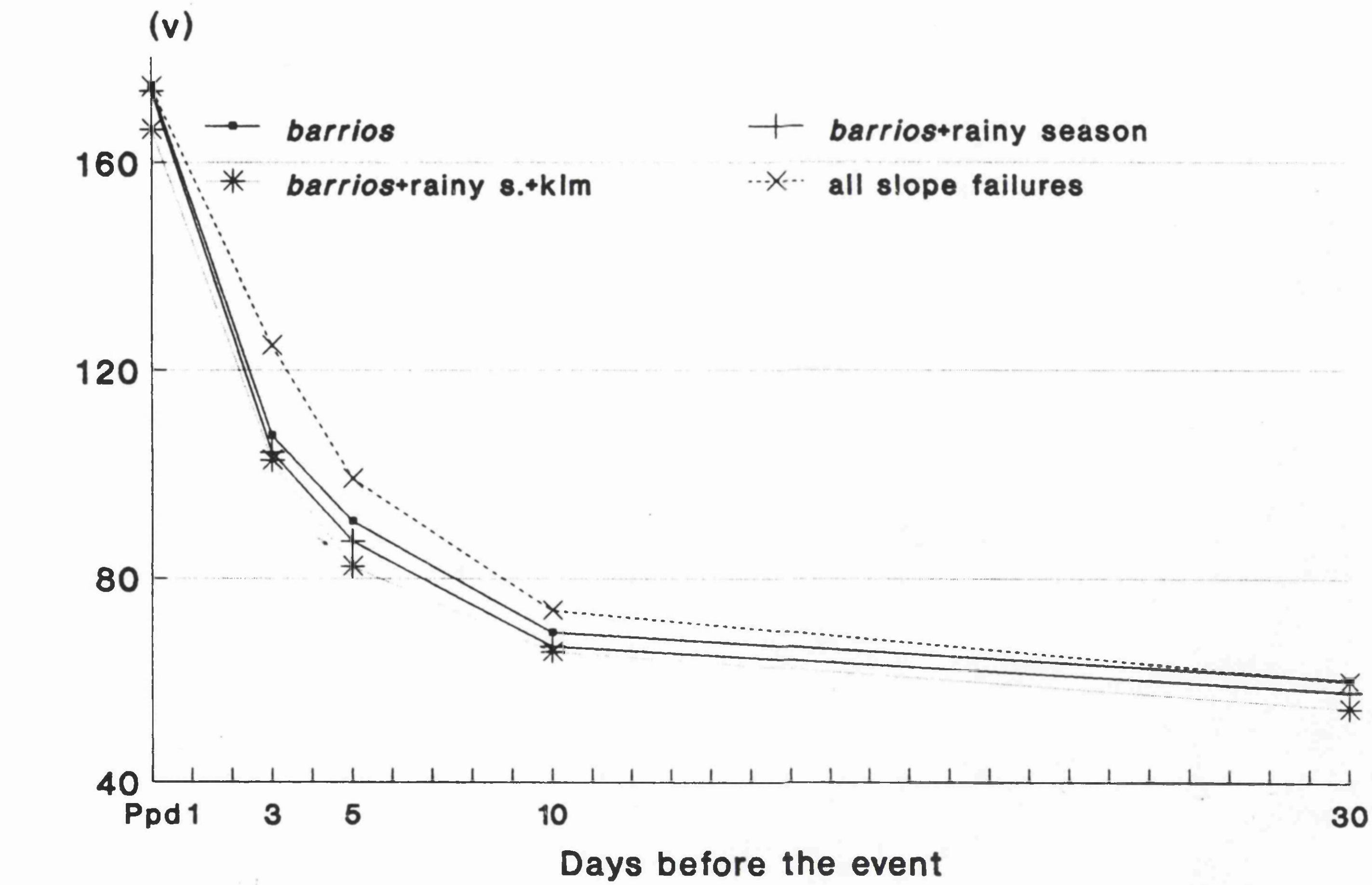
As a result of the analysis of the rainfall and the slope failures which occurred between 1974 and 1979 (chapter 3), a range of values of cumulative rainfall were identified before the movements occurred. These values are used here to identify different thresholds which have to be exceeded for failures to occur.

Figure 5.1 shows the coefficient of variation of the cumulative rainfall values for all slope failures occurring in the period, compared to values for events occurring in *barrios* during the rainy season. The values for the latter show less variation, and this could support the hypothesis that the coefficient of variation of the suggested thresholds decreases for failures of similar characteristics. The same graph shows that when lithology (KLM-*Las Mercedes* formation) is added to the graph, the coefficient of variation is the lowest.

On the other hand, the mean values for cumulative rainfall itself slightly increased in the short term when the slope failures occurred in *barrios* during the rainy season. The cited values suggest that *barrios* needed slightly more rainfall than other artificial cuts or areas in order to reach the threshold in which failures occurred (table 5-2). This may be because the closely-spaced houses, cemented paths and stairs in the *barrios* intercept the rain and promote superficial runnof, thus draining the water out of the slope. Therefore more water in the slope seems to be needed to trigger the event.

In the long term, the residential areas other than *barrios* showed less vulnerability, as the amount of rainfall accumulated needed to be higher for slope failure to occur. Although the different situations illustrated are modified slopes, Crozier (1986: p. 179) quoted an example where the amount of rain required in unmodified slopes was higher before failing than in cut & fill slopes. The latter is a common practice in the settlement process of *barrios*. Sidle *et al.*,

Figure 5.1: Coefficient of Variation (v) for cumulative precipitation values



Ppd: daily rainfall

(1985: p. 86), pointed out for the case of the residential areas and unmodified slopes that, "Natural rainfall and intercepted drainage as well as introduced water tend to be discharged onto the developed hillslope less uniformly than is natural rainfall on undisturbed slopes."

Table 5-2: CUMULATIVE RAINFALL VALUES (mm). RAINY SEASON

Slope Failures	CR10	CR 30	n
Barrios	39.1	103.8	99
All artificial areas*	34.3	110.1	63
Residencial other than barrios	36.3	116.7	26

CR: Cumulative rainfall in the preceding 10 and 30 days. Mean Values.
* : Includes residential, road-cuts and other artificial areas.

Table 5-3 shows the cumulative rainfall values for the different variables considered for the slope failures. Although the difference between the means are not significant, the values reflect some of the physical characteristics associated with each variable.

In terms of lithology, the thick regolith of the *Las Brisas* formation allowed more moisture to be stored before the failures occurred. *Deslizamientos* exhibits higher amounts of water. Regarding slope angles, the cumulative rainfall values for ten days show how the steepest slopes, possibly corresponding with a rock face, needed more water in order to fail. Hall's findings (1987, p. 146) regarding physical properties of quartz-micaschist could be applied here:

> "It was found that the moisture content of cliff-face rocks was low whilst that of loose blocks residing on the ground was much higher, with some even being fully saturated. The low degree of saturation for the cliffs is thought to be due to four main factors: (1) the water absorption coefficient for the rock is low, (2) The schistosity is normal to the direction of water movement which thus does not increase the ability of the rock to take-up water, (3) water moving down the steep cliff-face has only a short reside time, and (4) available moisture is limited..."

Table 5-3: CUMULATIVE RAINFALL VALUES
LITHOLOGY, TYPE OF FAILURE AND SLOPE ANGLES
(Slope failures in *barrios* during the rainy season)

VARIABLES		CR= 10 days	CR= 30 days	n
LITHOLOGY	KLM	37.6	104.7	68
	JLB	40.9	110.3	26
TYPE OF FAILURE	Desl	41.1	106.4	43
	Derr	37.6	101.8	56
PREDOMINANT SLOPE ANGLE	24-32%	36.2	116.6	36
	32-40%	38.6	101.3	27
	40-48%	40.8	114.3	16

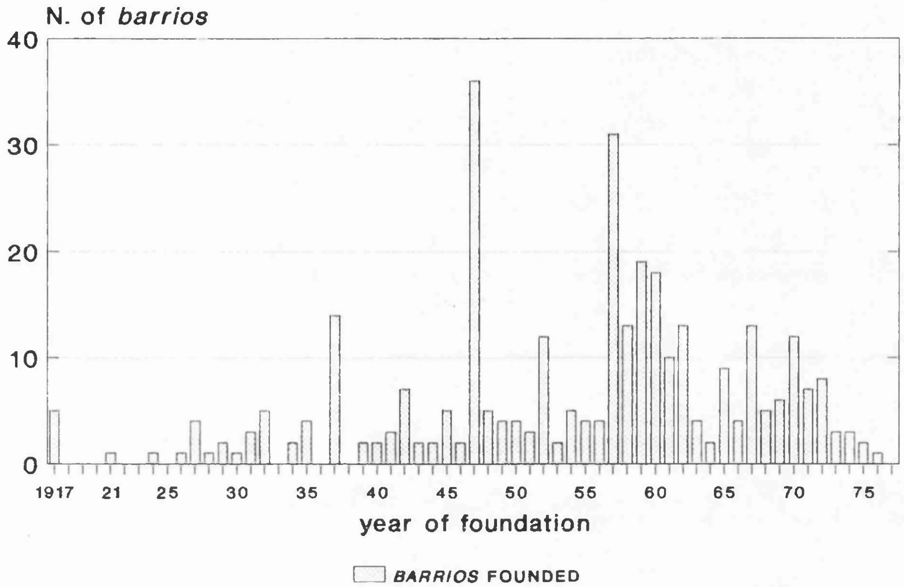
CR= Cumulative rainfall in the preceding 10 and 30 days. Mean values.

5.4 INFLUENCE OF *BARRIOS* ON SLOPE INSTABILITY

There is an explanation for the effect of some of the physical characteristics displayed by the slope failures in *barrios* compared to those of Caracas. The vulnerability of these high density areas might be explained also in terms of the effects of the induced modifications in the slopes as a consequence of the occupation.

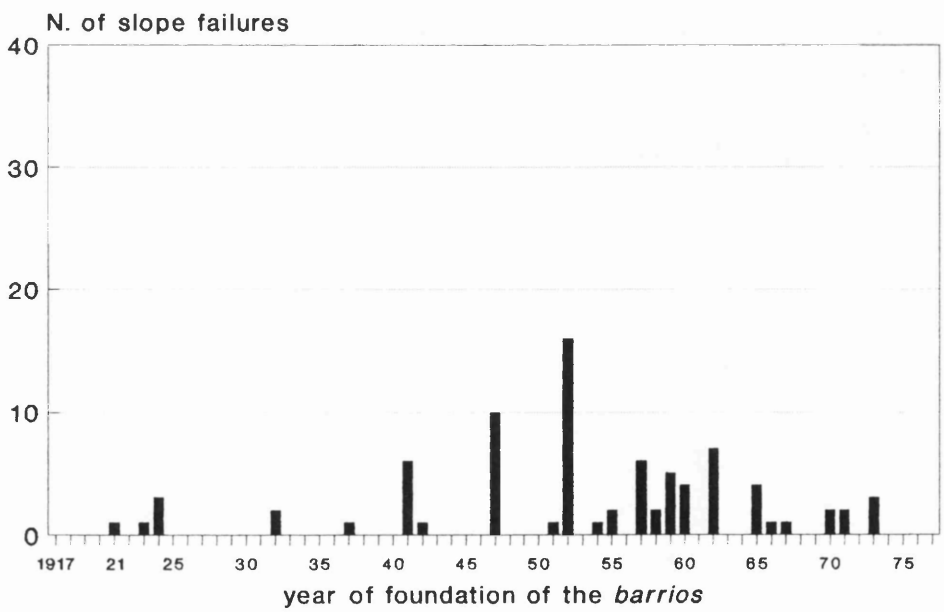
As a first step towards identifying the effect of the settlement process figures 5.2 and 5.3 are given to compare the chronology of the foundation of the *barrios.* The first figure comprises all the *barrios* founded up to 1976 in the Metropolitan Area of Caracas. The year given marks the start of the invasion by groups of people without land titles. Subsequent occupation, the permanent growth and increasing population densities of these areas are not illustrated here. The second figure (Fig. 5.3) gives the year of foundation of the *barrios* affected by slope failures within the period studied (1974-79).

Figure 5.2: Chronology of foundation of *barrios* in the Metropolitan area of Caracas



Source: FUNDACOMUN (1978)

Figure 5.3: Chronology of foundation of *barrios* affected by slope failures between 1974 and 1979



n=99

The *barrios* mostly affected are those founded in 1947 and 1952. The year 1947 (36 barrios created) and the period between 1957 and 1962, in which *barrios* were also affected, coincides with years in which also a majority of the *barrios* were founded. It is important to point out that for some cases one *barrio* registered more than one failure (La Silsa 8-10-74, 1-09-75, 8-07-1978). As a result of this, in the year 1952 (for example), the number of slope failures registered is higher than the number of *barrios* founded in the same year.

A reason for the incidence of slope failures in barrios founded in 1947 and 1952 could include crucial decisions in terms of the policies directed towards the spread of the *barrios.* During the periods of the *Junta Militar* (1947-1950) and of the dictatorship (1950-1958) the creation and spread of illegal settlements was inhibited. The policies at the time amounted to definite war on the *ranchos*, or the 'bulldozer policy' as it is often described. Families were evicted: some of them were relocated in the high storey buildings or *super-bloques*, others decided to go to further afield areas or return to the areas from which they were originally moved (Bolívar, 1988: p. 21). Consequently, in order to obtain access to the land and to be away from the authorities people invaded some of the most inaccessible and topographically abrupt places (such as: *La Vega, Cementerio, El Valle*), and other areas far from the central parts of Caracas at the time, or the slopes ignored by the construction sector because of their physical instability. People were not allowed to establish themselves in new settlements, and there was no attempt to improve services in the areas already settled. The subsequent slope failures may reflect the influence of this period in the *barrios.*

5.4.1 Relationship between slope instability and basic services in *barrios*

A way to answer this question would be to study in depth the relationship between the form of intervention in the existing settlements (supply of material, technical help) and the quality of services provided or improved, and the conditions at the time of failure.

Ramirez *et al.* (1991: p.1), described the *barrios* and basic services of Caracas:

> "Massive squatting in developing countries conveys an image of extreme misery, shacks, lack of facilities and squalor. The **barrios** of Caracas show a different picture. Those qualities exist but are by no means overwhelming. The dominant landscape is one of rather large, solid houses built with bricks and other industrially produced materials, concrete surfaced roads and basic facilities. Although they have been illegally, on invaded land, very little is temporary or precarious in these squatter areas"

As this author himself states this is the picture that the *barrios* show specifically in the central *barrios* of Caracas. But this is largely due to the fact that the government has used housing and services as a populist way to gain votes from these communities in the national election every five years for the past 30 years.

In some cases what efforts have been made to improve services are weakened by an emphasis on aesthetic aspects such as the reconstruction of facades, painting, and so on. Such was the case of the *Programa de Consolidación de barrios* in 1987 (Camacho and Bolívar, 1987: p.15).

In any case the supply of services in many *barrios* is outstripped by the permanent growth and the physical expansion of the settlements. The situation is exacerbated when such services (especially aqueducts and sewage) are provided, but not maintained.

Moreover as Bolívar (1986, p.114) shows, the *barrios* include an enormous variety of houses. Some have houses in good condition, but much depends on location within the *barrio* and the existence of road access and communications with the rest of the city, among other factors (Rosas *et al.*, 1986).

In terms of services the only data available are in the inventory of *barrios* produced by FUNDACOMUN in 1978. The slope failures studied occurred between 1974 and 1979 and the situation of the services in the period 74-79 can be illustrated with that data (table 5-4).

The *barrios* are divided into four zones according to their location within the city. The highest percentage of area covered by services (aqueducts and sewers) is found in the eastern zone, also one of the areas that shows a high concentration of landslide incidence (see fig 4.2 in Chapter 4). The less serviced area at the time (south-west zone) also coincides with areas which presented less cases of slope failures. In short the provision of basic services or the consolidation process in the barrios might not be entirely beneficial in terms of slope stability.

In the built environment of the barrios of Caracas "... *el problema de los pobres en Caracas no es el techo, sino el piso!*" "...the problem of the poor in Caracas is not the roof (referring to the shelter), but the floor!" (Arq. A. Cilento, ex-Dean of the faculty of Architecture, Universidad Central de Venezuela, *pers. comm.*)

Table 5-4: SERVICES IN THE *BARRIOS* OF THE METROPOLITAN AREA OF CARACAS (Number of *barrios*)

SERVICES		North-West	South-West	South	East	TOTAL
AQUEDUCT	% OF AREA	77.83	56.44	82.85	83.42	75.18
	AVAILABLE SPASMODICALLY	23	45	5	36	109
	AVAILABLE AT ALL TIMES	76	27	50	54	207
	NOT AVAILABLE	2	2	-	1	5
SEWERS	% OF AREA	76.62	44.16	72.42	78.20	69.36
	AVAILABLE SPASMODICALLY	24	44	5	28	101
	AVAILABLE AT ALL TIMES	75	18	49	57	149
	NOT AVAILABLE	2	12	1	6	21
LIGHTING OF PUBLIC AREAS	% OF AREA	76.00	79.89	88.09	86.07	81.22
	AVAILABLE SPASMODICALLY	16	31	1	19	67
	AVAILABLE AT ALL TIMES	82	42	50	72	246
	NOT AVAILABLE	3	1	4	-	8
DOMESTIC ELECTRICITY	% OF AREA	96.69	95.24	96.02	94.98	96.63
	AVAILABLE SPASMODICALLY	8	18	-	8	34
	AVAILABLE AT ALL TIMES	93	56	55	74	278
	NOT AVAILABLE	-	-	-	9	9
VEHICLE ACCESS	AVAILABLE	84	73	54	79	290
	NOT AVAILABLE	17	1	1	12	31

Source: Inventario de los barrios pobres del Área Metropolitana de Caracas y el Departamento Vargas (FUNDACOMUN, 1978).

5.5 CONCLUSIONS

This chapter showed the behaviour of the variables considered in this study in the particular case of *barrios.* Although rainfall plays an important role in the incidence of slope failures, there is no evidence that the rainfall alone acts influencing slope failures in the *barrios.* The susceptibility of the barrios to the incidence of the slope failures must involve other actors, such as services. Rainfall then acts as a triggering factor.

In the light of the material discussed in the previous sections, housing conditions in *barrios* seem to contribute considerably to the mechanism of slope failure by exacerbating or reducing the chances of occurrence of slope failures. This association between slope instability, urban growth and service availability will be examined through a case study in subsequent chapters. But it is already clear that the supply and improvement of services and of housing conditions are crucial considerations in efforts to avert major disasters.

Plate 9: *La Vega*, Caracas sept. 1986.

CHAPTER VI

BARRIO EL CIPRES - CASE STUDY

6.1 INTRODUCTION

On 18 May 1983, after 23.8 mm of cumulative rainfall in the preceding 10 days and 103.4 in the previous month, a landslide occurred in the *barrio El Ciprés*. No victims were reported but nearly 50 families were affected.

Information about material damages varies according to the different sources but some facts are certain. Approximately 40 houses were damaged. A newspaper (El Universal 19, May 1983), reported the collapse of 18 houses, 6 of them completely destroyed. During the night of 23 May after a day of rainfall, a few other houses collapsed and the bent lamp posts were threatening the security of the inhabitants of the area[1].

This case study seeks to shed some light on the possible influence of the physical expansion process on the stability of the *barrio*. Rather than draw generalizations from this one case study, however, the aim is to identify the process by which physical expansion leads to instability.

Assessing landslide susceptibility in the *barrios* has been hampered because of the lack of information on the low income areas. No systematic study of the physical characteristics has been carried out in these areas and, as mentioned in the introductory chapter, the available information lacks detail. The programme by FUNDACOMUN, SAIB (System for the Analysis of Information in *Barrios*) made notable progress in incorporating physical and socio-

[1] Diario 2001, 24 May, 1983.

economical information, but unfortunately the study has been stopped. The Third National Inventory of *barrios* is due to start in 1992. Most of the public bodies do not even consider a detailed plan for the location of the services they provide.

Although certain key items are wholly lacking, notably data on groundwater conditions, the available material, the results of the fieldwork, and indirect sources, such as *Metro de Caracas* carried out for a line through *Las Adjuntas* station, next to the *barrio El Ciprés* have made it possible to evaluate the factors controlling instability.

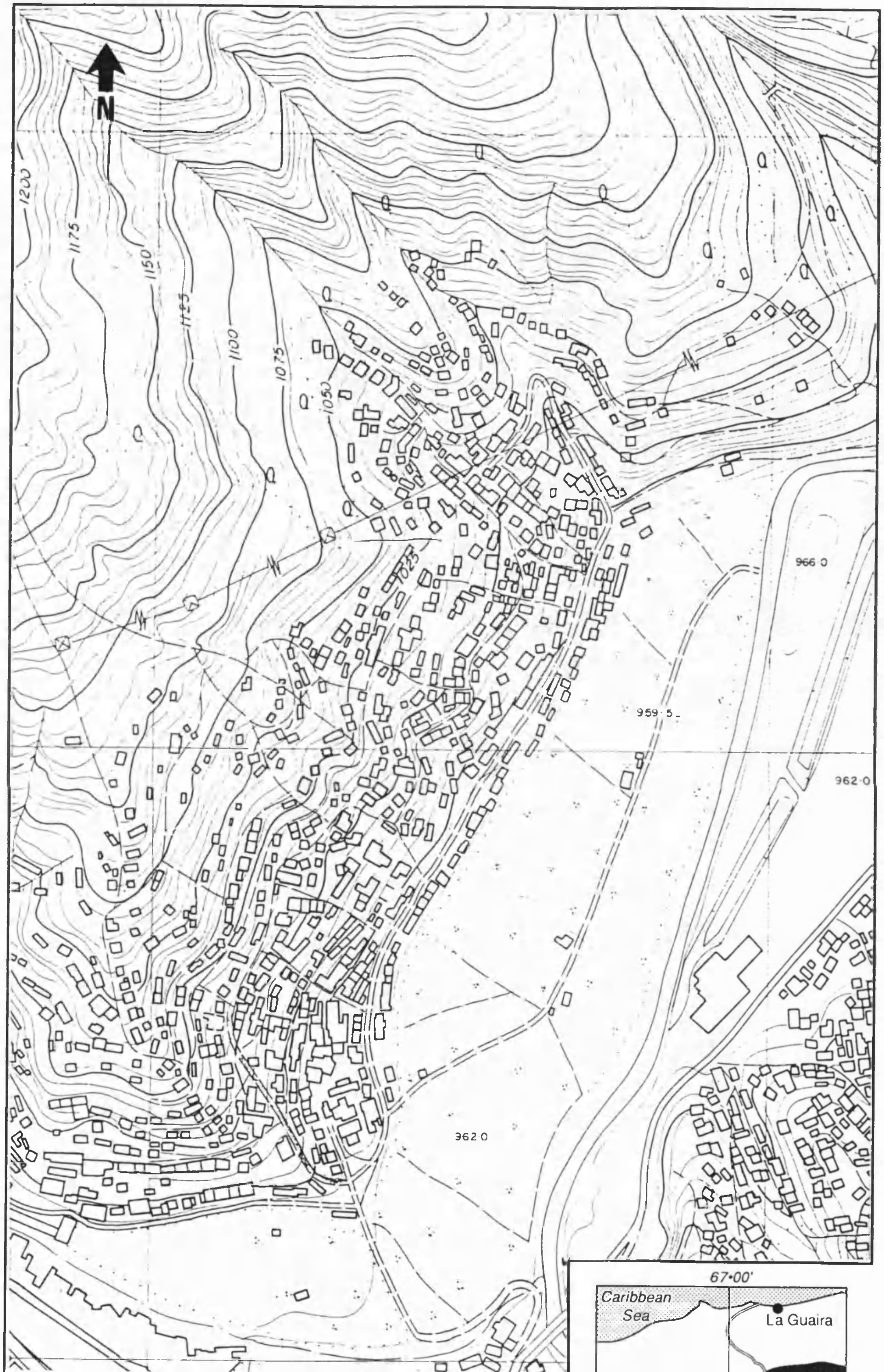
The *barrio El Ciprés* was chosen for two reasons: because it experienced instability problems in 1983 and in 1987; and because CECODAP (*Centros Comunitarios de Aprendizaje*), an organization which has been actively working on the problems of the *barrio*, was willing to provide information about the occupation process and the history of the *barrio*. CECODAP also allowed access to internal documents and archives.

6.2 PHYSICAL ENVIRONMENT

Barrio El Ciprés is located in the western area of Caracas. It belongs to the *Macarao* Parish of *Departamento Libertador* of the Distrito Federal. It occupies an area of approximately 19.8 ha (fig. 6.1) on a south-east facing slope. Four maps have been produced to characterize the physical environment of the area. They formed the basis of the landslide susceptibility map.

6.2.1 Slope steepness

The degree of steepness does not in itself specify the likelihood of failure. It is a parameter that must be used in conjunction with other factors, such as lithology and structure, and it influences geomorphic processes and superficial water flow.



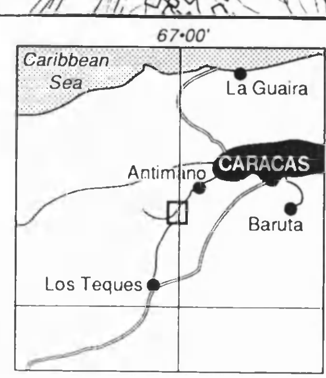


Fig. 6.1: BARRIO EL CIPRES
Scale 1:5000 0 m 100

Source:
Cartografia nacional
Tranarg C.A. 1983

Key
Street
Path
Houses
Irrigation Channel
Electricity pylon

The slope steepness map was derived from a contour map of scale 1:1,000 (sheet RR-10 and S-10 provided by *Cartografía Nacional*). The contour interval is ten metres. Although the contour lines were often interrupted by houses it proved possible to fill the gaps sufficiently for the purpose of this study. The original topography has been modified by the practice of cut and fill. The contour lines were digitized and the map processed using ARC-INFO.

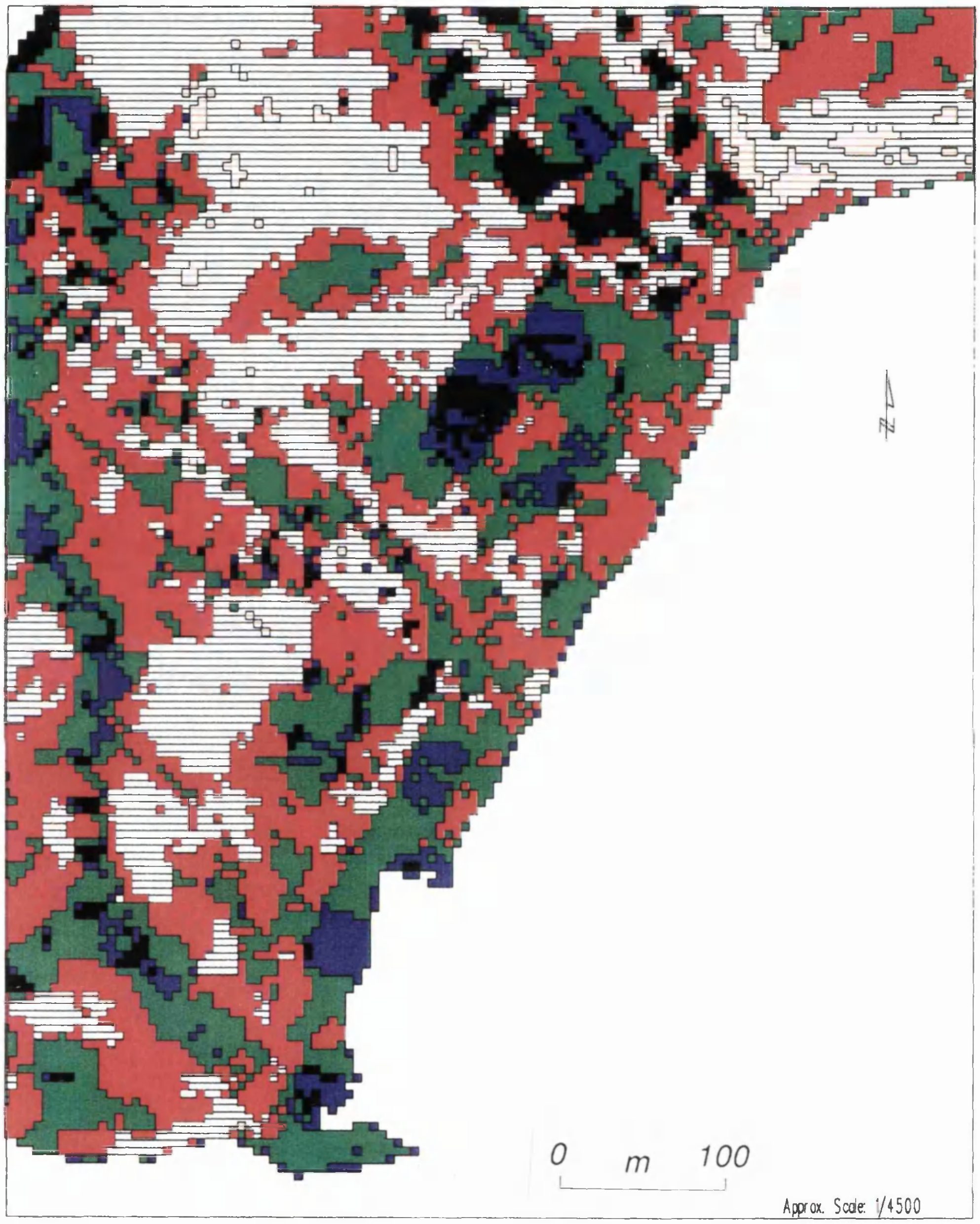
For the purposes of the stability assessment the value of 32% (18°) was considered the limiting angle for failures, as according to the study carried out by Feliziani *et al.* (1985), it is governed by the average angle of internal friction of the lithologic units displayed in the Caracas region. Figure 6.2 shows the distribution of different slope categories that characterize the area. They are the same as those used when analyzing slope failures for the whole of the Metropolitan Area of Caracas. The south east facing slope occupied by the *barrio* has an average slope angle of 35% (19.2°).

6.2.2. Geology and structure

The main geological features are shown in figure 6.3, which also includes information collected in the fieldwork. The area is located within the zone of influence of the southern limb of the *El Cementerio* syncline. The faults marked on the map were inferred from aerial photographs and derived from the study made by the *Oficina Técnica Topieca* (1980) for the *Metro de Caracas* company.

A total of 39 foliation measurements were made in the area and plotted on an equal area stereographic projection. Two main trends emerged: sector A, N88°E/38°N; and sector B tending N70°E/51°S. These sectors are separated by the NW fault running through the area. The distribution of the measurements is shown in figure 6.3. This zonation formed the basis for the assessment of structural stability. Local folding, where detected, was taken into account for the structural assessing stability.

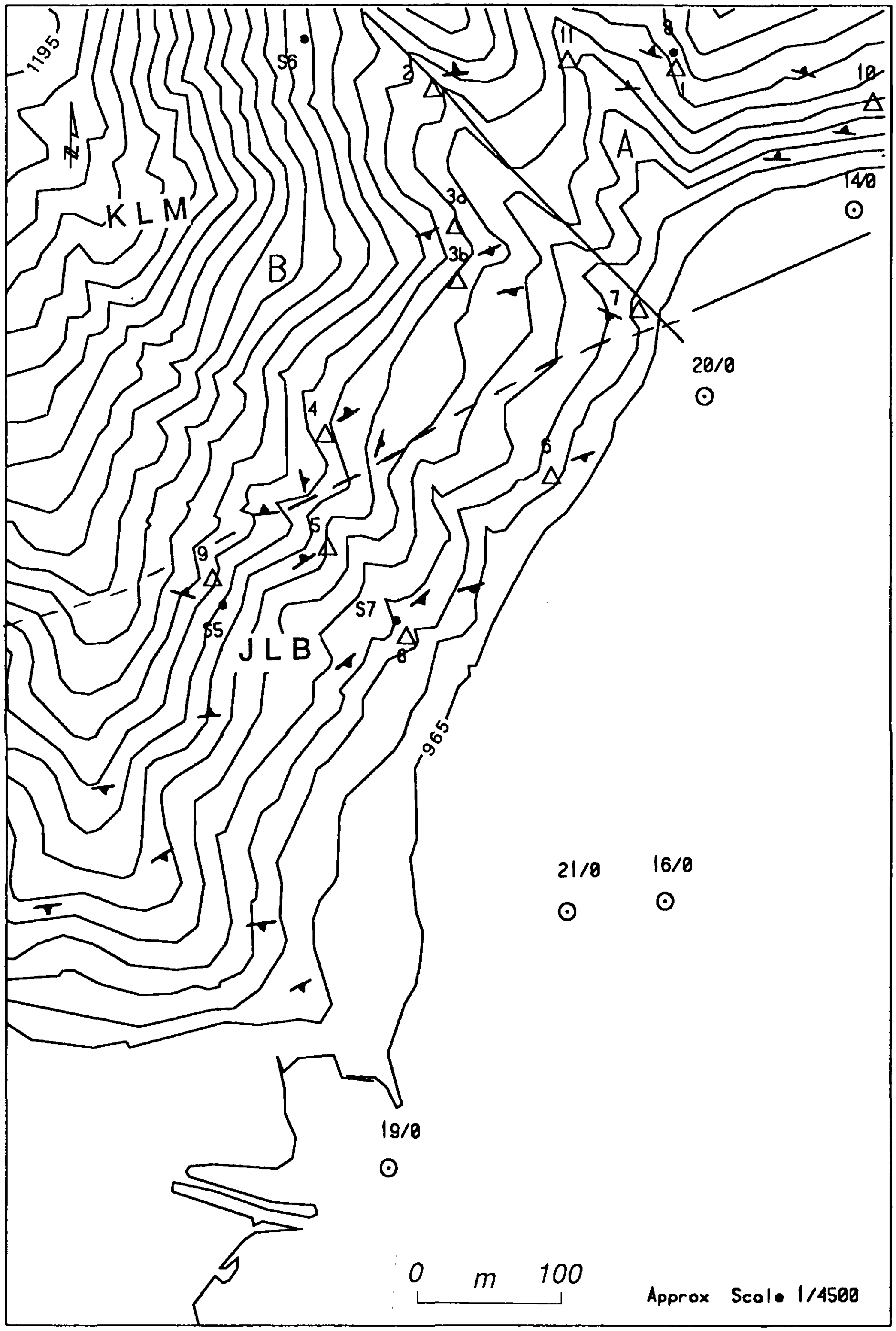
FIG. 6.2: SLOPE MAP



SLOPE CATEGORIES

■	0 -24% / 0-14
■	24-32% / 14-18
■	32-48% / 18-26
■	48-64% / 26-33
☰	64-100%/ 33-45
☐	>100% / >45

FIG 6.3: LITHOLOGY AND STRUCTURE



KLM
Calcareous Unit
JLB
Mica-schist Unit

⊙ Boreholes

• Soil samples

△ Rock samples

Faults

A/B Structural Sectors

Foliation

Figure 6.4 shows the orientation and geometrical stability of talus in the *barrio* in the two sub-regions. The relationship between foliation or bedding planes and the orientation or aspect of the slope was found to control the structural stability of the talus: when foliation coincides with the slope of the talus, the slope is unstable; the opposite situation is considered stable; the intermediate situation will generally lead to moderate stability. As has been mentioned, the statistics on foliation obtained in fig.6.5 (page 141) for the two sectors described in the previous paragraph formed the basis for the division of sectors later used to produce fig. 6.4 'Structural Stability of Talus'. Not all the slope talus in sector A is shown on the map because the same key had to serve for all possible slope orientations in the two structural sectors.

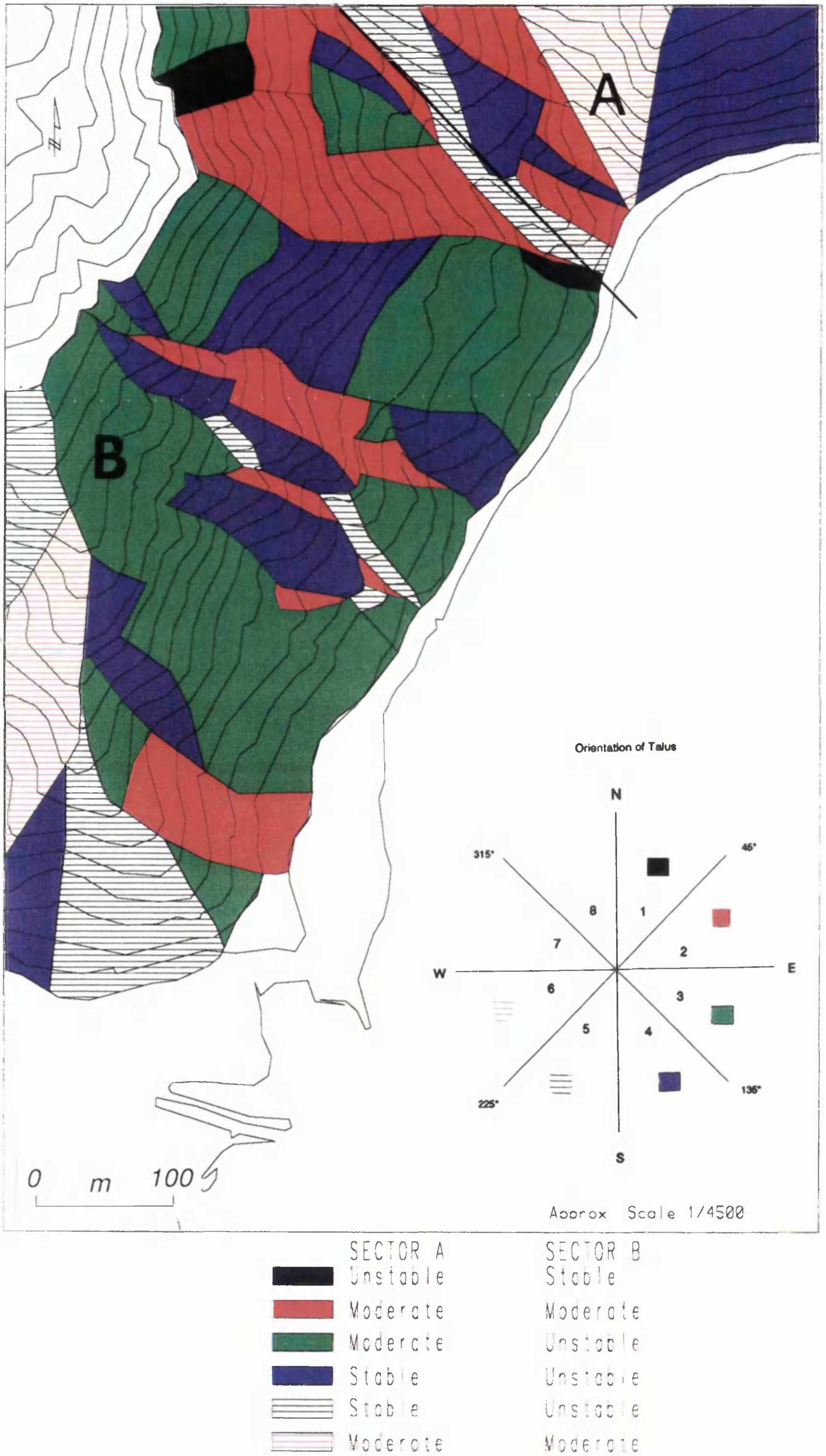
Minor discontinuities in the rock were also taken into account. 72 joint measurements were gathered from the field and from the above mentioned study by the *Oficina Técnica Topieca* for the *Metro de Caracas.* Although they show considerable scatter, it was possible to determine four patterns. Joint density was found to be from 5 to 10 per lineal meter. It directly affects the degree of resistance of the rock because it facilitates infiltration and thus weathering. The density or frequency diagrams resulting from the stereographic projection of foliation and joints are shown in figure 6.5.

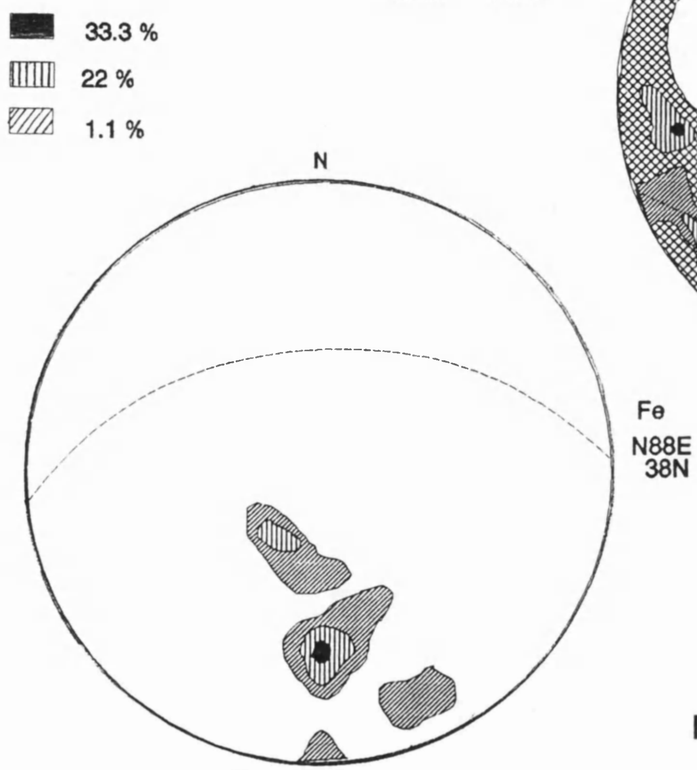
6.2.3. Lithology and soils

i) Lithological Units

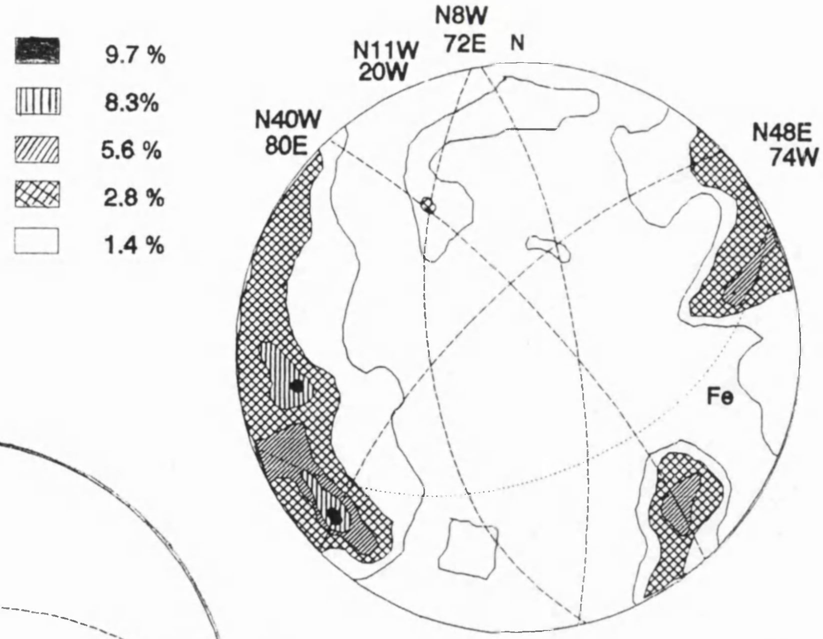
The area was divided into two main lithological units: the calcareous unit in the upper part of the *barrio*, and the mica-schist unit in the lower part. Regional geology maps show that the *Las Mercedes* formation (calcareous unit) is found throughout the area, but more detailed studies, such as the one carried out by *Oficina Técnica Topieca* (1980), showed the presence of the *Las Brisas* formation in the southern part of the area occupied by the *barrio.*

FIG 6.4: STRUCTURAL STABILITY OF TALUS

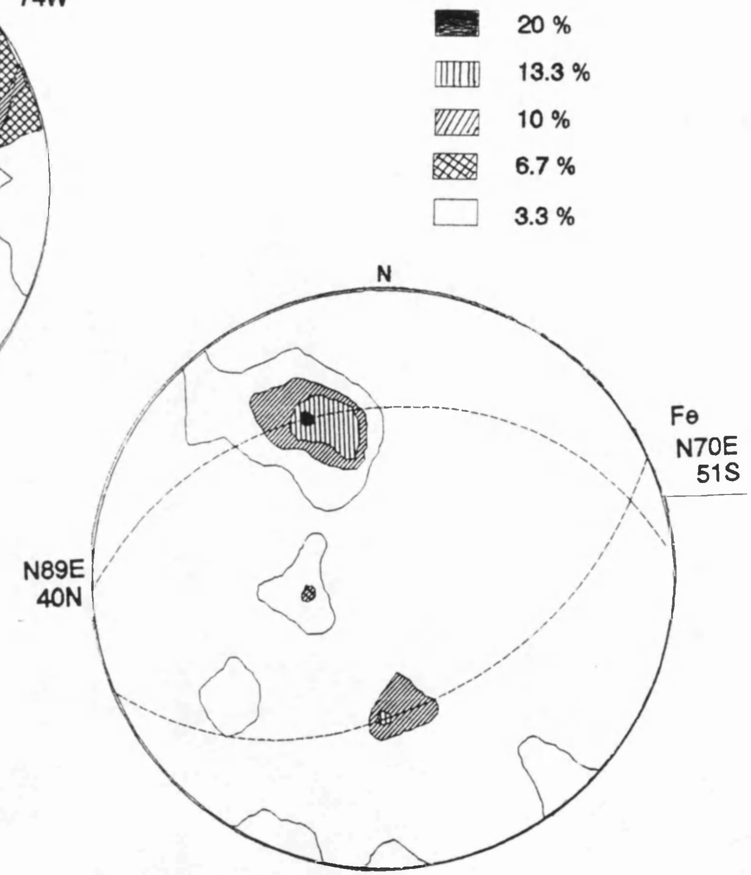




Foliation. Sector A
(9 measurements)



Joints
(72 measurements)



Foliation. Sector B
(30 measurements)

Figure 6.5: Foliation and joints

Frequency diagrams , stereographic projection

See section 6.2.2. for explanation (p. 136)

Figure 6.6 includes information derived from boreholes taken for Metro de Caracas in 1980[2]. It shows that mica-schists characteristic of the *Las Brisas* formation form the bedrock of this sector of the area of study, except for the northern borehole (see fig. 6.3 for location), where calcareous schist is the bedrock unit. The borehole adjacent to the slope failure that occurred in 1983 showed that the mica-schist was soft and weathered whereas in the other boreholes the same material displayed a low degree of weathering.

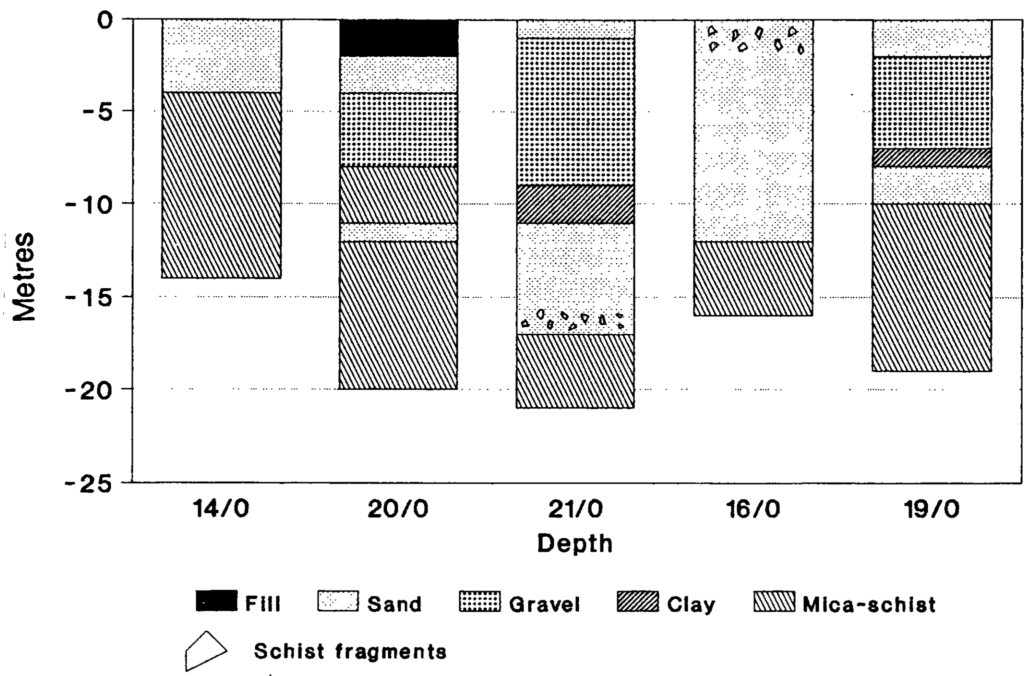
a) Petrographic Analysis

In general it is considered that *Las Mercedes* formation offers more favourable geotechnical conditions than the *Las Brisas* formation (Mapa Geológico de Caracas, 1986). *Oficina Técnica Topieca* (1980) observes that in similar conditions samples with a higher content of calcite are more resistant to weathering than those containing quartz, mica and feldspar. Another feature observed by Feliziani *et al.* (1985: p. 4629) is that in the calcareous unit the weathered profiles are shallow and that they increase in depth as the mica content increases. Petrographical analysis for seven hand samples collected during the fieldwork in the *barrio* was carried out by the *División de Petrología* (*Dirección de Geología*, MEM). The results are shown in figure 6.7 showing the mineralogical composition of the samples. These seven samples together with those identified by Topieca (1980) were considered sufficient to characterize the area in which only 2 lithological units outcrop. The area is currently occupied by houses and that limited the choice of sampling sites.

All the samples collected for petrographical analysis and observed in the field were classified from less to more resistant according to the mineralogical composition, proportion and arrangement of the minerals in question. In this scheme, samples identified as calcareous gneiss in the study carried out by Topieca (1980) were considered the most resistant, and calcareous schist were considered more resistant than quartz mica-schist. Consequently, samples from the upper part of the barrio were more resistant that those in the lower part of

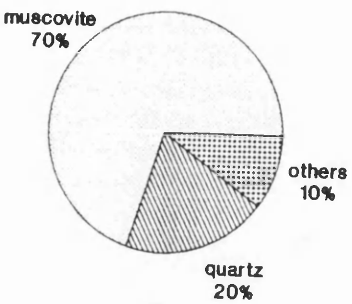
[2]Study of soils. Contratista: C.A Oficina de Suelos. Ing. Luis Galavis.

Figure 6.6: Boreholes

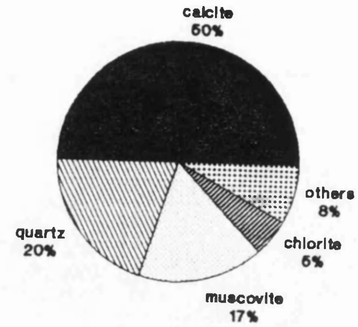


Data source: Metro de Caracas
Own elaboration

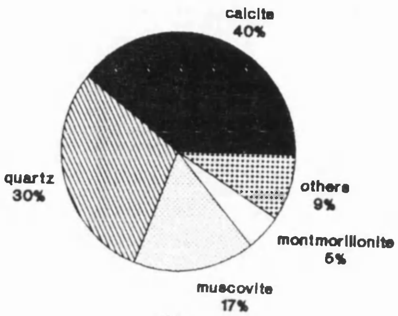
Figure 6.7: Petrographical Analysis



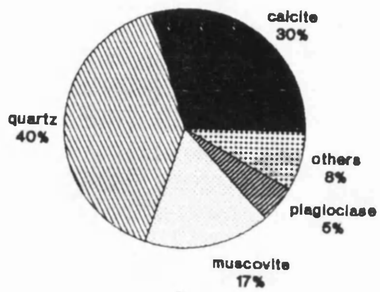
3a



1



3b



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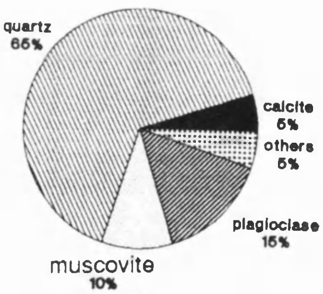

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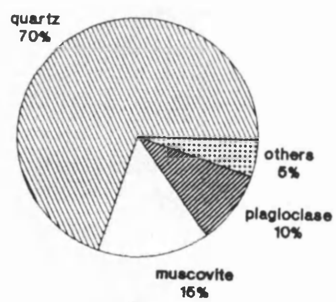
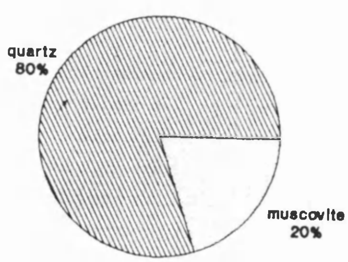


6

	Rock sample	
1 –	3a	Quartz mica phyllite * *Filita micáceo-cuarzosa*
	8	Quartz muscovite phyllite *Filita cuarzo-muscovítica*
2	5	Quartz feldspar mica schist * *Esquisto cuarzo-feldespático-micáceo*
	9	Feldspar mica schist *Esquisto feldespático-micáceo*
	6	Quartz mica feldspar schist * *Esquisto cuarzo-calcareo-micáceo-feldespático*
3	7	Quartz calcareous mica feldspar schist * *Esquisto cuarzo-calcareo-micáceo-feldespático*
4	1	Calcareous quartz muscovite chlorite schist * *Esquisto calcareo-cuarzo-muscovítico-clorítico*
	2	Calcareous quartz mica schist *Esquisto calcareo-cuarzo-micáceo*
	3b	Calcareous quartz muscovite schist * *Esquisto calcareo-cuarzo-muscovítico*
	4	Calcareous quartz mica schist * *Esquisto calcareo-cuarzo-micáceo*
5 +	10	Calcareous mica-quartz gneiss *Gneiss calcareo cuarzo-micaceo*
	11	Calcareous mica-quartz gneiss *Gneiss calcareo cuarzo-micáceo*



8

* Samples with petrographical analysis

Data Source: *División de Petrología (1988), Dirección de Geología* (MEM).

the area. Exception was made for the two samples corresponding to phyllite of the *Las Brisas* formation that outcrops in some sectors, whose geotechnical characteristics are unfavourable i.e. highly weathered and with a very low angle of internal friction (12°) (Feliziani *et al.*, 1985: p. 4633).

b) A Rock mass strength classification

At all observation points, the criteria for rock mass description proposed by Gardiner and Dackombe (1983) were considered. The observations were combined to apply 'A rock mass strength classification for geomorphic purposes'. According to Selby (1980), this method of assessing strength allows to "... be concerned with the total rock mass complete with its structural features and not just with the strength of intact hand specimens..." as well as "...provides a basis for understanding the features of the rock mass which give that mass its characteristic resistance to weathering and erosion..." (Selby, 1980: p. 32).

This method required a minimum of equipment and of samples. The classification uses the following eight parameters: strength of intact rock; weathering; spacing, orientation and width of discontinuities, lateral or vertical continuity, infilling of the joints; and movements of water in the rock mass. A rating is given for each parameter (table 6-1), and the result is the sum of those ratings. The last parameter, outflow of groundwater, could not be assessed in the field. The originators of the method recommend:

> "...that an estimate be made of the volume of water flowing out of each 10 m^2 of rock face in the wettest season. It is recognised that in many situations it may be impossible to do better than express the flow as 'none, trace, slight, moderate or great'" (Selby, 1980: p. 43)

As the fieldwork was made in the dry season, direct observation was not possible in the field. Here, the parameter was calculated from rock type and coverage (joints are already

Table 6-1: GEOMORPHIC ROCK MASS STRENGTH CLASSIFICATION AND RATINGS

PARAMETER	1 Very strong	2 Strong	3 Moderate	4 Weak	5 Very Weak
INTACT ROCK STRENGHT	100-60 r:20	60-50 r:18	50-40 r:14	40-35 r:10	35-10 r:5
WEATHERING	Unwea-thered r: 10	slightly weathered r:9	moderately weathered r:7	highly weathered r:5	completely weathered r:3
SPACING OF JOINTS	> 3 m r:30	3-1 m r:28	1-0.3 m r:21	300-50 mm r:15	< 50 mm r:8
JOINT ORIENTATION	Very favourable Steep dips into slope, cross joints interlock r:20	Favourable Moderate dips into slope r:18	Fair. Horizontal dips, or nearly vertical (hards rocks only) r:14	Unfavourable moderate dips out of slope r:9	Very unfavourable. Steep dips out of slope r:5
WIDTH OF JOINTS	<0.1 mm r:7	0.1-1 mm r:6	1-5 mm r:5	5-20 mm r:4	>20 mm r:2
CONTINUITY OF JOINTS	none continuous r:7	few continuous r:6	continuous no infill r:5	contin. thin infill r:4	continuous thick infill r:1
OUTFLOW OF GROUNDWATER	none r:6	trace r:5	slight 25 l/min/10 m^2 r:4	moderate 25-125 l/min/10 m^2 r:3	great >125 l/min/10 m^2 r:1
TOTAL RATING	100-91	90-71	70-51	50-26	<26

After Selby (1980).

Table 6-2: *BARRIO EL CIPRES*. RESULTS

Rock sample	Intact rock strength	weathe ring	spacing of joints	joint orient.	width of joints	contin. of joints	outflow of water	total
1	14	7	15	14	6	7	4	67
2	14	7	15	14	6	7	4	67
3a	14	5	15	5	5	5	1	50
3b	-	-	-	-	-	-	-	na
4	5	5	-	14	-	-	-	na
5	10	7	15	18	5	4	3	62
6	-	-	-	9	-	-	4	na
7	14	9	21	9	7	4	4	68
8	5	5	15	9	6	7	1	48

taken into account). Table 6-2 show the results of the ratings from all the field points for the parameters mentioned.

In the latter assessment, the result of the rating defines almost all samples as 'moderate'. Nevertheless, within that category the differences in the values themselves helped to consider the differences between the samples. The two assessments do not necessarily agree, but they support the division of the *barrio* into two lithological units.

ii) Soils

Assessment of the characteristics of regolith was taken into account. Soils are in general little developed on the slopes. They are also altered by the effects of clearing (for the subsequent location of the houses in the *barrio*). Only five soil samples were taken as indicative. Information about grain size, moisture content, humidity and Atterberg limits are given in table 6-3. Information about the petrographic analysis of rock samples located near the soil samples is given in the table as an indication of rock type. Sample 6, collected outside the area occupied by the *barrio*, was the only sample thought to be undisturbed.

The soil characteristics were determined by routine analysis in the Soils and Geomorphology Laboratory at Universidad Central de Venezuela. Colour was determined using the Munsell Chart; moisture content is expressed as a percentage of dry soil; separation of the amount of fine material was done through wet sieving with U.S. Standard sieve mesh N.230 (ASTM E-11-70) which retains the fraction greater that 0.0625 mm in diameter; Atterberg limits were determined using the Casagrande liquid limit apparatus with the procedure as described in Goudie (1981: p.122).

Soils derived from mica-schist with a lower proportion of fine- grained material presented lower plastic and liquid limits than soils derived from calcareous units. This may

Table 6-3: SOIL CHARACTERISTICS. *BARRIO EL CIPRES*

SOIL	COLOUR	SAND (%)	SILT AND CLAY (%)*	MOISTURE CONTENT	USSC**	ATTERBERG LIMITS			Mineralogical composition of rock samples located nearby
						LL	PL	PI	
S7	10YR 5/6	65.1	34.9	4.1%	SC ?	-	-	-	quartz=80% musc=20%
8b	7.5YR 6/2	46.3	53.7	4.7%	CL	44.2	27.3	16.9	calcite= 50% quartz=20% muscovite=17%
S6	10YR 3/4	38	62	10.9%	CL	48.6	25	23.6	calcite=50% quartz=30% muscovite=17% ***
8a	10YR 7/2	-	-	1.9%	-	-	-	-	-
S5	7.5YR 3/4	45.7	54.3	7.5%	CL	37.2	13.7	23.5	quartz=65% plagiocl=15% muscovite=10%

*: Sieve 230= 0.006 mm
**: USSC= Unified Sistem for Soil Classification
***: contains 5% of montmorillonite

stem from the high capacity of moisture retention attributed to the calcareous unit (Feliziani *et al.*, 1985: p. 4629). Among the samples corresponding to calcareous materials, moisture content was higher in the sample that had organic matter and clay (montmorillonite=5%). The latter had the highest liquid limit of all samples.

6.2.4. Vegetation

As mentioned in section 5.2, according to Greenway (1987) the mechanisms by which vegetation influences slope stability derived mainly from its effects on soil properties that in turn lead to failure, namely pore water pressure and shear stress.

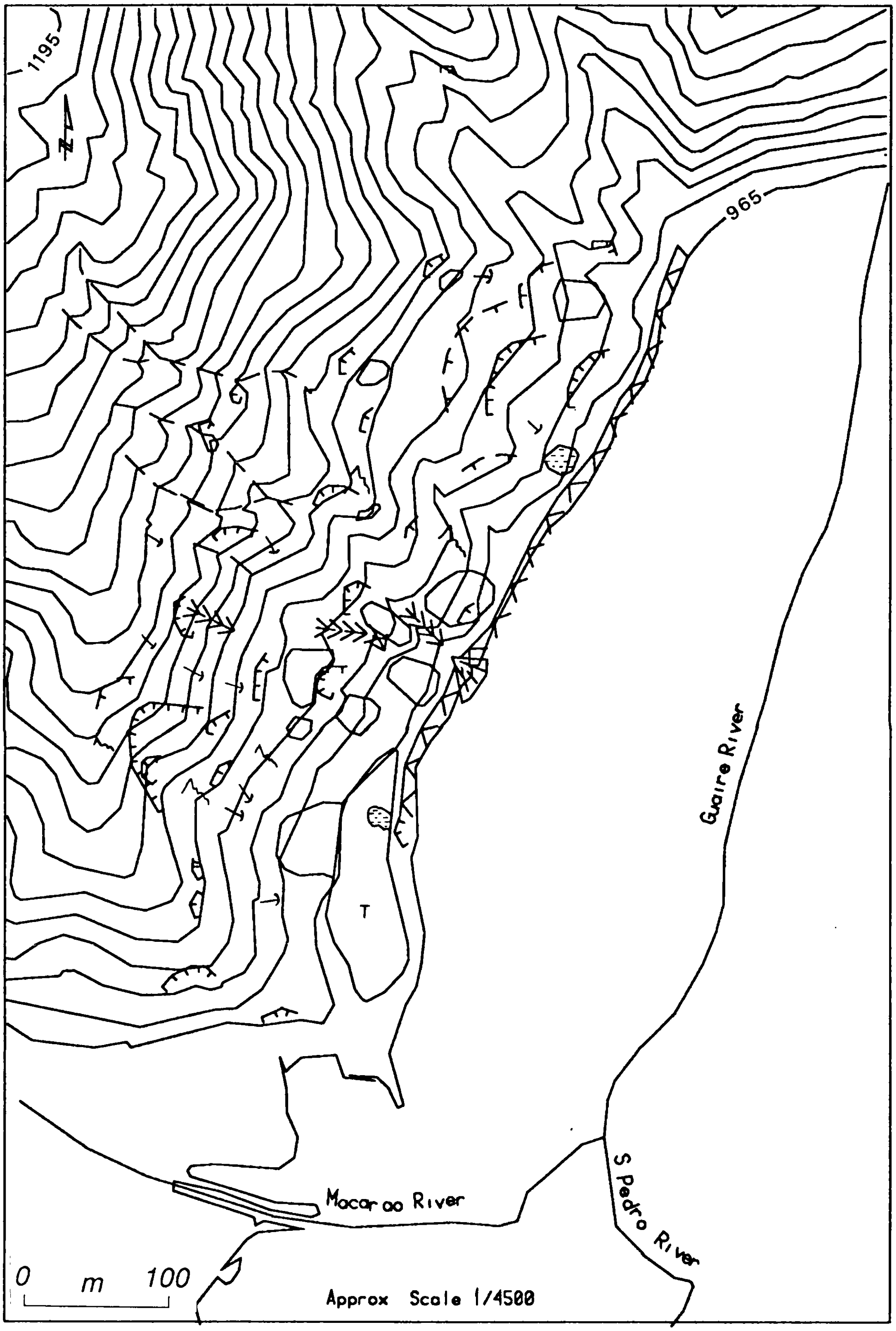
The aerial photographs show the vegetation coverage since 1953 (plates 10-16). Particularly noticeable is the spread by 1957 of crops onto the terrace, and the colonization of scars and accumulated material from micro-slides evident on the 1953 photographs.

Another feature is the retreat of the vegetation cover as the barrio was expanding in the area, with trees concentrated along the drainage lines and small groups of scattered trees in the latest available photograph (1983). The process creates unfavourable conditions, especially in the metamorphic sequence that outcrops in the area, due to the highly fractured structures of the rocks. Thus roots penetrate the cracks and joints, widening and increasing the susceptibility of the rock to disintegration, and facilitating the percolation of water to deeper levels in the talus.

6.2.5 Evolution of geomorphological processes

The main geomorphological processes identified from the aerial photographs and subsequence field checks are shown in figure 6.8 They were followed spatially three years before the settlement process of the barrio started, i.e. 1953, until 1983 when the first landslide affecting part of the *barrio* occurred.

FIG 6.8: GEOMORPHOLOGICAL FEATURES



Channels. Lateral erosion, Strong dissection, Concentrated flow.
Laminar flow
Moisture concentration
Alluvial fans
Fragments of river terrace
Active slides
Scar of ancient slip
Slipped block. Potentially unstable.
Surficial microslips
Break of slope

In 1953 and 1957 (plates 10 and 11), before the settlement process started, one can detect the presence of scars and deposits, the microslips, and evidence of laminar erosion and sheetwash (fig. 6.8).

The 1966 photograph (plate 12) showed evidence of local movement in which the scars were still evident and the channels had become deeper and wider as a result of the lateral erosion (fig. 6.8).

In the photographs dating from the 1970s (plate 13, 14 and 15), erosion processes are widespread.

The photograph taken in 1983 (plate 16) shows a stereoscopic pair of the movement that occurred in May 1983. The area showed the scar of a previous movement in the earliest photograph available (see also fig. 6.8). The material moved is shown in plate 17. It clearly consisted of regolith and unconsolidated accumulated material and not bedrock. In other words, the movement may have reactivated an existing landslide.

In 1987, another small movement affected the area. A report prepared by the *Garami, Grupo de Proyectos* (1987) for the *Metro de Caracas* Company, stated that the site of this recent movement had been affected by a previous landslide, and proposed engineering measures for its solution. The study mentions the coincidence of foliation with the orientation of the talus. Joints were recorded at a density of 7 to 20 per linear meter in the very fractured material.

The natural condition of the area was hardly the most favourable for settlement in the first place. Yet the photographs show that other areas on the slope could also have failed.

Plate 10: *Barrio El Ciprés*, **1953**

Plate 11: *Barrio El Ciprés*, **1957**

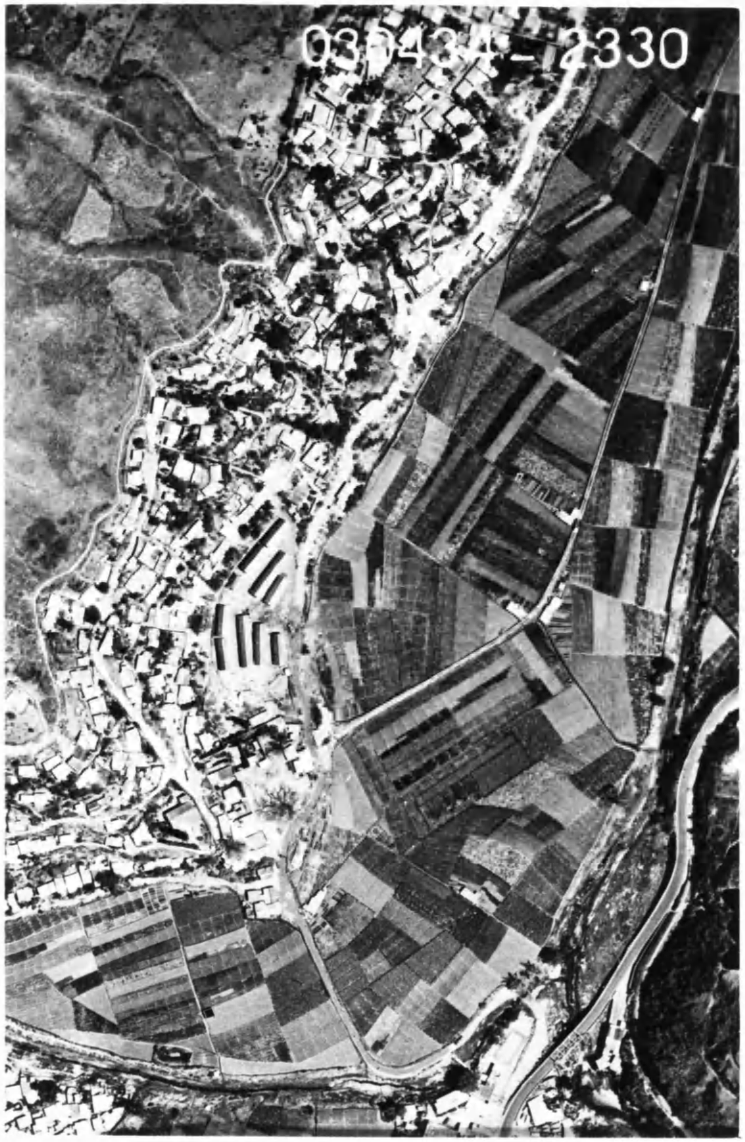


Plate 12: *Barrio El Ciprés*, **1966**

Plate 13: *Barrio El Ciprés*, **1970**

Plate 14: *Barrio El Ciprés*, **1976**

Plate 15: *Barrio El Ciprés*, **1979**

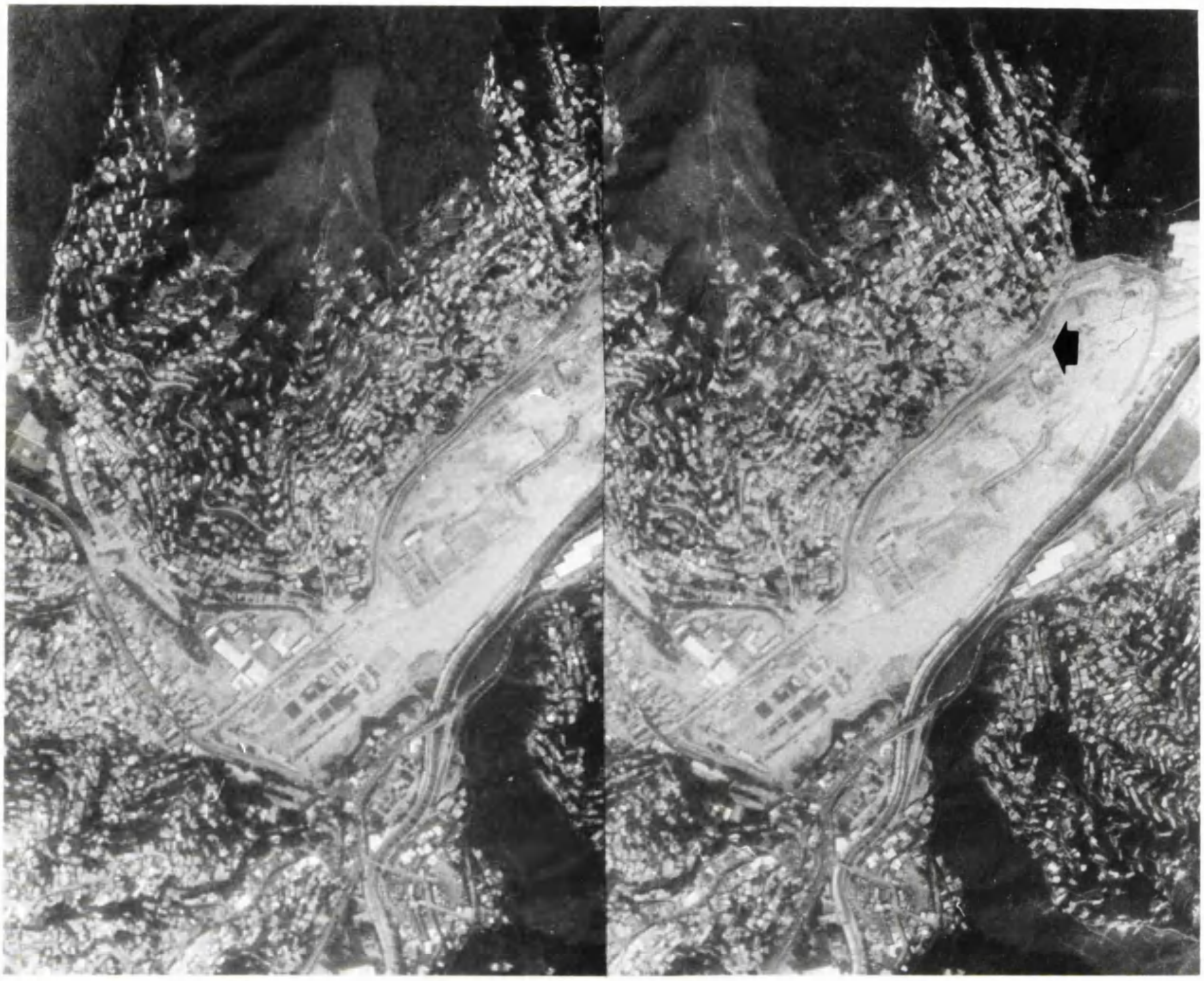
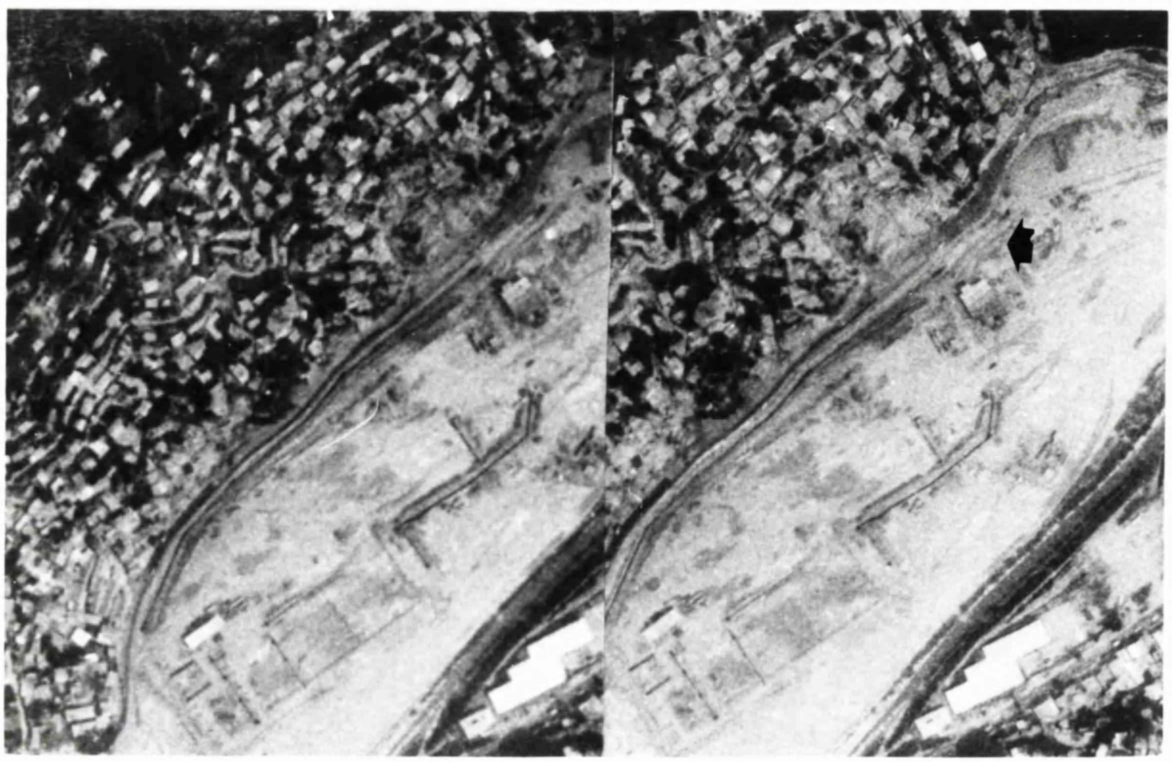


Plate 16: Stereoscopic view. *El Ciprés* landslide, **1983**



Photograph by CECODAP

Plate 17: Material moved. *El Ciprés* landslide 1983

Hence unless we are dealing with a process of headward destabilization, the possible influence of the settlement itself has to be borne in mind.

6.3 HISTORY OF THE OCCUPATION PROCESS: FROM *HACIENDA* TO *BARRIO*

In El Ciprés cuenta su historia, CECODAP (1987), collected information on the farm that occupied the area before the settlement, as well as stories about the construction process in the *barrio*. For the latter, interviews were carried out by the present author in order to obtain more detailed information about the changes made to the slope while occupation was in progress..

Interviews were carried out in eight sectors covering the *barrio* about the construction processes that might have had some influence in the instability problem. The interviews had to be carried out informally in conversation rather than by questionnaires as the of stability was clearly a sensitive one[3]. The points that arose in the interviews were divided into four parts:

a) data about the informant (occupation, number of people living in the house, date of arrival at the settlement);

b) Data about the house (site clearance, cut-and-fill practice, foundation, depth of digging and material - rock or soil); materials used for walls, floor and ceiling when construction began; approximate date in which the materials were changed or improved; and increases of area or weight (e.g. in the case of a second floor);

[3]The threat for eviction due to instability problems was a very important issue at the time. The author preferred to use informal conversation lest the interviewees claimed that the house was in perfect conditions.

c) Services (water supply, electricity, sewage or waste water - open or piped - overground or underground, waste disposal).

d) Information about house collapse in the barrio and information on slips and the two main failures that had occurred in the area.

According to the CECODAP archives, the area which the present *barrio El Ciprés* occupies belonged the old *Hacienda Caricuao*. The 'White house', one of the very few constructions and one of the most noticeable features in the 1953 photograph along with the sugar mill or ore-crusher, served as the local office for *El Ciprés* area as well as the residence of the steward and servant. According to the same source the sugar mill stopped working around 1913. Sugar cane was transported to the place by mules. Some paths can be seen in the earliest 1953 photograph. The name of the barrio comes from the cypress tree that stands near the house.

The area of the *Hacienda Caricuao*, later invaded, belonged to General Manuel A. Matos who died in 1929. The *hacienda* was later given by Matos descendants to the Bank of Venezuela as payment of a debt.

Near the area there was also located a house called *La Quinta* (top right corner of plate 19, 1957) also part of the *hacienda*. This was later sold to Bank of Venezuela and finally bought by Perez Jiménez (dictator between 1950 and 1958) to give to a close collaborator. At the end of the dictatorship the properties of Perez Jiménez and his friends were expropriated by the state.

The adjacent cultivated land comprised mainly sugar cane, tobacco and vegetables grown by Portuguese immigrants who leased the land from the Bank of Venezuela. The land was later acquired by the State and in 1981 the farmers were evacuated in order to proceed with the construction of the *Metro de Caracas.* The subway started functioning in 1987. Of this activity, only some crops for domestic consumption persist today in the upper part of the *barrio* (fruits and vegetables).

Another feature in the history of the barrio before the settlement process started was the presence of the '*acequia*' or irrigation channel.

Until 1873, water supply in Caracas was provided through public taps. In February 1873 the *Acueducto de Macarao* was inaugurated, and in 1876 is installed the first distribution network. From the *Macarao* River, west of the city approximately 5 km from *El Ciprés*, it was extended for a total of 46 Km over 57 bridges and it was an open channel with an average width of 80 cm extended to *El Calvario* (Zawisza, 1984). Water was lost by leaking and in 1916 parts of the water line was piped. The *acequia*, runs through the middle of the *barrio El Cipres* and can be clearly seen in the 1957 aerial photograph (plate 19).

The main settlement process occurred between 1958 and 1960. According to CECODAP (1987), "...it was the time in which everything was possible: land was invaded without the risk of repression, materials for construction were given away by the government...". Part of the terrain belonged to the *Banco Obrero* (at the present INAVI) and other parts were acquired by the *Gobernación del Distrito Federal* for the construction of the *Metro de Caracas.*

There are no population figures available for this period, the first 20 years in the *barrio.* Table 6.4 gives the population figures from 1978 until 1988. The Inventory of Barrios in 1978 gives an approximate population figure. According to FUNDACOMUN (1979: p. vii), "This figure was obtained by multiplying the 'number of houses' by 'the average of inhabitants per house' of the city". The latter in turns "...was obtained for each city through a socio-economic study carried out by FUNDACOMUN in 1978, in representative samples of 22.000 houses of 600 barrios in 30 cities of the country". The average for The Metropolitan Area of Caracas was 5.9 inhabitants per dwelling.

The figure for 1981 was collected by 'sectors'. These were units into which barrios were subdivided for its purposes by the Census. Four sectors were analyzed from the OCEI archives to obtain the results given here.

The source of the 1984 figures were obtained from *Gobernación del Dtto. Federal* (1984). The decrease in the figures was due to the eviction of the lower part of the *barrio* for the construction of the subway, and the landslide occurred in the area in 1983. The last figure available (1989), was obtained from records held by CECODAP in 1989.

Table 6-4: EL CIPRES, POPULATION GROWTH.

YEAR	POPULATION	HOUSES	SURFACE (HA)
1978	3,127	530	14.4
1981	4,449	814	NA
1984	2,047	347	19.4
1989	2,860	577-630	NA

6.4 THE SETTLEMENT PROCESS: PHYSICAL EXPANSION AND SERVICE AVAILABILITY

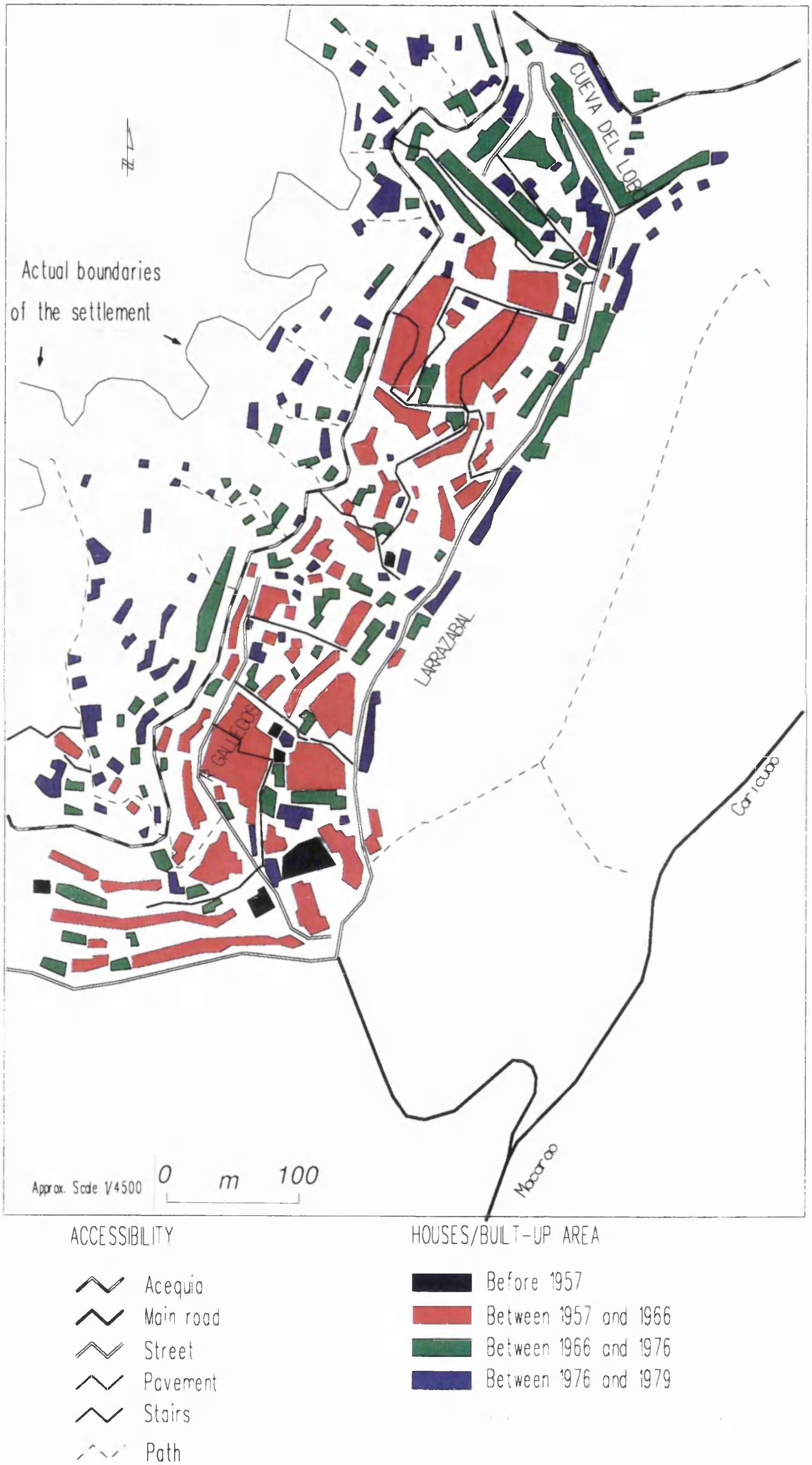
Fig 6.9 shows the physical expansion of the *barrio El Ciprés* between 1957 and 1983. The first area to be occupied within the settlement was *Romulo Gallegos* street, then *Larrazabal* street, *Cueva del Lobo* and finally the upper part of the *Acequia*. In the whole of the area occupied by the *barrio*, *Las Barracas* was the only area built officially by the government in 1964 during the Betancourt administration.

As mentioned earlier, the main period of settlement occurred between 1958 and 1960. At the beginning of this period the policies of the newly established Betancourt administration changed radically from the generous *Plan de Emergencia* (see chapter 2). The National Guard was ordered to repress any sign of land invasion or consolidation of *barrios*. Settlers of *El Ciprés* started working at night in order to supply their own infrastructure for basic services and house improvement. According to information provided by the residents to CECODAP and often mentioned in the interviews, while some residents were working others stayed on watch, in case the National Guard should come. There were various raids, and some of the settlers ended up in jail.

From that moment onwards a process of self-help housing was the answer to the basic need of the inhabitants. The *barrio* witnessed some official attempts to improve services during the 1970's, in terms of water supply and sewage. The reality was 'that the residents of *El Ciprés* had built a complicated network of pipes" (CECODAP, 1987).

The next major event in the history of the *barrio* was the construction of the Metro. The 1983 photograph (plate 16) shows that by then some areas had already been evacuated, especially in the lower part of the *barrios*. In January 1984, the Metro company began to

FIG 6.9: PHYSICAL EXPANSION OF BARRIO EL CIPRES



provide payment for improvements to the housing units (*bienechurías*). The community reacted by blaming the metro for causing the instability. It was the same company *Metro de Caracas* that was to provide the engineering work to stabilize the slope that later failed (plate 18), the planting of *Eucalyptus*, an artificial watercourse, fences, stairs (in the lower sector of the *barrio*) and 'green' areas.

In terms of the construction process, it is important to highlight the following factors, influencing the instability:

i) Site clearance and house construction:

In the process of house construction, the first step is **site clearance**. Bolívar (1986) demonstrated how *barrio* settlements adapted to the topography by following the contour lines. Plate 6 (in chapter 2) gives a clear example.

From information on the construction process gathered in the interviews the cut is made manually to get a vertical 'wall'. The resulting waste material taken out of the cut is later used as a fill material (*material de relleno*) to level or to even the 'floor'. This step will also contribute to expand the house horizontally. Plate 15 (1979, aerial photograph) shows various examples in which the cut is shown and the resulting material is placed immediately adjacent.

In terms of the **foundations**, the site is usually dug up to about 1 m. In some cases the digging is done until 'the rock is felt' or until the 'soil is hard enough', as expressed by some of the informants. Some of the people interviewed were themselves builders. In those cases, special care was taken when building pillars. Detailed information about the arrangement of the pillars was given: thus iron reinforcements (*cabillas*) were buried between 80 cm to 1 m approximately. This was done by the owner of the very few houses left between the areas affected by the landslides.

Photograph by CECODAP

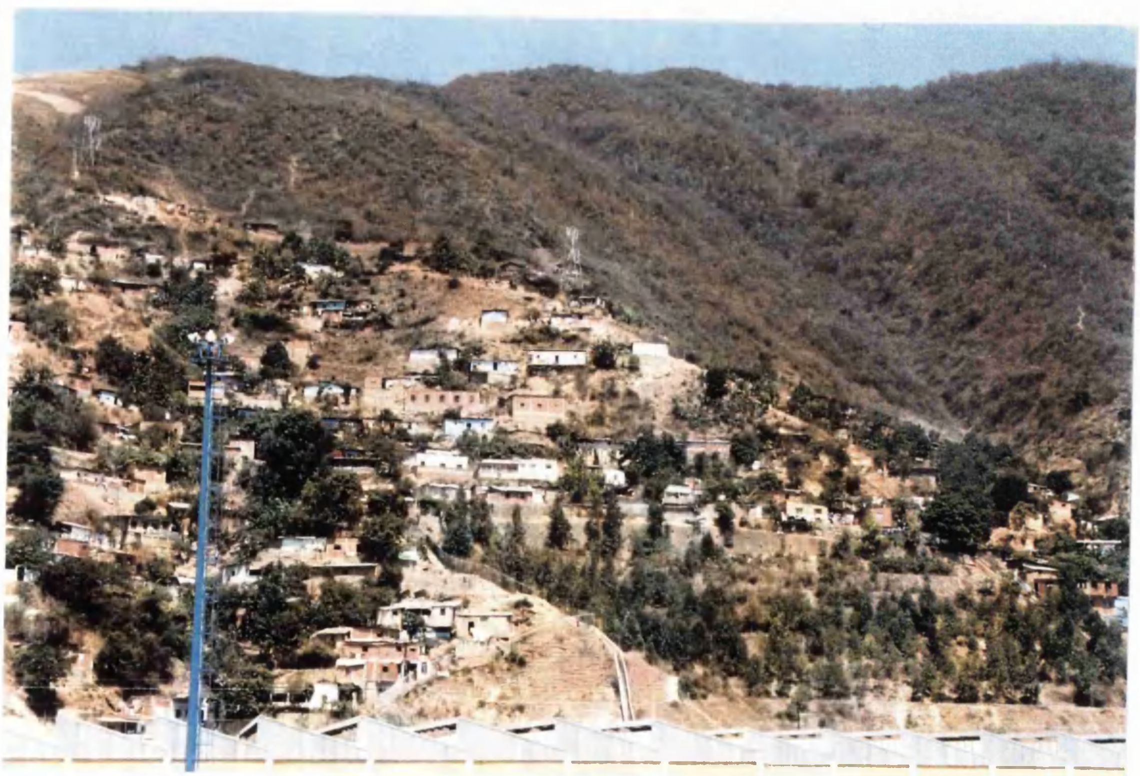


Plate 18: Area of slope failure and subsequent stabilization work. *El Ciprés*

The time in which **change of material and geometry** takes place varies greatly. Rosas (1986) showed how the improvement of the houses was related to the proximity to access routes in the three *barrios* studied. For the case of *El Ciprés*, the informants stated that the houses located in the 1983 failure **presented durable materials** by 1967[4]. The materials were mainly bricks and *bahareque* (a mixture of mud and stems). The area where the failure occurred was one of the first sites occupied.

During the fieldwork, an attempt was made to assess the development of cracks in some houses in the area. Observations were made in 1988, on walls of three different houses located consecutively in the upper part of the slope that was displaying instability problems. The width was measured, and the following year the difference was 1 mm more open (plate 19).

Table 6-5: WIDTH OF CRACKS DEVELOPED IN THE CONSOLIDATED HOUSES

	Date	a	b	c	d	d'	e	f	g
C1	03-1988	6	7.5	12	1	<1	4	2	1
	02-1989	8	9	13	2	<1	5	3	1.5
C2	03-1988	11	4	3	-	-	-	-	-
	02-1989	13	4	3	-	-	-	-	-
C3	03-1988	4	8	5	4	-	-	-	-
	02-1989	5	9	6	4	-	-	-	-

[4]The precise dates were remembered because of several events taking places in the area, e.g, Caracas earthquake in 1967, flooding 1977, and the landslide in 1983. The interviews were carried out in 1989.

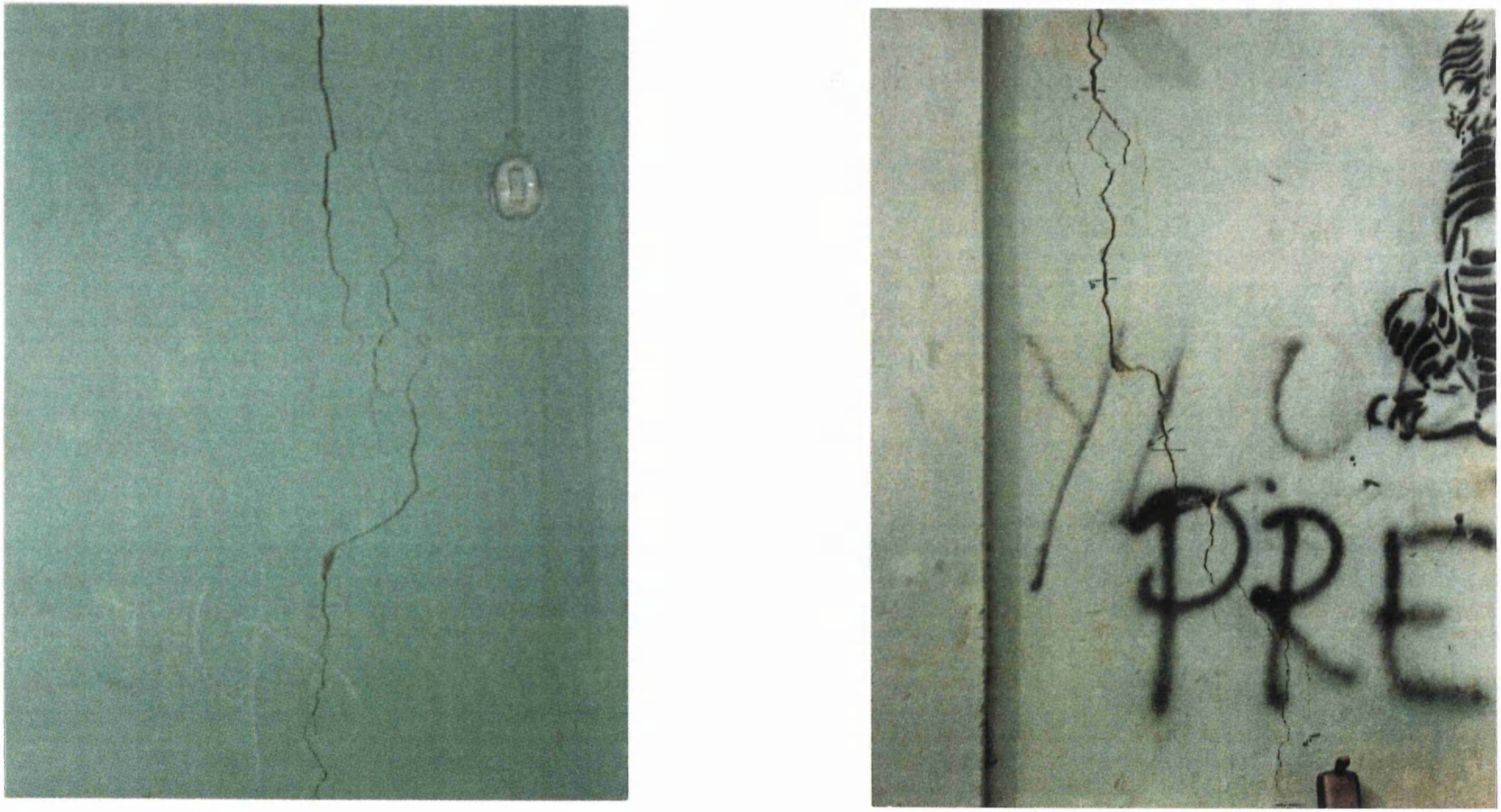


Plate 19: Cracks developed in the consolidated houses

The conditions of the material used in the *barrio* is varied. Some examples are shown in Plate 20. 62% of the houses are built of bricks. There is a marked difference in the proportion of houses built of bricks and those built with light materials in terms of their location in the *barrio*. Almost 50% of the houses in the upper sector are built of non-durable material, while in the lower part of the *barrio* only 27% are built of non-durable materials.

ii) Access: roads, pavements and stairs

As a result of the *Plan de Emergencia*, *Romulo Gallegos* street was asphalted and the adjacent stairs of the same name were built. Figure 6.9 shows the physical expansion process and highlights the mentioned structures. They remained the only paved surfaces until the 1970s. The remaining stairs and paths were built by the community as expansion progressed.

In the earliest stages the stairs were cut down following the traces of previous paths, but when made of concrete they were built up in the fill surface and not on solid rocks. Plate 21 shows some examples. Note the remaining stairs in the slope failure that occurred in 1983 (plate 22). Such surfaces formed a zone for accumulation of the water once the gap between the stairs and the fill broadens as a result of the fill material being washed out. These paths and stairs adjacent to the site of the landslide, were parallel to the slope, promoting the accumulation of water at two different levels in the slope.

In the *Romulo Gallegos* sector, however, the stairs were located down to the slope, promoting the flow of water out of the slope (see fig. 6.9). Both areas displayed features of previous movements (deposited material, see figure 6.8, geomorphological features). But in the *Romulo Gallegos* sector, in spite of the very similar situation shown in the geomorphological map, no sign of instability is to be seen.

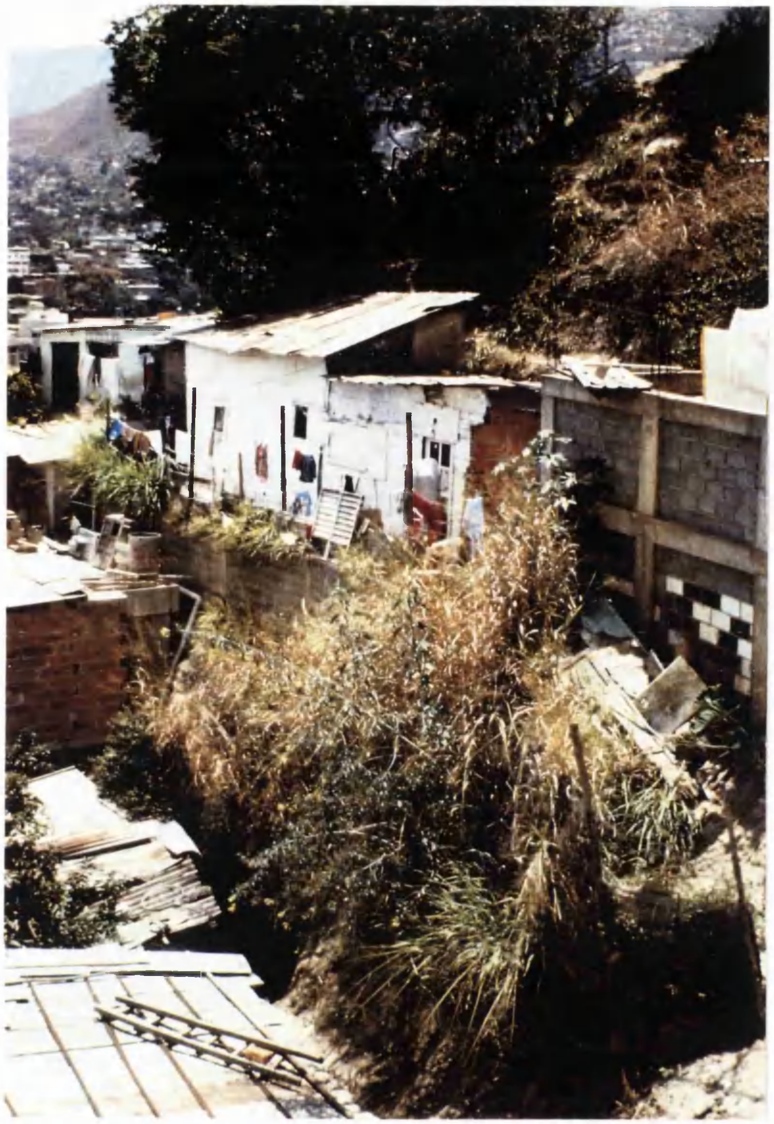


Plate 20:

Building materials

El Ciprés

Plate 21: Stairs built up on infill material

Photograph by CECODAP

Plate 22: *El Ciprés* landslide, 1983

The upper part of the *barrio*, north-west of the *Acequia*, paths and stairs have been built down the slope. They again concentrate the water at the *Acequia* level causing even more problems to the lower part as they serve as catchment areas that the lower part cannot discharge efficiently. There are several cases where the houses has been placed very near the water channels. This might also contribute to the problem of water discharge owing to the obstruction of the natural drainage lines.

iii) Water supply

When the first settlers of *El Ciprés* occupied the area, they secured their provision of water through clandestine pipe perforations for tap connections or '*plumas*'. Such connections caused leaking at different points of the *acequia*.

It was not until 1974-75 that the INOS placed a tank in the upper part of the barrio and added some pipes to the already complicated system built by the dwellers for their water provision. The presence of the water channel was the basis for the figures in the inventory of 1978 That *El Ciprés* was supplied 100% by aqueduct.

Some parts of the *Acequia* have been opened up to serve the upper part of the area still without access to water (plate 23). More recently the Metro company has provided some storm drains (*torrenteras*) to cope with waste water.

iv) Sewage

Contrary to what was stated in the inventory of 1978, there was no sewage system in the *barrio*. Septic tanks and latrines were the only options available. In more recent times, people have supplied their own systems. The materials used (plate 24) and the maintenance given to the infrastructure built (plate 25) create other problems. For example, point of

Plate 23: *Acequia*

Plate 24: Inadequate material for basic services

concentration of water as a result of leakage, or water cannot drain away because the channels are also misused for waste disposal.

An attempt to evaluate the effect of waste sewage water on weathering was conducted in *El Ciprés* during 1988-1989. Twenty-one cubes of Portland limestone of known weight and dimensions were buried at different depths and distances from channels used as sewers. A year later, of the nine cubes that had not been tampered with three had been displaced and also split into two. These effects suggest that subsurface weathering proceeds at a rate fast enough for such experiments to be worth pursuing despite the problems faced by the fieldworker in the *barrios*.

v) Disposal area

Two main disposal areas and several other localized dumps were located in the *barrio* as sites for waste disposal until 1984. They were located mainly in the paths of the drains. Plate 26 shows one of such sites. As mentioned before, the 'torrenteras' and water channels constructed recently to dispose of sewage are also being used to collect waste or are simply filled by rubbish carried in runoff (plate 25). Proper maintenance of these water channels would improve the efficient discharge of water from the slope.

6.5 CONCLUSIONS

The area occupied by *barrio El Ciprés* did not present the most favourable conditions for the settlement before it was settled. The basic services in the area and infrastructure were provided mainly by the community itself.

The layout of the area in terms of the modifications made, illustrates the role of such modifications in the internal environment of the *barrio*. The layout of the path and stairs, and

Plate 25: Watercourse (*torrentera*) misuse for waste disposal

Plate 26: One of four waste disposal areas in *El Ciprés*

its influence on the runoff, are seen to be important elements to be considered, as shown by the location of the landslide.

There is still not enough evidence to show how far the new, heavier materials used to improve the houses promote movement. How much weight a new unit can add harmlessly to the slope depends on the material and physical conditions of the slope as well as the care taken in site preparation and in building.

VII. CONCLUSIONS

Although Caracas has a history of more than four centuries, it is only in the last 40 years that rapid population growth has become evident in terms of space. The ways in which the population has progressively spread into the valley and the configuration of the valley itself played an important role in the occupation process; the flat areas facilitated continuous urbanization towards the east. With increasing pressure on the limited space, urban growth has taken place in the surrounding hillsites both in squatter settlements and in middle and high income urban developments. The physical stability of the areas occupied by squatter settlement has received little attention.

Until the 1960s the majority of the slope failures recorded were associated with earthquakes but probably because only earthquakes were thought newsworthy. (see page 16, paragraph 2); from the 1970s onwards the occurrence of slope failures in Caracas began to be more noticeably associated with the incidence of rainfall. Slope failures occurred during the rainy season in 81.5% of all 205 slope failures that took place between 1974 and 1979.

The highest concentration of slope failures in Caracas has been in *barrio* settlements. If cumulative rainfall over 30 days is considered, residential areas other than *barrios* show less vulnerability in the sense that the amount of accumulated rainfall required for slope failure to occur is greater than in *barrios*. In the short term, however, the *barrios* need more rainfall than other areas to reach the threshold for movement, perhaps because closely spaced houses, cemented paths and stairs intercept the rain and promote superficial runoff.

There is also a relationship between susceptibility to failure and lithology. Mica schist fails at lower angles than calcareous rocks. In the *barrios*, slopes failed at even lower angles and the calcareous unit was the most widely affected rock type.

As one would expect, the physical conditions immediately antedating present-day settlement in the *barrios* are also important. In the case study, the area did not present the most favourable conditions for stability in terms of physical environment before the settlement process: deposits of accumulated material showing evidence of previous movements (or landslide activity) were evident in photographs dating from 1953. The susceptibility of the area to landslides increases where potentially unstable areas with unconsolidated material already present in the slope are modified (i.e. steepened or loaded as a consequence of the settlement process).

The *barrios* with poor services presented fewer cases of slope failures; thus the provision of basic services or the consolidation process in the *barrios* might not be entirely beneficial in terms of slope stability. The case study showed that site clearance by cut and fill, whose outcome is the subsequent accumulation of unconsolidated material, is important since new houses are later located in these sites. Changes in the unit weight caused by house construction are not readily assessed, but it is evident that the lower part of the *barrio* in which slope failures occurred showed a concentration of houses built with durable, heavier materials. As a result of the settlement process, natural drainage lines are also altered. The configuration of the pavement areas and stairs may mean that the slope does not discharge runoff efficiently.

In the squatter settlements of Caracas, progress in terms of services has taken place periodically. Both public and community improvements have been made in health, roads, and building materials, among others. However, ways have to be found to ensure that sectoral interventions are coordinated to avoid contradictory goals. As an example, an important improvement in terms of health, such as providing piped water and sewers in the settlement, should be regularly monitored and pipes should be built with resistant materials to avoid leakages that might concentrate water in the slope, thus contributing to failures. Similarly, improvements in construction materials, which in Caracas generally involve replacement by heavier structures, can place extra weight on the slope and may make instability more likely.

In short, the different components of the problem of slope instability in the squatter settlements of Caracas have to be considered in unison, especially at the stage of prevention. But a great part of what needs to be done lies in improving inter-institutional coordination and gathering the necessary political will to act more effectively in improving conditions in squatter settlements. As has been mentioned in section 1.2.4 the grounds for eviction used by the government need to be revised. Such political decisions will need to consider not only physical conditions but also any modifications made by the people in the settlement to the site in question in terms of how they influence its stability. It will also need to identify the specific houses that have to be vacated.

The outcome of the research has prompted questions in two different areas: a) the role of rainfall as a triggering factor needs to be examined in more detail. Rainfall intensity, the timing of the slope failures, as well as the characteristics of the failed mass, are facts required if we are to elucidate more clearly the role of different contributing factors and the possibility of assessing pre-failure conditions, so that if necessary emergency services can be placed on standby. b) In terms of the effect on the slopes by settlement, zones of water accumulation in the slope need to be identified. Aerial photographs can be used to examine the configuration of the pavement areas and the density of the built-up areas (in terms of building materials) in relation to the location of slope failures. If possible, this information should be included in the assessment of stability along with the physical factors taken into account when evaluating relative risk.

It is now possible to draw up a landslide susceptibility map based on the parameters considered for 'El Cipres' in the previous chapter.

A Geographic Information System (ARC-INFO) was used to produce the a landslide susceptibility map (figure 7.1). After combining the physical characteristics as explained in chapter six, the resulting 43 sectors were grouped into 9 sectors defining 4 categories from stable to unstable. This susceptibility map is only preliminary and not suitable as the basis for political decision. The assessment uses indirect mapping as described in Hansen (1985: p.545) to consider "the possibility of landslide occurrence in relation to the controlling factors". The map overlay of environmental factors includes slope angle, geology and structure, lithology and soils, and geomorphology. The scales of analysis were 1:1,000 and 1:2,500; the scale of representation is 1:4,500. The 9 sectors are characterized as follows:

Sector 1: Stable Areas.

Sector 2a: Areas of medium slope angles (not exceeding 64%), moderately stable in terms of structure but where calcareous material is relatively resistant.

Sector 2b: Comprises zones of medium and high gradients, medium structural stability and predominantly calcareous material.

Sector 2c: In this sector, at least one of the parameters considered for assessing stability is unfavourable.

Sector 2d: zones of slope angles ranging between 32% and 64%, structurally unstable and mainly composed of mica-schist. The area has been occupied by settlement. Natural drainage has been altered and vegetation cover removed.

Sector 2e: Corresponds mainly to areas located in the mica schist unit. Underlain by slipped materials.

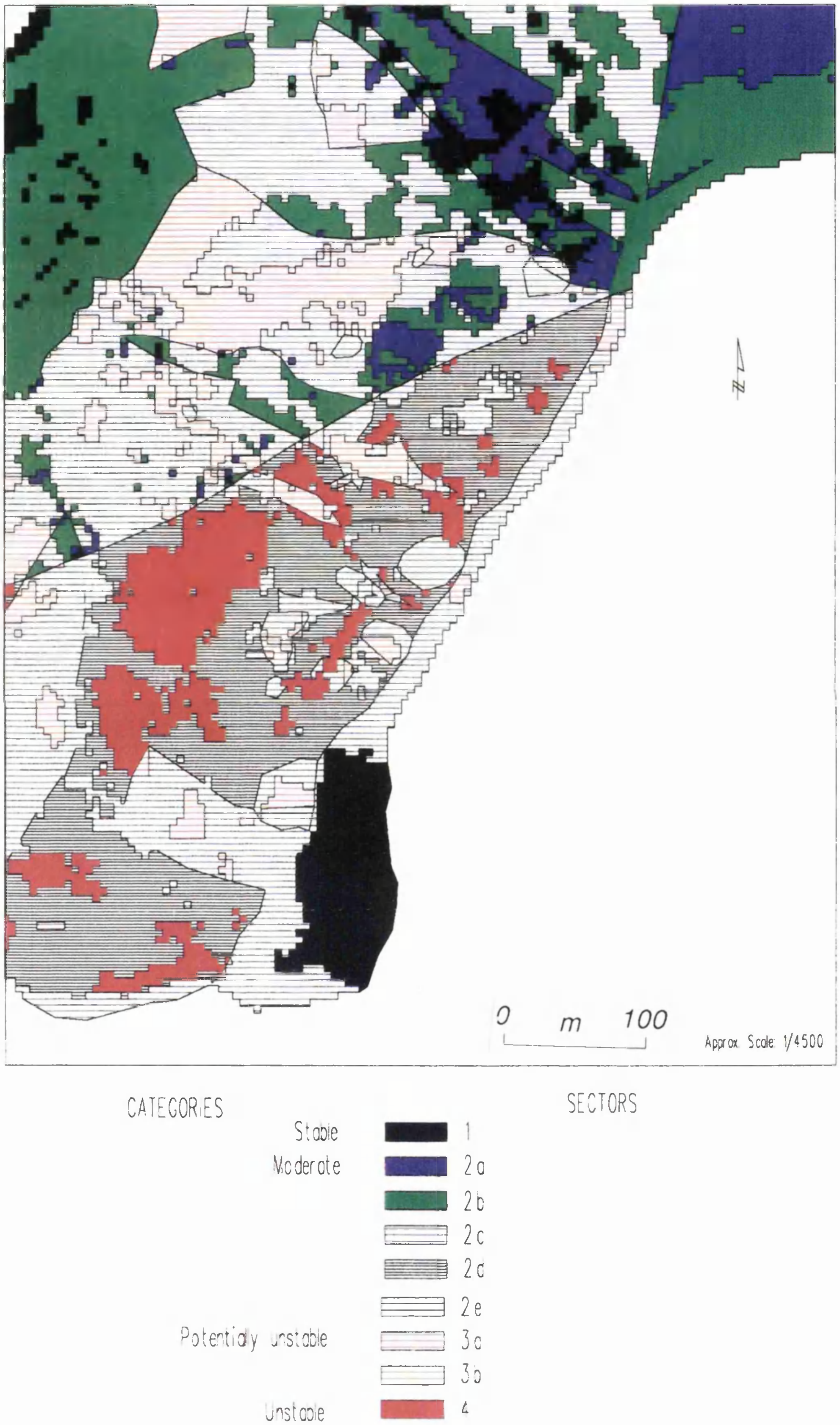
Sector 3a: Areas of slope angles greater than 64%; structurally unstable.

Sector 3b: Area located on slipped material; slope angles are greater than 32%.

Sector 4: Areas of high gradient (more than 64%); structurally unstable and located in highly weathered mica schist.

The study has confirmed, that heavy rainfall, landslide susceptibility, and the configuration of the *barrios* have all to be taken into account when assessing the likelihood of slope failure in Caracas. The problem now becomes a political one.

FIG.7.1: LANDSLIDE SUSCEPTIBILITY MAP



NOTE: Characteristic of the sectors are explained in the text

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Next time, close the door more carefully!!