INGEOMINAS

OCHO ARTÍCULOS TÉCNICOS

(PARTE DE LOS ESCRITOS 1995 - 1998)

POR: ING. CARLOS A. FORERO-DUEÑAS

ÁREA DE INGENIERÍA GEOAMBIENTAL

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República de Colombia
MINISTERIO DE MINAS Y ENERGIA
INSTITUTO DE INVESTIGACIONES EN GEOCIENCIAS, MINERIA Y QUIMICA

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Señores: **INGEOMINAS**

El listado de los artículos que anexo es:

- 1995. HAZARDS EVALUATION DURING EMERGENCY SITUATIONS. Coventry, UK.
- 1996. FURTHER STEPS IN A GEOTECHNICAL ZONATION. Trondheim, Norway.
- 1996. INVENTORY AND STUDY OF LANDSLIDES IN CUNDINAMARCA. Trondheim, Norway.
- 1996. EXPERIENCES FROM THE PAEZ EARTHQUAKE. Acapulco, México.
- 1996. DISCUSSION ON "THE OBSERVATIONAL METHOD". London, UK.
- 1997. MODELLING GEODYNAMIC ENVIRONMENTS: THE COLOMBIAN EXPERIENCE. Athens, Greece.
- 1998. SHEAR MODULUS-TIME VARIATIONS OF A SILICA-GEL. Brighton, UK.
- 1998. INFLUENCE OF WATER CONTENT ON THE MECHANICAL PROPERTIES OF A SILICA-GEL. Brighton, UK.

Confío en que estos escritos sirvan para crear algunas inquietudes entre los Geocientificos, e igualmente puedan servir de documentos que incentiven la discusión. Igualmente, espero que puedan ser de cierta utilidad en la concepción y desarrollo de algunas de nuestras actividades presentes y futuras. Para aquellos interesados, la bibliografía que se incluye permitirá complementar los temas analizados.

Cordialmente,

CARLOS A. FORERO DUEÑAS
Area de Ingeniería Geoambiental. INGEOMINAS.

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HAZARDS EVALUATION DURING EMERGENCY SITUATIONS

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ABSTRACT

Geoscientists have among their missions to analyze the stability conditions of areas triggered by natural hazards, handling the especial circumstances which follow immediately after the beginning of an emergency situation. The job is not a simple one having many facets to be considered, it being necessary to go beyond the basic technical matters. Ecological considerations about interactions between culture, biosphere and physical environment must be taken into consideration to ensure the benefit of a geoscientific evaluation.

Some steps are recommended in relation to the role that Geoscientists can have in those situations with special reference to landsliding, including field methods, techniques to use, and the organization and interpretation of information that come from several sources, including confusing reports based on the people's imagination. One of the common responsibilities in these situations is to guide the National authorities in taking crucial decisions such as evacuating the population. Even if the hazard hits areas with hazard plans, commonly it is necessary qualify or confirm the state of possible shelters, as well as the location of strategic points such as heliports and operative and coordinating centres.

Because commonly first order hazards can develop several more, as in the case of landslides and avalanches triggered by earthquakes, activity must be concentrated on the prediction of additional hazardous areas. A classification system to present an Emergency Hazard Zonation is proposed.

The careful observation of the post disaster situation is encouraged, both for a better assessment during the emergency, and to use in more formal studies later.

The field application of these principles is shown in studying the effects of the Earthquake of june 6th 1994, which hit the Paez River basin in Colombia.

1- INTRODUCTION

When dealing with natural hazard evaluation perhaps one of the most difficult activities is related to the analysis of emergency situations. Modeling nature is difficult in any circumstance, but especially when the time is pressing.

In order to fulfill the task of assessing the imminent risk to people and facilities it is necessary assemble highly motivated multidisciplinary teams, taking the best of many sciences that can contribute the building of the complex model of a geohazard evaluation.

A major objective of the above teams might be the creation of emergency susceptibility zonation maps.

2- EARTH, ENVIRONMENT AND ECOLOGY

With the winds of environmental protection and sustainable development, it seems to be a different attitude of the man towards the environment, changing from feeling the rightful conqueror to become a protector. The technical understanding of the environment demands a proper knowledge of its complex components, and hence no single science is able to cope with this goal alone.

The Ecology deals with the study of the interactions between life forms and the environment (1,2). The Environmental Science studies the mechanisms of environmental processes, being interested in understand them but also having the goal of contributing to their solution, becoming then also an applied science (3). With this frame of reference, is worth to understand our position as earth scientists within the ecology and the environmental sciences, having clear that the physical environment analysis is linked to the other components within a given ecological system.

The former consideration has dramatic importance, in the case of emergency situations when attached to the scientific or technical evaluations are several cultural consequences with social, economic and political implications.

The complexity of the environmental sciences deserves that the problems being considered within a definite broad and multidisciplinary context. That sort of investigations must not be considered a luxury anymore, but a necessity (2). There are already some examples of the marriage between ecology and specific scientific disciplines, as in the case of biochemistry (4), producing a whole new scientific area named ecological biochemistry or chemical ecology.

Because its wide interest, the ecology is within most of the scientific fields. specially in the applied ones, when the environment is part of the earth surface phenomena and must be included in the analysis. The earth sciences, dealing with the physical environment, can be also located under the broad umbrella of the ecology. Names as Ecological Geosciences or Geoscientistic Ecology could be a solution to put together the efforts of the geoscientistics in fields known today as environmental geology, engineering geology or geoenvironmental engineering, usually dealing with the same problems using similar or complementary tools and techniques making them more similar day by day .

To feel all us under the same umbrella, could be a solution to the final junction in the efforts to deal with the earth related problems which affects a given ecosystem. In solving environmental problems, there is a big urgency to put together what the specialization is taking apart (5). Ecological Geoscientistics must have an open and creative mind to integrate the knowledge of each of the disciplines involved in the multifacet, complex problems related with the physical environment.

We are able then to apply the available knowledge, building a model representing a given earth science problem. As example, the theory of Croll of the ice ages linked astronomy with geology, oceanography and meteorology producing an interactive explanation (6). In constructing a model to give an approximate representation of a real situation, we are aware that the theories give a point of view of nature to assemble in a comprehensible form the essence of a variety of related observations concerning physical phenomena (7).

3- ELEMENTS IN AN EMERGENCY SITUATION

3-1 GENERAL ELEMENTS

Due to the nature of the geoscientific evaluation during an emergency situation, the ecological frame is a suitable place to be located; concerns about the interrelationships between the organism and its environment acquire dramatic importance.

The technical assessment of the physical conditions will produce a basic layer over which the relevant social and cultural aspects of the specific region of study also must be taken in consideration. This is a practical guide to facilitate the express application of our geoscientific conclusions, diminishing the waste of valuable time, critical to save lives and avoid further disasters, delaying practical decisions.

In the evaluation of the physical environment, either during an emergency situation or in long term hazards evaluation, a fundamental component is the geologic factor, and its understanding requires a broad-based comprehension of the earth sciences and other related disciplines (8); so according to the specific problem we can use disciplines such as : soil and rock mechanics, hydrology, hydraulics, oceanography, meteorology, physics, chemistry, seismology, structural engineering, and the geologic-related disciplines that can be useful including hydrogeology, tectonics, geomorphology, sedimentology, geophysics, geochemistry, glaciology, and volcanology among others. Terms as environmental geology, engineering geology, geotechnics, and geoenvironmental engineering are complementary and superimposed, having the goal of build the global model of the ecological geosciences.

The cultural aspects involved include ethical, economic, politic, aesthetic and religious elements and their interaction controls in great extent the way the man perceive and respond to the environment ; in some cases it is not easy to put them an economic value, as in the case of environmental intangibles such as the pleasures of outdoors experiences (8).

3-2 TECHNICAL EVALUATION

The hazard or probability of occurrence of a magnitude of a dangerous phenomenon within a given time in a given place, is not an easy element to calculate, even in long term studies when it is possible to include most of the variables and there is time to make the probability calculations. For that reason, in emergency situations it is common to make an approximation to the hazard value, by estimating the Susceptibility

It is not possible to give a sole procedure to the hazard or susceptibility evaluation during emergency situations, taking into consideration the various possible geohazards such as volcanic eruptions, earthquakes, landslides and floods, all of them having the possibility of occurrence in quite different environments, and having different consequences. You should also bear in mind that the different worldwide regions of occurrence may have quite dissimilar quantity and quality of relevant technical information. In spite of these variations, general guides are possible.

EVENT MAGNITUDE

In practice , when the forces of the nature alone or with the intervention of man hit a given region, some possibilities can be considered with regards to the magnitude of the effects. One is that the consequences are Very Important, when are effects on populated areas, or on non populated but strategic areas for reasons such as economic, environmental, or infrastructure importance. The opposite case is when a natural hazard hits a Low Important region, unpopulated and with low strategic value. There are intermediate possibilities between them. Usually, the governmental interest, specially in less developed countries follows this scale of importance when assigning resources to the attention of emergencies.

Of course, that since the geoscientific point of view any event has an intrinsic scientific value, wherever it be located, as its study is of great importance in the understanding of the global behavior, preventing future disasters in more strategic places. This is perhaps more in agreement with a pure environmentalist viewpoint, to which the preservation of an hostile desert could be as important as the protection of a rain forest.

In terms of population damage, the urban areas of our civilized world are critical places because of the number of inhabitants that can be hit by a geohazard, deserving special care from the geoscientists. Man has located many cities close to water sources such as lakes and rivers, and in addition to the normal geohazards that must be evaluated, attention must be paid to the fact that have being common to have watercourses covered up by the urban development; also some cities have old mine shafts beneath as source of catastrophes (9), being potential hazards that can attack alone or triggered by more regional events.

ORDER OF THE EVENTS

The triggering or First Order events such as earthquakes, volcanic eruptions or rainfalls, can hit a given area developing Intermediate events such as erosion, landslides and stream damming, ending in some cases in High Order events such as flooding and avalanches (10). Tsunamis can also be considered as intermediate events, Also, there are other cases , as in the case of landslides as high order events triggered by erosion.

Since big events such as the first order ones only occur infrequently, as extreme events have a very low probability of occurrence, we can think that after the triggering event has happened we can make the emergency evaluation of the physical medium starting with the immediate effects of the trigger, but awaiting for intermediate and high order hazards which can occur some time later depending of the local environmental factors.

In the case of earthquakes, the aftershocks should be monitored by means of a seismic network being able to prevent the field geoscientistic and the population about the possibility that the first earthquake had been the premonition of a coming big event . In spite of its danger, the collection of field data is a vital technical support for decision making to the Government and the National Systems for Attention and Disaster Prevention .

Also in the case of earthquakes, the event produces immediate consequences as structural damage on houses, buildings and infrastructure, and over the physical medium, being necessary to go to search for intermediate and high order events such as damming in the streams that can develop catastrophic events such as avalanches. In some cases, the earthquake can develop debris flow as an immediate intermediate event, without the existence of a dam, avoiding to take any special evacuation policies hence affecting huge areas and producing many casualties.

AVAILABLE INFORMATION

The technical information available can be very different. Essential elements to be requested are: has the region a hazard map already done?, if the answer is yes then follow to see its specific purpose , constitutive elements and scale. To have clear the geologic context of the region is a primary goal. Is possible to have a hazard map for volcanic activity in a region affected by an earthquake, being necessary to take the pertinent information and make the field corrections to the new trigger.

The topographic maps are also key elements. They give us ideas both of the circumstances of possible intermediate and high order events such as damming, landsliding, avalanches and so on and also about the areas under risk such as lowland places inundated by rivers or debris flows. The slopes usually are a controlling parameter in the unstability development and in the understanding of the direction of movement of earth masses and flows.

To have available data from remote sensing techniques before and after the event is a quite useful tool for the technical evaluation. If is possible obtaining aerial photographs immediately after the emergency it is important to use them in the emergency evaluation as well as in possible additional long term studies.

FIELD ACTIVITIES

The field activities usually cannot last as long as you could wish, and experience in similar situations, the practical training and local knowledge of the area are key elements in understanding the environmental consequences of a geohazard. The interdisciplinary complement is of great importance in this regards, as in the case of working teams of experienced geologist and trained geotechnical engineers , producing practical assessments about slope stability including back analysis estimating local average conditions at failure, structural damages on buildings and infrastructure and so on.

In the case of landslides, the steep slopes, areas of drainage concentration and seepage, landforms and materials susceptible to landsliding, areas of concentration of fractures and bedding planes, areas with historic and recent landsliding, and land use effects are important elements to cover. It is worth putting special effort in the analysis of Quaternary and weathered deposits (11,12).

In any case, but specially in areas with low technical information, the personal camera is a valuable tool and when it is possible to make helicopter shots the pictures can be the base for sketching our technical evaluations.

3-3 COMMUNICATING RISKS

CULTURAL ELEMENTS

This is a complex subject which deserves expert assessment; however it is possible to make clear some of the basic ideas. Cultural aspects not always easy to evaluate make difficult the task of predicting the public response; frequently there are differences between technical and cultural dimensions and perceptions of risk (13). The university curriculum in Geosciences should consider the inclusion of formal lectures in this topics, not at least at undergraduate level but as a duty in post graduate courses.

The so called conventional meaning of risk communication neglects cultural themes, being necessary to have an Intentional or Directed meaning towards specific audiences, the population under risk, looking for behavioral changes (13). To understand the cultural expressions that can worth consideration , field activities should allow the exchange of ideas with the population getting information about their own perception of the environmental problems. As an example, there are cases where traditions of indian cultures and religions bonds their individuals with the land and nature ; this would make difficult to persuade them to move from even highly dangerous areas.

Superstitions can be also the source of erroneous information and descriptions about natural and disaster situations, also controlling the behavior of the people. Men are prone to this when they ignore the laws of chance and probability, and superstition appears when there is an apparent connection between impressive events which coincide by chance is done (14).

DATA PRESENTATION

Common action after each day of work is to make a review of the observations with the technical team, in the light of local and regional geoscientific considerations. After that follow meetings and discussions with governmental representatives, which can be at national. regional or local level according to the magnitude of the disaster, and also with delegates of the local authorities and the community. In that way, the final conclusions of the situation can consider some socio cultural considerations and wont arrive at the final user as an imposition.

The hazard evaluation will show a result which is often summarized in maps. The final users being the local planning offices, the local branches of the disaster organizations and the public. The presentation should be appropriate to them, their needs and capabilities, being the product easily applicable to decisive actions concerning most critical areas, shelters and temporary heliports location and immediate corrective or preventive measures if any. The user may or may not have technical background, so the final map must be translated from technical geoscientific terms, to equivalent common language descriptions (12).

With the restrictions of time and the usual limitations of technical data, the presentation of more than three zones in an emergency evaluation is not common. Besides apparently well defined safe and unsafe areas, an intermediate one when the situation is not quite clear could be included; that practice can also clarify our situation as technical evaluators of extremely complex environmental situations when the exact answer is not always found . Usually there is a useful visual impact in the presentation of the maps, when the red color is used over more unsafe areas, the green color over more safe places and the yellow color is over intermediate complex situations only discernible with detailed studies.

As is well known, some problems are not easily recognized in field evaluations. This should be make clear to the users of the study conclusions. We as geoscientifics are the most qualified professionals to perform the evaluations but the task is complex and is possible to have doubts and also give analysis with some limitations.

4- FIELD CASE. THE PAEZ EARTHQUAKE

4-1 THE EVENT

On june the sixth, 1994, an earthquake triggered the southwestern part of Colombia, with the epicenter zone in the municipality of Paez, in the Cauca Department; the event had a 6.4 magnitude in the Richter scale, being of surface character at about 10 kilometers depth, affecting the basin of the Paez river, and surrounding sectors, causing multiple human casualties, and severe damages to the physical environment, houses and infrastructure.

Ingeominas, the Colombian Institute of Investigations in Geosciences, Mining and Chemistry, with the coordination of its Geoenvironmental Engineering Area has the duty of evaluate the geohazards, and was in charge of the technical evaluation. The National Seismologic Network, which Ingeominas operates , located the epicenter at 2.9 degrees north latitude and 76,08 degrees of west longitude. Up to june 30, the network located about 800 aftershocks with Richter magnitude up to 4.8 (15).

4-2 EMERGENCY EVALUATION

GEOLOGIC FACTORS

Colombia, located in the northwestern corner of South America is subjected regionally to a complex field of stresses as product of the tectonic interaction of the Caribbean, Nazca and South American plates, having many sources of energy release in the subduction zone of the Pacific border as well as in multiple fractures inland. The country has three dominant positive topographic elements known as Western, Central and Eastern cordilleras, associated with the Andean System. The epicentral area was located in the eastern side of the central cordillera, which is mainly composed of precambric and paleozoic metamorphic rocks intruded by batholiths and stocks; tectonically is limited at the west by the regional faults system known as Romeral.

The Paez earthquake was originated in the Moras Failure System, which includes elements of high angle following a general N40°E direction, ten kilometers southwest from the Nevado del Huila Volcano. The local tectonic emplacement of the epicentre also is complex and seems to be related to the intersection of more than one single failure; the aftershocks monitoring of events greater than magnitude 2.5 shows a narrow band of about 10 kilometers wide and 40 kilometers long with a local N25°E direction, that could encompass the rupture zone.

The epicentral area included a variety of geological materials ranging in age from Paleozoic to Quaternary. The materials have been formed by deep magmatic processes, by contribution of lavas from the Nevado del Huila volcano, by metamorphism, and also include sedimentary materials.

EVENT MAGNITUDE

The event caused severe landsliding processes on the rocks and sediments which were already saturated because of high rainfalls which preceded the earthquake; the Volcano is 5365 metres high and the epicentre at around 2500 m.a.s.l., facilitate the mass movements. Part of the unstable material run slope down towards the drainage system, including the San Vicente, Moras and Símbola rivers, starting a progressive accumulation process of materials in the form of a debris flow centralized in the main discharge canal in the Paez river. The height of the flow varied between 10 and 40 meters over the normal river bed, demolishing everything in its way including the total destruction of bridges , access roads and little villages such as Irlanda and Toez (where the time gap between the trigger earthquake and the debris flow arrival was only around five and ten minutes respectively), and the partial damage of the municipality of Paez, among others. Some of the materials reached the Magdalena river traveling up to the Betania reservoir , one of the most important of the country. The event magnitude was classified as Very Important.

ORDER OF EVENTS

The event sequence of the disaster was evaluated as follows. The First Order, trigger element was the earthquake. Some contributor elements were: type , state of geological materials, high rainfalls, and land use.

The direct consequences were landslides as an Intermediate Order event, and structural damages on houses , roads and bridges.

Without evidences of important damming, part of the landslides were accumulated in the River Paez, shaping a High Order Hazard known as debris flow, which caused most of the casualties and the damages to the regions located along the slopes of the rivers. The estimated maximum velocity of the flow was around 50 kilometers per hour in the upper basin close to the epicentre, with a progressive lowering downstream, being around 30 kilometers per hour close to the municipality of Paicol, at about seventy five kilometers downstream the Paez river.

AVAILABLE INFORMATION

There was a hazard map against possible mud flows coming from the Nevado del Ruiz volcano in the Paez river basin but not covering the specific problems of the case under analysis. Regional geological maps were available, but without enough detail to be readily used in the emergency evaluation, especially in local details. Topographic bases on 1:100.000 , 1:25.000, and some 1:10.000 scales were available in parts of the epicentral area. Continuous seismologic information from the national network was a great support.

FIELD ACTIVITIES

Teams of geologist and geotechnical engineers with experience in similar evaluations were placed at critical points agreed with the national disaster prevention office, using helicopters. Overall and specific flights were done, the relative stability of the physical medium was estimated, collecting some samples for the Geotechnics laboratory, doing also the general description of structural damages on houses and infrastructure; those were useful to establish the epicentral intensity. Walking trips around each dropping point allowed quick stability assessments to be made; photographs were taken at each site.

OFFICE ACTIVITIES

After each journey there were discussions of the observations at the centre of operations in the city of Neiva, out from the hazard zone.

CULTURAL ELEMENTS

With the support of members of the national disaster prevention system, surveys were carried out to understand the local feeling towards the situation. Also in situ it was necessary in several occasions talk with the population, many of them from the Paez indians tribe, to explain our mission and the main local hazard factors.

Nightly meetings with the community were done, being aware then about the location of special points of interest such as sacred and religious places ; simple explanations were made of the geoscientific advantages of the modeling of geohazards . Some specific field missions were done to clarify informations coming from superstitions, including appearance of smoke and sulphur smell that the population related with spirits

DATA PRESENTATION

The approximate hazard zonation was made both on local and regional scales. Some of the local details were presented in the form of sketches. Three levels of relative susceptibility were defined in both scales, using the red (non suitable zones for living), green (most suitable areas for living) and yellow (non clear stability zones which deserves more study) color convention in the maps . Each zone representing the summary of the different possible present or potential hazards.

The emergency evaluation allows the Government to take direct actions and make decisions upon a geoscientific basis. A formal study was suggested to confirm or adjust the first hand evaluations. Some special recommendations were made with regards to the installation of alarms systems against debris flows; the volcano observation was also encouraged.

5- CONCLUSIONS

- In emergency situations it is essential to have an ecological approach in the application of the geosciences, otherwise the technical assessment of risk could lose their practical value.

- Elements such as event magnitude, analysis of order of events, use of available information , field activities, consideration of cultural aspects and data presentation could be part of an emergency situation assessment.

- Identify and involve the final user during our technical evaluations is a strategy to improve the application of the geoscientific conclusions.

- Three summary levels of relative stability is enough in the emergency zonation which follows a geohazard. This allows better understanding by the end users.

- Local (1:25.000, 1:10.000) and regional maps (1:100.000) have been found useful both to the final users and to the decision makers.

6- ACKNOWLEDGMENTS

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As part of a national proud campaign of some of the Colombian Students Abroad, the first author would like to state that WE ARE PROUD TO BE COLOMBIANS, land of work, future and hope.

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Landslides

GLISSEMENTS DE TERRAIN

Volume 1

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Further steps in a geotechnical zonation

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ABSTRACT: The systems of zonation usually used can be reinforced with techniques coming from complementary scientific fields, as is shown in a conceptual framework with the help of a literature review on related subjects. The lack of a model which comprises the weighting of such new factors should not be a definite obstacle to try them in a complementary basis. As consequence, benefits in the analysis of damaging phenomenon such as landslides will appear. These analysis are also a strategy to encourage the understanding of why the Earthen materials behave as they do, yielding new insights in the interpretation of the physical environment.

Radiocarbon dating have been used in dating the frequency of large scale volcanic debris avalanches, as well as in establish the age of materials immediately close to slip surfaces in landslides to help in the definition of age and environmental evolution.

Geochemical analysis and in general all the suggested techniques deserves careful sampling and storage of cores and statistical tools as interpretative techniques.

The residual strength mechanisms of clays, a key concept in modelling reactivated landslides, are brought along as an example, highlighting the relationships between macrobehaviour and microstructural elements such as clay shape and clay fraction. Cases of relationships between field behaviour and composition are shown, as well as between structure, fabric and geological evolution.

In addition to the technical tools, ecological considerations are worth following in order to estimate both cultural effects on the environment and to help in operative stages to make more easy the interpretation of our recommendations by the final users. The Geoscientific evaluations acquire new dimensions by performing more frequently these suggested activities and might lead to find new insights in the complex task of modelling the behaviour of Earthen materials.

1 INTRODUCTION

1.1 Systems of Zonation

The methodologies used to derive so called Geotechnical Zonations, that can be used to study mass movements or other geological-related hazards, are more or less established.

The usual objectives include to define areas with different potentials for landsliding, as well as make recommendations of land use. It is well known that no one system is appropriate for all needs (Varnes, 1984). Specific analyses should be considered in specific environments or projects.

The maps can range from simple extrapolation of the possible behavior of the geologic units, to complex mathematical modeling with multiple analysis of slope stability (Brabb,1993).

Among the methodologies to study landsliding, many of them have as basic step the use of landslide inventories with the reconnaissance of places that appear to have failed by slope failure processes, having the advantage of showing where landsliding processes seem to be concentrated and as a consequence where is worth developing more detailed studies (Brabb, 1984).

The figure 1 shows the representation of the usual stages followed in a Geotechnical Landslide Zonation (Forero-Dueñas, et al,1994).

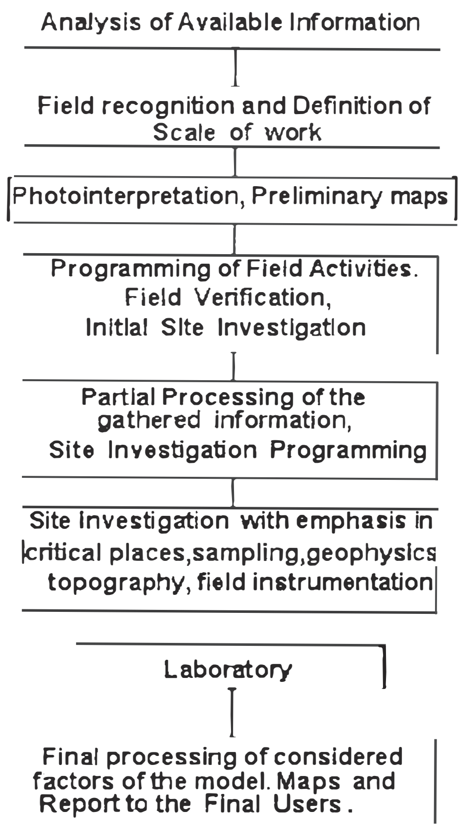

Fig. 1 Summary of the common stages in a Geotechnical Zonation (Forero-Dueñas et al, 1994).

1.2 The problems

The considered factors vary with the scale and objectives of the job but generally speaking include slopes, climate, lithology, structure, seismicity, geomorphology, vegetation, shear strength, volumetric changes, and land use, among others (Varnes 1984, Forero-Dueñas et al 1994).

It is well known that the transition between field recognition and hazard prediction is usually difficult. The complexity of the subject, and the application of approximated modeling makes the conclusions to be indeed an approximation.

Another problem to face is the operational one that is to ensure effective understanding of our conclusions and recommendations for action by the final users. Cultural elements will have an effect on land use on the one hand, and also on the response of inhabitants of a zoned area to advice.

Suggestions to apply techniques of complementary disciplines coupled to analysis of soil and rock mechanics are made, to be used in zonations leading to the incorporation of factors usually not considered in the models. The subject is presented including basic ideas about geochronology, geochemistry, structure and fabric, and ecology, accompanied by some examples.

The incorporation of these layers of information in between other more "standard" ones, might be useful to improve our predictions; the fact of the absence of an overall model which allows to add all the factors must be managed with criterion in any given situation.

2 GEOCHRONOLOGY

2.1 Some methods of dating

Historical records are used where return periods of hazardous events are relatively short but for long periods, alternative dating methods are required.

With the discovery of radioactivity in uranium by Becquerel in 1886, and its consequent revolution in physics, tools were provided to allow the elapsed time since the beginning of the Earth started to be clarified (Eicher, 1976). The definition of the ages of rocks from the Earth using the family of techniques of Radiometric Dating, are based on the spontaneous decay of long-lived naturally occurring radioactive isotopes (Dalrymple, 1991).

Radiocarbon dating (Carbon-14 radioactive isotope) is useful for the last brief portion of geologic time, when huge climatic changes affected the earth; carbon-bearing substances have been successfully dated, including wood, peat, bone and marine shells among others (Eicher, 1976).

Radiocarbon dating has provided a useful tool for assessing the chronology of the last 50000 years (Easterbrook, 1988) being of high value when dealing with Quaternary events, including mass movements, as a tool for understand values of return periods of events that do not have any other possible way to be recorded and interpreted.

There are other dating techniques of Quaternary Sediments, including : fission track dating, thermoluminescence, amino acid dating of wood, aminostratigraphy of mollusks, paleomagnetism, and geomagnetic variations (Easterbrook, 1988).

2.2 Volcanic related events

When making zonation studies in areas affected by volcanism is necessary to understand the kind and source of the different deposits in the surrounding or even at long distances from a volcano.

The volcanism can be interpreted analyzing tephra layers, studying chronologic and compositional evolution of volcanic regions; the tephrochronology has improved its techniques and the Casignol technique improve precision of K-Ar dating in samples in Quaternary layers (Bitscheme and Schmincke 1990).

In Japan, more than 130 debris avalanche deposits have been found around 66 Quaternary volcanoes, being a large scale mass movement of difficult prediction. These deposits are found on steep sided strato-volcanoes and lava domes, with high volcanic edifices. To understand the possible frequency of the phenomenon some of the debris avalanche deposits were dated by the carbon-14 method; the average frequency rate of major debris avalanches in Japan is estimated once in 100 years (Inokuchi, 1992).

2.3 Some landslides in England

Skempton, has done some interpretations of landslide activity, taken the geochronology of the quaternary as one of his tools. Skempton and Petley (1967) studying the characteristics of slip surfaces in Sevenoaks, Kent, England, using exploration pits found a fossil soil whose carbon-14 dating gave an approximated date of 12200 years before present, allow them to make theories about the period and climatic circumstances of its formation; the combination of these dating was coupled with the famous concepts of residual shear strength.

Skempton (1985, 1995) while analyzing landslides near Swindon, England, reactivated by the construction of the M4 motorway in the winter 1969-1970, found organic matter of a woody nature below the slip surface, found a radiocarbon age of 12600 years, which allows him to suggest that the landslide had been originated in a late period of the last (Devensian) glaciation.

Skempton (1995) recalling the studies of the Man-Tor landslide, in Derbyshine, England found a peaty fossil zone below the slip surface, which was dated with carbon-14, handing an age of 3000 years before present at the landslide toe, and with some extrapolations and the estimating of the average magnitude of the slips, allow him to have a rough idea of the time when the slip started, about 3600 years ago.

Whit the former few examples, coming from experiences that have contributed to the developing of key soil mechanics concepts, is clear the importance of involve such analysis in some stages of the zonations; in particular doing landslide inventories it would be desirable, specially in complex areas or in strategic projects, to have an idea of the dates sequences of slides in the mapped areas.

3 CHEMICAL COMPOSITION

3.1 Geochemistry

In some circumstances, might be worth considering the possible links between chemical composition and field behaviour.

Geochemistry is mainly concerned with understand the behaviour of the chemical elements through the natural processes, giving important guides with regards to the physical and chemical environment of rocks throughout their geological history (Reeves and Brooks, 1978).

The evaluation of the concentrations of trace elements is important also for giving possible uses of mineral resources, agricultural uses, and also to trace contamination of the environment. To complete some of all of these objectives will depend of course on the specific kind of project, but in doing a Zonation there are also recommendations of land-use that can be refined with the help of some the former analysis.

Geochemical analysis require care in the sampling and storage of cores, and in interpreting the results is necessary to manage statistical concepts (Reeves and Brookes, 1978).

3.2 Mechanisms of residual strength in clays

The composition of the materials is also a factor that affects its field behaviour. Skempton (1985) in studying the post-peak drop in drained shear strength of clays shows how if the clay fraction is around 50%, residual strength is controlled in great extent by sliding friction of the clay minerals; the clay minerals can have little effect on residual strength when the clay fraction is less than about 25% as the strength is largely controlled by sand and silt particles.

Lupini (1980) studying the fundamental mechanisms of drained residual shear hypothesis that clay soils formed predominantly by platey shape particles would have preferred particle orientation at large shear deformations, causing a reduction in the interlocking and the residual friction angle will approximate the interparticle friction angle between clay platelets in parallel configuration. Turbulent residual shear is the name given to the state at constant volume involving rotation and translation of particles with random particle orientation in soils with a predominant fraction of massive shaped minerals; a transitional behaviour occur in between the former cases.

Lupini also concludes that the residual strength depends on mineralogy and pore water chemistry, factors which control the dominant particle shape and the coefficient of interparticle friction.

Is clear then, that the bulk behaviour is directly related to microstructural elements not usually taken into consideration in the zonations analysis.

3.3 Field behaviour and composition

Moore (1988), established associations between spatial variability of physico-chemical properties and landslide distribution within the London Clay Basin; a broad regional association between the mineralogy of sediments and landslides in southern and south-east England was established.

Mitchell and Solymar (1984) found evidence that sand deposits may have substantial stiffening and strength increase with time, and also can loss strength as consequence of disturbance, and relate those effects in the Jebba sand of the Niger River in Nigeria to possible solution and precipitation reactions involving amorphous silica gel in the material.

Butenuth, De Freitas, Frey, Passas and Forero-Dueñas (1995), proposed that the role of silica gels as a cementing agent might be the source of slope failures given the time-related changes of the gels under environmental variations.

4 STRUCTURE AND FABRIC

The microfabric and microstructure are also important aspect not easy to handle and not usually covered in a zonation. The spatial arrangement of the particles and the interparticle forces make contributions to the macrobehaviour of earthen materials. Burland (1990, 1995) using oedometer and triaxial tests, points out the importance of the behaviour of clays reconstituted in the laboratory with intrinsic properties inherent to the material, as a frame of reference for assessing the properties of the natural material particularly to establish the influence of micro-structure (fabric and bonding).

Rowe (1972) stress the effects of fabric on the coefficient of consolidation, permeability, and undrained shear strength of silty clays. Rowe gave practical examples of fabric types in recent alluvial deposits, sandstones, carboniferous and ordovician materials; analysis of the influence of fabric in foundations, cuts, retaining walls, anchors, and cast in situ piles. The recognition of the role of fabric suggested fundamental changes in site investigation practice.

Forero-Dueñas (1995) reports attempts of correlate the fabric of the clays of Bogotá, Colombia, with the geological history of the Sabana Formation, making also comparative studies between natural materials and samples reconstituted in the laboratory.

5 ECOLOGICAL CONSIDERATIONS

Environment must be understood as all that surrounds, opening the minds to the establishment of relationships between the lithosphere, hydrosphere, atmosphere and the biosphere and its consequences on both the technical evaluation of the studies and their practical communication. This ecological approach has been proved successfully when dealing with the hazards evaluation in emergency situations, when knowledge of cultural considerations was key to apply Geoscientific evaluations, under ideas of Ecological Geosciences (Forero-Dueñas, Booth, 1995).

We must remember that is worth taking into consideration those aspects that can be called operative, leading to the useful application of the recommendations of our studies and zonations. All the technical efforts can be missed if we do not also take into account some considerations towards the multi-composition of the environment specially in relation to the man, as part of the biosphere.

CONCLUSIONS

- The geotechnical zonations are developed in several scales and leading to obtain different objectives considering usually basic factors. Some suggestions are done to introduce other less commonly used methodologies and procedures of the science. The task of construct the modeling of the field response of earthen materials requires to use all the available tools in Geosciences.
- Geochronological techniques can be applied to date the age of the rocks of the earth including events from the Quaternary period, and might give a clue in understanding landsliding evolution and in trying to establish return-periods.

Links between geochronology, composition, field behaviour and laboratory testing were useful to develop the concepts of residual strength in clays, as an example of the ideas of the paper.

Geochemical analysis are important in the difficult task of understand the physical and chemical environment of earthen materials throughout their geological history. The field behaviour also might has connections with this subject.

Structure and fabric, make a contribution to the in situ response that is worth following researching to complement other factors.

- Last but not least, the ecological approach in field and desk activities might be useful both to understand cultural-related effects in the rest of the environment, and to apply in operational stages to improve the application of Geoscientific evaluations.

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Inventory and study of landslide hazards in Cundinamarca

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ABSTRACT: The inventory of geologic-related hazards in the Cundinamarca Department of Colombia with special reference to mass movements was done, following a methodology given by a hierarchical approach in Geoscientific studies. The inventory started with regional studies as a reference framework to which medium scales (1:50000 to 1:25000) and big scales (1:10000 to 1:5000) analysis were tied up as basis of detailed (1:5000 to 1:2000 scales) and designs (great than 1:500 scales) studies in the selected fifty most critical places which might be affecting people and infrastructure in the short term. Drainage systems were the basic remedial work, deformation monitoring and groundwater levels control were also suggested in some cases. Factors as the nature of the geological materials which includes soft rocks and Quaternary unstable deposits, intense rainfalls, tectonic activity, high energy torrential rivers, and man made actions contribute to the great environmental damages related to landsliding and erosion. Emphasis was placed in study the Quaternary deposits, as source of periodical and destructive unstability. Multiple scientific fields were combined in the modeling. The study is the base of present and future capital investment policies by the politicians and decision makers, and has been found as a good example of the applied side of environmental studies, giving knowledge of regional and local geoscientific elements as well as allowing to arrive to engineering solutions helping to the well-being of the population.

1 INTRODUCTION

1.1 General Situation of Natural Hazards in Colombia

Colombia with a territorial extension of 1'141.748 km2 and located in the N.W. corner of South America, is a country with multiple natural hazards, including earthquakes, volcanoes, tsunamis, floods and mass movements. The tectonic emplacement as well as our particular topographic, climatic and geologic conditions make a big proportion of the national land prone to the development of the natural hazards. Recently, disasters as the Quebrada Blanca landslide in 1974, el Guavio landslide in 1983, the Popayán earthquake in 1983, Nevado del Ruiz lahars in 1985, Tumaco tidal wave in 1979, Utica debris flow in 1988, and so on are just some examples of the daily interaction of the country with these events (Forero-Dueñas, 1992).

After such painful situations, the Colombian Government created the National System for Disaster Prevention (Law 49 of 1988 and Decree 919 of 1989) which has as one of the main advisors in geological-related matters the support of INGEOMINAS, the National Institute of Investigations in Geosciences, Mining and Chemistry.

INGEOMINAS has assumed its role developing projects at national, regional and local levels. The Institute has as a main goal to put the available scientific knowledge to the service of the people, having an air of applied science specially in the Geoenvironmental Engineering and Mining Sub directions, but without losing the original research aims.

Environmental Sciences have this flavour of being an inquirer of the reasons of the environmental changes but with the final goal of knowing how to applied them in benefit of the human kind.

1.2 General Tectonic Setting

The N.W. corner of South America is affected by a complex tectonic field , as an answer to the interaction of three main tectonic plates known as Nazca, South American and Caribbean. The energy is released in the subduction zone as well as in the Benioff zone and in faults inland showing huge neotectonic activity.

The Cundinamarca Department and its capital Bogotá (Santafé de Bogotá), which is also the country capital, has both Intermediate and High Seismic Hazard areas.

2 THE CUNDINAMARCA DEPARTMENT

2.1 General Conditions

The Cundinamarca Department with an area of 24210 km2 is located in the central part of the country (fig. 1), in the Eastern Cordillera, which is one of the 3 local branches of the Andes System which runs across the South American Continent.

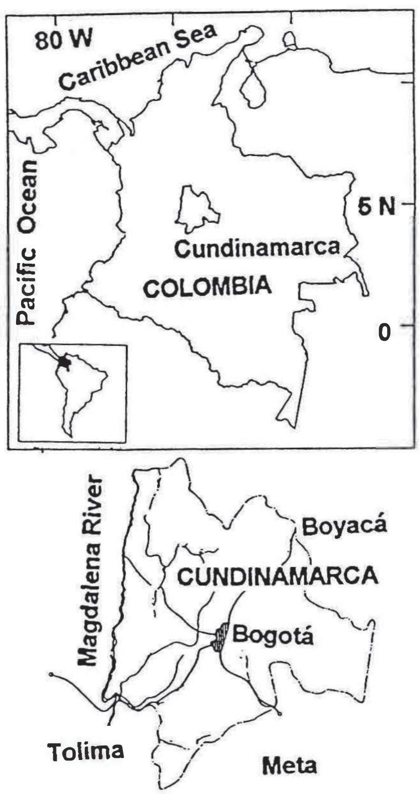

Fig. 1 Location of Cundinamarca.

According to the altitude and the local environmental conditions, there are several climates within the Department of Cundinamarca, as happens in many others places of the Andes mountains, having temperatures ranging from 30° centigrades to a near or less than zero in high altitude areas or Paramos.

As examples we have that Bogotá is located at 2600 m above sea level, has a medium temperature of 14° centigrades, and a medium precipitation of 1013 mm/year; on the other hand, Utica, a small town located 119 km. N.W. from Bogotá also within the Cundinamarca Department, has an altitude of 497 m.a.s.l., a mean annual temperature of 26° centigrades, and a mean annual rainfall of 1350 mm.

The region has two major annual rainy seasons (April to May and September to November) in between two more dry periods. The abrupt topographic conditions of the region make that the rivers and creeks display high hydraulic gradients being of torrential nature, contributing to the erosion and the general unstability.

2.2 Natural Hazards in Cundinamarca

Following also the course of the impact of painful tragedies as well as the gradual interest of the politicians in charge, INGEOMINAS (1992) develops the first part of the project " Regional Inventory of Geological Hazards in Cundinamarca ". The project was a jointly paid one between INGEOMINAS and the Cundinamarca Governor Office, and was finished in 1992, after one and a half years of work.

The objectives of the study were:

- To make the regional inventory and evaluation of the main geologic-related hazards including Mass Movements, and Erosion.
- Among the former ones, choose the fifty most critical ones since the point of view of risk to the population or infrastructure, to make the local analysis and the design of the stabilization solutions.

3 METHODOLOGY

3.1 Personnel

The basic team was composed by geologist with experience in similar evaluations and knowledge of the Department, and by geotechnical engineers (civil engineers with postgraduate studies) with experience in zonations and in designs. As supportive team were used: civil engineers, geophysicists, topographers, photo interpreters, and technicians.

The Geoenvironmental Engineering area of INGEOMINAS has among his goals, the fulfilment of earth science-related studies, following the steps of Observation, Quantification and Judgment (Einstein, 1991) that were the origin of the ideas of Terzaghi coming from Geology to Geotechnical Engineering and to Engineering Geology. The Institution is aware of the fact that direct " empirical " relationships between geology and engineering usually are not good enough and has reinforcing the quantitative element with experts in soil mechanics and rock mechanics as key element; also we have the support of experts in other Geoscientific fields and in hydraulic and hydrology among others.

There are also in INGEOMINAS interests to note the importance of consider the interactions between all the components of the environment in a given ecosystem, including the man's actions in the studies. Suggestions exist to increase the evolution of purposes in the natural hazards evaluation, looking the Ecology (study of the interactions between life forms and the environment) as a general body under which the Geoscientists can also be located, and the Ecological Geosciences approach can be one answer to make more complete analysis in Geosciences, considering new elements involved in a given problem; this approach has already proved to be successful and very recommended when dealing with hazard evaluations during emergency situations (Forero-Dueñas, Booth, 1995).

3.2 Scales of Work

The work Scales suggested to use in Geotechnical Studies are summarized in the table 1.

The present job started at Regional Scale having a national and a Departmental knowledge of the geological conditions of the country. After that followed a Medium scale work to define the critical points, and then follow a local job in which Big and Detailed scales studies when solving punctual problems with complete geotechnical designs.

SCALE	OBJECTIVE	APPLICATION
REGIONAL <1:100000	In planning, to locate critical sectors to decision makers. First hand regional evaluations in big engineering projects.	National and Departmental maps, Big Basins, Coast lines studies. Big Projects in Prefeasibility Levels.
MEDIUM 1:50000/ 1:25000	Rural / urban planning; critical zones; location of specific areas.	Some basins, coastal zones and big cities.
	In engineering projects at Prefeasibility level to help in selecting alternatives in key places.	Continuing the information refining in specific zones.
BIG 1:10000/ 1:5000	Urban planning. In engineering projects at Feasibility levels.	In some cities (1:10000) and towns (1:5000); critical sectors of coastal line.
DETAILED 1:5000/ 1:2000	Urban Planning. In engineering projects at Feasibility levels.	In towns or in critical zones of any project of land - use.
DESIGNS > 1:500	Solving local problems with engineering countermeasures and detailed designs.	Punctual studies with variables clearly identified.

Table 1. Work Scales in Geotechnical Studies (Forero-Dueñas et al, 1994).

3.3 Hierarchical Approach

The philosophy of follow hierarchical studies in earth sciences is summarized in the figure 2, and likes to remind the necessity of having a knowledge of the surrounding conditions, before attempt any engineering stabilization work. This approach is a necessity in Geotechnics, specially in dynamic environments. Unfortunately, there are still cases when it is forgotten, and the failure of costly structures is the consequence.

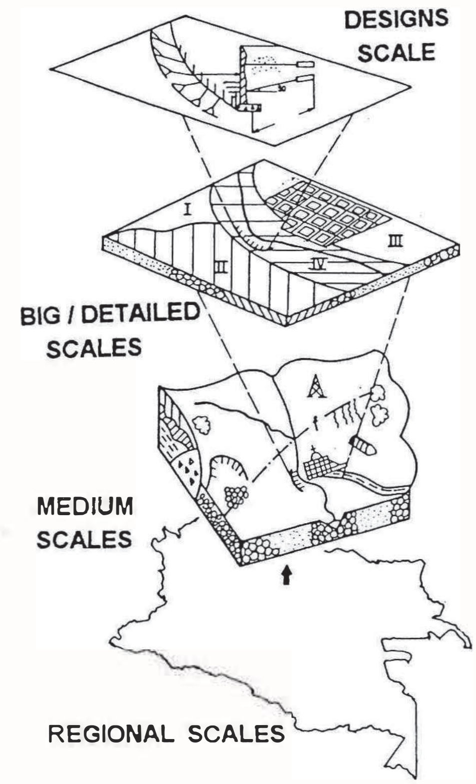

Fig. 2 Hierarchical Approach in Geoscientific studies.

3.4. Specific Methodology

Under the previous consideration, the Zonation of the most critical areas of the Cundinamarca Department was done following the steps summarized in the fig. 3.

Every one of these steps was developed as follows :

1. Use of Available Information: Regional (national and departmental) information about geology, climate, hydrology, hydraulics, previous studies in the area, remote sensors (only aerial photographies were available to use in practical way), , pedology, agronomy information, topography, reports of disasters associated with geological factors consulting files of the National System of Disaster Prevention and newspapers, and so on.

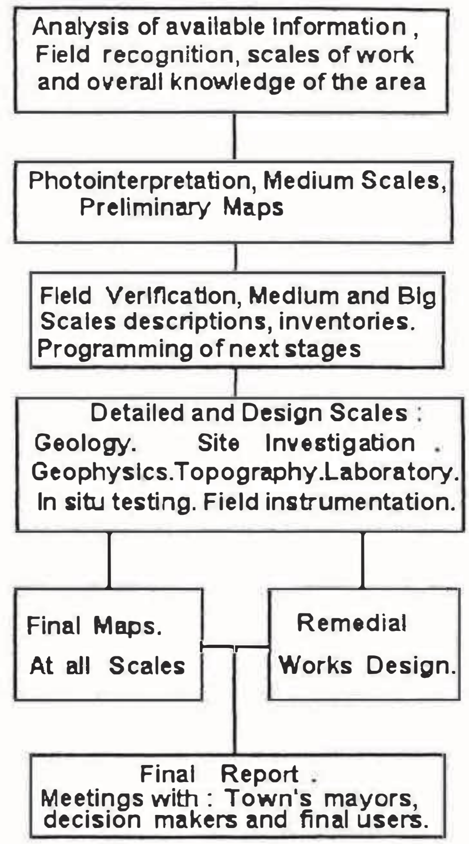

Fig. 3 Methodology of the study.

The establishment of a clear reference framework was done analyzing the collected data. Also a recognition field trip was done to familiarize the team with the regional features.

2. Photointerpretation: As quoted by Varnes, 1984, many mass movements are associated with the most superficial materials, and that was the case in Cundinamarca. Particular attention was given to the Quaternary period differentiation, finding a number of slope failures associated with recent deposits and with

residual soils.

Aerial Photographs in scales ranging from 1:20000 to 1:50000 were worked in that sense, in multi-temporal analysis. Preliminary maps were produced, including lithological, structural and morphodynamic features.

3. Field Verification: Having the preliminary mapping in Medium Scales as working reference, the teams of Geologist and Geotechnical Engineers were spread into the different regions of the Cundinamarca Department, making verification, adjustments and corrections to the preliminary maps.

The description of the critical places was done using Big Scales, a preliminary site investigation, and the inventory of the geological-related hazards were done. The definition of the 50 most critical followed, producing a new program of work to cover working in Detailed and Design Scales. In the mass movements inventory, the classification system proposed by Varnes (1978) was followed.

4. Detailed and Design Scales Activities: The eastern cordillera comprises locally many sedimentary rocks, including sequences of sandstones and shales; the quaternary period include alluvial, colluvial deposits and some residual deposits. Upon the action of environmental factors, intense rainfalls specially, many mass movements of varied type and size are part of the landscape of the region.

Having the inventory as reference, on critical places a detailed program of activities was followed, including geology (with emphasis in the relevant applied aspects), a site investigation program with sampling by means of drill holes and recovery of block samples from trenches, and geophysics; the electrical resistivity proved to be very useful in identifying phreatic levels and the transitions between superficial deposits and the bedrock.

Some in situ test also were done, specially to check field permeability. Topographic surveys were performed both to produce Detailed and Designs maps, and as part of a program of surface deformations control in the most critical sites.

Cores and block samples were taken from the deposits and bedrock, to make the geomechanical characterization in the soils and rocks laboratory of INGEOMINAS and the National University of Bogotá. Classification, Volumetric changes (compressibility and swelling pressures), permeability and shear strength test were done (triaxial, direct shear box and unconfined compression tests were used). Back analysis were done to estimate the average conditions at failure.

In some places (as in the deposits of the town of Pacho) chemical analysis were performed to understand better the existing environment, and towards the proper design of the steel reinforcement of the retaining walls, to avoid corrosion. In other cases, petrologic analysis also were done.

5. Final Maps: As product of the previous activities and analysis, the final lithology, structural, morphodynamic, and hazard location maps were produced, locating the most important potential geological-related risks in the surroundings of the main towns of the Cundinamarca Department.

Among them, a priority map of hazards was done, with the critical 50 places most dangerous in the short term. These included all types of landslides, river erosion, infrastructure damaged by swelling pressures, heavy eroded areas, and damages in main and secondary roads among others.

The critical places were studied in detail, and the design of the countermeasures done. At this stage, the interaction between geologists and geotechnical engineers were at maximum stage satisfying the study ideals.

Most of the designs of remedial works were water-controlling elements, including drainages, trenches, ditches, filters, horizontal buried pipe-drains, erosion-control features, and so one. In other cases retaining walls were designed but accompanied also by filters. Also specific designs of roads, bridges, box coulverts, and other infrastructure were done.

The remain critical points not stabilized are the base for future detailed studies within the Department, and a guide for capital investment in towns and rural areas.

6. Final Report: The final report was produced with the summary of the activities. Effort was put in the explanation of the conclusions in simple terms, in order to facilitate their understanding; to complete that task meetings with the final users and decision makers were organized.

A copy of each report was given to the Governor office and an additional copy of the particular hazards within his particular town was given to each mayor.

4 CONCLUSIONS

- The study of geological-related hazards in the Cundinamarca Department produced a zonation of mass movements and erosion in regional, and also in more detailed scales. This technical tool became a guide for the decision-makers and land-use planners, also the mayors of small towns are become aware of the main problems of their physical environment.
- The applied character of Environmental Geosciences was proved in this study, producing the enlargement of the scientific knowledge of a specific region, but towards the control of the unstability and the well-being of the population.
- The application of Hierarchical studies was done successfully, following the suggested working scales.
- The steps of Observation, Quantification and Judgment were performed, as a basic philosophy of the interaction between Geologist, Geotechnical Engineers and other complementary Geoscientifics in a feedback scheme.

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EXPERIENCES FROM THE PAEZ EARTHQUAKE, COLOMBIA

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ABSTRACT

On June 6th, 1.994, a 6.4 Richter Magnitude earthquake hit the southwestern part of Colombia; the event was superficial, less than 10 Km. depth, and was associated with the activity of the called Moras failure. The epicenter was located at about 10 Km. from the Nevado del Huila volcano which is one of the 15 active volcanoes of Colombia. The management of the immediate effects of the earthquake which stroke the Paez river basin, required both technical judgment but also a big dose of awareness of the culture of the Paez indians which are the inhabitants of the mountains which surrounded the epicentral area; without the appropriate combination of these factors, the technical recommendations could had been totally neglected, becoming bigger the nature of the tragedy.

The description of the huge difficulties of making the post earthquake emergency evaluation and the qualification of the hazardous areas in almost inaccessible regions by the experts of INGEOMINAS, the Colombian National Institution in charge of the Geosciences and the Geological Hazards, is done. The attitude and reaction of the indian organization towards the technical evaluations of places such as their sacred centers and crop lands is analyzed. Local maps and sketches were presented on 1:10.000 to 1:25.000 scales, and a regional zonation was produced on a 1:100.000 scale, showing the most and the least suitable areas for living; such maps were used to decide evacuation procedures, and the location of shelters and heliports.

The event experiences are used to make considerations about how the geoscientifics can help in the task of lowering the seismic risk in populated areas of developing countries, with complex and still not well understood seismicity. Suggestions are done to attack not just one but the two components of risk, hazard and vulnerability.

KEYWORDS

Ecological geosciences; emergency zonation; ethnic; pre-disaster vulnerability; post-disaster vulnerability; model basins; paez; prediction.

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EXPERIENCES FROM THE PAEZ EARTHQUAKE, COLOMBIA

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ABSTRACT

The 6.4 Richter Magnitude surface earthquake that hit the Paez river basin, southwestern part of Colombia, serves as example of the complex task of accomplishing both a reasonable stability emergency evaluation following geoscientific procedures, and to get a quick - positive response from a heterogeneous group of scared people, mostly of them indians without our same vision of the world. Right after the event, a group of experts of Ingeominas, the Colombian National Institution in charge of the geological hazards applied a novel methodology of hazardous zoning, assessing in short time, as the circumstances demanded, the main factors which appeared to control the stability of the area. The technical reports allowed to produce a zoning of the Paez river basin, in 1:10000 and 1:25000 scales, and summarize the overall state of the epicentral area, in a 1:100000 scale map. The event experiences are used to make remarks about the respect and consideration of the indian beliefs, as the main local culture found, and also about hazard and vulnerability and our role as geoscientifics towards the lowering of the components of risk in developing countries.

KEYWORDS

Ecological Geosciences; emergency zonation; ethnic; pre-disaster vulnerability; post-disaster vulnerability; model basins; paez; prediction.

INTRODUCTION

On june 6th, 1994, at 20h 47' Greenwich time, an 6,4 Richter magnitude earthquake with a focal depth of less than 10 km., hit the Paez river basin, in the Cauca Department. The National Colombian Seismological Network, NSN, managed by Ingeominas, the National Institute of Geosciences, Mining and Chemistry, located the earthquake at 2.9 degrees north latitude and 76.08 degrees west longitude; the epicenter was located about 10 Km. southwest of the Nevado del Huila volcano.

The earthquake effects included a combination of damaging events, starting with direct structural failures of houses and infrastructure, following with all sorts of mass movements, and ending with a huge debris flow which causes most of the about 1100 casualties.

The geoscientific emergency evaluation, done by teams of geologists and geotechnical engineers, allowed to make a zonation of the main damaged area in sectors with less or most suitability for living (Ingeominas, Forero-Dueñas,edit. 1994), being a technical base-layer over which decisions regarding understanding the nature of the hazard situation, identification of critical points, shelters location, evacuation procedures and so on were taken by the Colombian National Office for Disaster Attention and Prevention, NODAP.

The difficulties about the technical evaluation were great both because of the nature of the task itself, in a short period of time, and for the access problems, being only possible arrive by using helicopters. But having done this step, the geoscientistics found a different culture living in the epicentral area, the indians.

They have a different authority organization, and see the world under different parameters, being bonded to the so called mother earth; these conditions put an additional, and perhaps at the end quite useful, ingredient in the immediate task of control the disaster situation and perform the disaster management under the most efficient, less arguable, parameters.

THE EARTHQUAKE AND ITS GEOENVIRONMENT

The main shock was located by nine of the stations of the NSN, which is a modern 14 seismometer satellite system; the network also received around 800 aftershocks from the 6th to the 30th. of june, ranging in magnitude from 1,8 to 4.8 in the Richter scale (Ingeominas, 1994, Dimaté *et al.*, in Forero-Dueñas, edit.).

The location of the epicenter was done with the seismological stations of the NSN, reinforced with data coming from other stations belonging to the Southwest Seismological Observatory, a regional Colombian network, and the National Seismological Network of Ecuador. In the Mercalli Modified intensity scale, the event had an epicentral grade of VIII.

The field activities identified the Moras Fault, of high angle and with a general N40°E direction, as the most possible source of the energy liberation. In general was evident the lack of detailed knowledge about neotectonics in the region, having as a working base only regional maps but without including the ideal necessary information and not oriented to the specific problem. This is a common matter in many areas of our country.

Ingeominas (París and Romero, 1994) has developed an updated simplified version of the neotectonic situation of Colombia, including the Moras Fault; this is a purpose-built map towards the understanding of a basic layer in any seismic hazard assessment for the country. The Andean zone , where was located the epicenter of the Paez earthquake, is covered by a cluster of faults, all of which have more or less possibility of being an earthquake-generator.

The materials found around the epicentral area includes many sorts of rocks and soils, ranging in age from paleozoic up to quaternary. The genesis includes magmatic processes, metamorphism and sedimentary sequences (Ingeominas, 1994, Orrego *et al.*, in Forero-Dueñas, edit.).

The Nevado del Huila volcano (5365 masl) is one of the 15 active volcanoes of Colombia. The location of this right in the upper basin of the Paez river made at the beginning of the hazard evaluation think in an obvious relation between an avalanche and the volcano. As a matter of fact there was already a preliminary hazard map modelling this event (Ingeominas, 1986, Cepeda *et al.*,). However no relation was found, and only an slight effect was observed in the glaciers. The volcano did not show any main seismologic abnormal behaviour by comparing the activity pre and post earthquake.

THE EMERGENCY EVALUATION AND ITS APPLICATION

When a couple of days after the earthquake the first news of the magnitude of its consequences arrive to the Ingeominas central office in Bogotá, a group of engineers and geologists were sent to act as the technical mission supporting the NODAP. The initial group was composed by senior environmental-engineering geologists, Mr. P. Caro and Mr. M. Moreno, and by a couple of geotechnical engineers, with specializations also in hazards and seismic matters, myself and Mr. J. Martínez, who was the general coordinator of the mission given his position as Subdirector of the Geoenvironmental Area. The group had a strong geoscientific formation and experience in engineering projects and hazard evaluation, of several years of practice and study. The group was reinforced by Dr. A. González-García, President of the Colombian Geotechnical Society, as an advisor.

The former background is quite important, when is intended to gain lessons from our experience in the earthquake. When the group arrived and started flying the area, was shocked by founding hundreds and hundreds of landslides, a huge mark of a high energy event in the Paez river channel, the debris flow, and a general damage situation in the basin of the Paez river. The complicated part was that immediate pressure was put to get the stability concept of the Ingeominas team. The technical formation and good sense of Mr. O. Cardona, head of NODAP, a seismologic engineer himself, was useful to explain to everybody the difficulties of the task in a short period of time, and that we were ready to do the best possible job.

After the first aerial impression of the situation, the team had a meeting and from the exchange of ideas and to cope with the situation, the next zonation strategy was agreed
- Select targets of evaluation, according to the reports of people in danger sent to NODAP by the local emergency committees.
- At the same time additional targets were chosen to carry out the understanding of the physical phenomena and prevent possible new events.
- Groups of two, geologist-engineer, were spread over each selected target by helicopter. In many cases the landing was not possible, and was necessary to jump to reach the ground. After a time of observation-assessment-evaluation, the geologic-geotechnic setting of each place was defined;

this time of walking-sampling ranged from 1 to 3 hours in each place.

- The local community, Paez indians mostly, were amiable in general. As part of each mission, the geoscientifics also include an explanation of the situation to everybody, and to respect the local cultural-hierarchical organizations, we try to speak and make the walking with the head of the community which at the end was the one who understood more our explanations, spreading them afterwards.
- Sketches of the targets were done, in plain and profile, also taking helicopter pictures to help in the zoning, later on. In most of the cases we had topographic bases in 1:25000 to 1:10000 scale to help in the drawing. The sketches were jointed in a 1:100000 scale map, summarizing the overall stability situation.
- To improve the usefulness and the quick understanding of our geoanalysis for everybody, all the collected data of geology, geomechanical indexes, failure mechanisms, ground-water levels, stability assessments, slopes, and all the hard technical information was simplified. Three summary zone were shown, including the expected ground-structures response to all the possible hazards in a given target.
- The three zones were presented with emphasis in the aptitude for living, as it was one of the most common questions in every place. The zones were: Most suitable zones for living (in green color), Non suitable zone for living (in red color), and Non clear-stability zones (in yellow color) in which either the complexity of the situation or the lack of proper observations (in some cases the landing was not possible) did not permitted to make a clear definition; in these later zones temporal activities were allowed.
- Nightly meetings were done with all the institutions involved in the emergency, with the coordination of NODAP, and the active participation of the indian organization representatives. Questions were solved, and the final decisions about the location of possible shelters and evacuation points were taken in common agreement.
- The official concepts by Ingeominas, after each day of work, only were communicated directly to NODAP, institution that was in charge of spreading the results to the people and the media. That was very important, concentrating our team in the technical assessments.

The difficulties of the hazard assessment were very big, and not were few the cases in which our group had to walk alone in between the failed slopes, and the destroyed roads and houses, given the fact that neither the locals nor the red-cross people liked to walk in extremely risky and unstable ground. However, at the end this fact was also valuable to gain the respect of everybody, having a general feeling that the central government sent people really interested in helping traditionally forgotten areas. In some of those cases, we had to do it, because it was the only way to draw profiles and sketches and assess the stability; it is also necessary to say that for one reason or the other, we could not obtain proper post-disaster aerial photographies to help us in evaluating the emergency.

The sequence of the hazards was modelled, starting with the earthquake (first order hazard) damaging structures and producing mass movements (second order hazard); part of the shook soils, rocks and debris reached the streams, without any important damming, and shaped almost instantly a debris flow (high order hazard) centralized in the Paez river channel. The violence and speed of the flow, around 50 kph close to the epicentre, added to the surprise of having something else just following the earthquake, were the cause of most of the casualties in the towns and villages located in the flow route.

CULTURAL CONSIDERATIONS

The area affected by the earthquake is populated by a mixture of ethnic groups, and cultures. This lack of uniformity among the population makes very difficult to reach every one with a single technical speech.

In that area is located the Tierradentro region, mainly composed by Paeces indians, being a world-recognized centre of anthropologic value. Also in the Silvia region Guambianos indians are settled. We found a mixture of world conceptions, including a diversity of religious centres with catholics and evangelical churches, among others. There are also people of mixed race as half-castes (mestizos) and mulattos; also we found whites and some black populations.

The indian inhabitants speak their original language, and many of them also speak or understand spanish as well. Most the area is divided in indigenous Resguardos as a way of land property; the indigenous are ruled by Cabildos as the traditional authority.

We found some crops of poppy (amapola) in the lands cultivated near the border of the debris flow in Paez river basin. As a matter of fact, natives told us that some of them saw the disaster as a punishment of God for being cultivating illicit crops. These illegal activities had been detected by the police, and before the disaster the helicopters, the same that were serving us as transport media, were used in antidrugs missions; that fact did not help us very much in some cases, and some distrust was felt when we, the white government, arrived to help them, the hunted and in some extent the traditionally abandoned.

The Paeces had the avalanche among their ancient events, linking similar phenomenon with life signals of the earth, the mother. And any such event is related to their particular conception of the world, calling for a truthful bonding with the earth. Histories about the birth of Juan Tama, the mythical Paez ruler, associated to an avalanche were told to us. These facts put new pressures over our group: how to move them with evacuation procedures supported with a three color sketches and some geoscientific ideas about friction angles, recurrence periods and undrained shear strength, if they took the event as an expression towards the reinforcement of their believes, and the attachment to their lands and sacred places?.

The only way was to understand their vision of the world, agree that some, even dangerous places, might be used for temporary uses only under their own responsibility and that the evacuation places were selected by them among a set of choices identified with our maps. In some cases many meetings were done, to try to clarify to the governors of the Cabildos that we were not taking advantage of the situation to help to destroy their culture, and that after more formal-detailed studies were done, starting right after coping with the emergency, the return or at least the preservation of their lands will be guaranteed.

The reconstruction phase have to consider all these complexity, and as a fact the Government created a special Institution, with indian name, called Corporation Nasa-Kiwe with an open and what seems to be following truly multicultural bases.

RISK SITUATION AND PROPOSALS

Considering the risk as the product between hazard and vulnerability, and remembering the lack of input parameters found to make a precise hazard assessment, is also worth commenting about it.

The risk is only assessed properly when its two components are defined. It is worth remembering the overall location of our country in a region where interacts the South American, Caribbean and Nazca plates, in a tropical mountainous environment with all sorts of associated geodynamic events (Forero-Dueñas, 1992), and having in mind the scenario coming from the inland active faults (Paris and Romero, 1994), the situation seemed to be complicated. And it is worst, given the fact that we did not have identified yet all the input parameters that requires a proper seismic hazard assessment. Of course that we already started doing it, and projects as the NSN, the National Acelerographs Network, NAN, and the Seismic Zonation of Bogotá, lead by Ingeominas are going to give us a clue about our real state of hazards and the right design spectra to ensure the physical stability of the structures.

However, today we have a vulnerable situation by definition in most of our Andean zone, because if we do not know who is the enemy (hazard) how could we might be able to fight properly against him (vulnerability reduction). And in our Andean region is settled most of the population and infrastructure of the country.

The Paez earthquake is the evidence that the seismic risk is a hand grenade that is able to exploit at any time in any place. The huge costs associated with the recovery actions are the testimony of how vulnerable we are. However, with the creation of the new Ministry of the Environment and the associated Regional Autonomous Corporations, RAC, and the economic reinforcement of the local governments, is now worth carrying out steps such as :

- Establish a definite educational campaign, starting with children, to try to have a basic knowledge of the earth activity and the geodynamic events among the population. If our present generation of adults is not able to be educated, the coming ones will. This single geoscientific layer might be a key to undertake properly any disaster-related action (prevention, emergency, recovery), having a common language to talk about.
- Establish-reinforce local seismological networks, as complement of the NSN and NAN, which are more interested in high magnitude events. To do that properly, it is possible to agree between one or more RAC, and the involved towns, the definition of Areas of Intensified Seismic Observation, AISO. Criterion to define them might be: areas that have had a large earthquake in the past, areas with active faults, areas with permanent seismicity, strategic areas with socioeconomic- ecological great relevance, and so on.
- When necessary, with the same institutional actors-sponsors, in the most populated or valuable areas, to define at least few model basins, MB, to prevent them against possible effects associated with earthquakes. That includes the aseismic structural designs, and the generation of high-order hazards such as landslides, dams and avalanches. In this MB might be applied model techniques of land-use and a general high level of countermeasures and cultural understanding against hazards, as a mean to lower the vulnerability. The example of the MB might be contagious, serving as a guide to adjacent ones. The initial costs will be compensated at the end; the control of our disaster situations have been found to be extremely expensive being worth

putting money in preventive stages.

At the National Level, Ingeominas can carry out the reinforcement of the NSN, NAN, neotectonic and microzoning projects, instructing and assessing regional technical groups, and act as an overall manager of all the data compiled at regional levels. The strategy intended to help in reducing the national seismic risk, as a primary goal, by :

- Proper quantification of seismic hazard, producing a suitable seismotectonic model of the country, considering elements as anisotropy in the seismic waves propagation, and the role and relative influence of regional and local faulting systems in our seismicity.
- Helping in lowering the Vulnerability with suggesting right acceleration design spectra, giving appropriate acceleration attenuation equations, studying local effects associated with topography and soils. Also with educational campaigns to regional bodies is possible to spread the knowledge and lower the uncertainty on the subject.
- To have as a secondary product of all the seismologic and field work, an strategy to earthquake prediction. Given the associated uncertainties it is not worth having it as a very primary flag, but with the use of all the collected data, we might be able to start some prediction stages in the future. As example, a programme of geophysical measurements might be a good complement to the instrumental data, as a well as a regular study of ground deformations. The analysis of seismological precursors such as : foreshocks, anomalous activity, seismic gap of the second kind, source analysis, and migration of microearthquakes, are among the parameters to study to our own seismic setting with all the collected information at regional and national levels.
- To carry on the researching on the geotechnical static and dynamic behaviour of our own soils. We have cases of unusual response in materials with very particular structure-fabric, originated in the climatic-environmental conditions of the Equatorial zone. Joint projects can be carried out with Universities and the RAC.
- To be aware of our role as conductors in great extent of the Vulnerability conditions of the population. Besides the emergency vulnerability, that might be understood more as a physical one, we as geoscientistics also are capable in reducing the pre-disaster and post-disaster vulnerability. That may be done spreading a sense of presence among the population, explaining what is all about geohazards, suggesting countermeasures and drawing scenarios of action in case of a disaster.
- Include in an explicit way the cultural analysis of the regions where we are going to develop our applied projects. This is valid not only to the disaster situations but for common studies. In that way, the geoscientifics might be giving a positive impulse to the social sciences, with a continuous research that will not be restricted to study behavioural changes during crisis. All this broad vision of the geosciences, are part of the Ecological Geosciences (Forero-Dueñas and Booth, 1995).

CONCLUSIONS

Among the main elements coming from this experience are :

- The physical and cultural complexity of the Paez basin help us to remind: complex emergency situations are better solved by well trained experienced teams; the methodology of zoning have been found to be useful and easy to catch up by the final users and the people; the way of understanding nature might affect evacuation procedures, being necessary to reach common decisions involving the affected population.

- The Paez earthquake hit in a violent way a basin with low population density, but if the same happened in a well populated one, the generated disaster might reach huge proportions. We are vulnerable in the Andean region.
- Cultural elements are part of any applied geoscientific evaluation, not only in disaster situations, if is intended to use it with the maximum benefit for the population.
- Among the suggested steps to reduce the seismic risk and its associated events, a combination of hazard understanding, reduction of vulnerability and preventive countermeasures are the strategy to follow. Neotectonic and geological studies, geomechanical modeling of our soils and rocks in static and dynamic conditions, effects associated with topography and local deposits, local seismic networks, areas of intensified observation, model basins of special management, and the beginning of prediction stages are suggested.
- To reduce the vulnerability, is possible to work in the traditional physical aspects, but playing also an educational , preventive and supporting role in pre and post-crisis scenarios.

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Also the use of the facilities of the Imperial College of Science (Centre for Geological Engineering) and the enthusiasm and advice of Liliana Sandoval-Huertas are gratefully acknowledged. As a part of a national campaign of some of the Colombian Students Abroad, I would like to state that I AM PROUD TO BE COLOMBIAN. land of work, future and hope.

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THE INSTITUTION OF CIVIL ENGINEERS

The observational method *in* geotechnical engineering

Thomas Telford

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Introduction

In the December 1994 edition of Géotechnique eleven papers were published on the observational method. These papers have been reproduced in this publication, together with a report from the meeting held on 11 January 1995 at the Institution of Civil Engineers. In addition, this publication contains 14 contributions to the discussion on the observational method. A summary section, drawing together the points raised at the meeting and suggesting 'the way forward' for the observational method has also been written.

The Rankine Lecture by R. B. Peck in 1969 forms the basis for the observational method and is referred to by most of the papers in this publication. Peck sets out a procedure for this method. However, over the years this procedure has often been modified or redefined. For completeness, a copy of Peck's original Rankine lecture is included as an Appendix to this publication.

Duncan Nicholson

needs clients, consultants and contractors who understand the method and appreciate the risk/benefit issues and who are prepared to work together. It needs professional and careful control throughout the process.

For the method to be adopted by a contract, I think the best options are when the contractual arrangements include

(*a*) a design and construct lump sum contract
(*b*) a traditional contract with a value engineering clause, which enables the client to achieve a lump sum saving and the contractor to receive recognition of the risk of providing a lump sum within the value of that lump sum
(*c*) a target cost contract.

In all cases I see the best future for the use of the observational method, which is often closely related to other activities in the project, when it is initiated by the contractor or at least includes the contractor in a contractual environment in which all parties have an interest in its success and when it incorporates flexible and efficient mechanisms for change.

C. A. Forero-Dueñas, *Research Student, Imperial College of Science*

The observational method (Peck, 1969) provides a different design approach by following steps that can satisfy client needs and successfully finish a project. But from the engineering point of view, what does the successful finishing of a project mean, and what else can we obtain from this method?

Engineering and science

Let's remind ourselves of a well known classical definition of engineering (Red, 1982): 'it is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience and practice is applied with judgment to develop ways to utilize, economically and with concern for the environment and society, the materials and forces of nature for the benefit of mankind'. However, some people see this sort of approach as a cliché, and in a profession with great diversity in its work activities the best way to remember the basic values is by going back to the sources.

Science (Parkes, 1961) is not just a mass of empirical knowledge gained by observation and experiment, but is an organized body of facts which have been incorporated and generalized into a system. When the observed facts have been properly codified and are systematically summarized and interpreted then it is possible to speak about scientific knowledge.

On the other hand, as a consequence of the many factors that produce stereotypes, people see engineers as those who do the hard work, using existing knowledge to make something happen (Perruci & Gerstl, 1969). However, scientists and engineers should not necessarily be seen as different sorts of creatures; the actual academic formation of engineers presents the profession as a science-based activity concerned with understanding nature as well as with the improvement of theories and the continual evolution of science.

Following the scientific method

To progress in the understanding of nature (Marion & Hornyak, 1982 and Moran *et al.*, 1986) it is proper to support conclusions on the results of observations and experiments, analysed with the logic and reason, of the Scientific Method. The observational method is part of the engineers attempt to understand the nature and representation of the Scientific Method, i.e. to emphasize the relevance of measurement when dealing with real problems.

In describing nature we use concepts and theories to explain the behavior linking concepts with observed phenomena to produce models and laws representing real situations. The rules of the game are: observation, experiment, analysis, prediction and verification (Marion & Hornyak, 1982; Moran *et al.*, 1986; Schofield, 1982). Science grows through refining theories and revealing links between them as new insights are developed (Marion & Hornyak, 1982).

Solving engineering problems is very important to society and worth following, but we can go further: with the systematic and organized application of the observational method and the insistence on the complete rules of the Scientific Method, as the strategy to take advantage of all the knowledge involved. Otherwise in some cases we would be acting in a way similar to our engineering ancestors, who built marvellous masterpieces but mainly with trial and error, achieving their projects by means of experience and intuition, while constrained by aspects such as the primitive knowledge of mathematics and sciences, and the lack of written documents containing the experiences and knowledge of others (Red, 1982).

Conclusions and suggestions

Under the former framework, the observational method can be seen as a medium towards the complete incorporation of the Scientific Method in geotechnics, with a feedback objective of multiple analysis and predictions that can be compared and verified leading to new theories supported by evidence, and forming part of a truly scientific knowledge. It is also clear that the observational method has limitations and drawbacks (Peck, 1969), but when choosing this way of work we must try to maximize all possible profits.

This active analytical approach will be helpful to bridge links between the sciences of soil and rock mechanics, the art of subsurface engineering (Peck, 1962) and geology, to produce a main body that is the geotechnics. Geotechnical engineering as well as geotechnical geology are the basic framework of a field that can also get its information from many other auxiliary sciences, such as in modelling and the solving of complex problems involving earthen materials and processes.

This conception should be explained to the client, with two basic headers: I will solve your problem (with quality, economy, safety and so on), and, as a scientist, the data obtained will help me and others to form a better understanding of nature. To this end perhaps it would be useful to clarify our position as engineers to the media.

Finally, perhaps the Institution of Civil Engineers could coordinate a Catching Data Centre with regards to the observational method. The data it receives from its applications from all over the world could be distributed to research centres and universities, to facilitate the development of our theories under the parameters of the science.

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Modelling geodynamic environments: The Colombian experience

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ABSTRACT : A summary of the main physical features of Colombia is shown, including regional geology and tectonics, together with the natural hazards that the country faces. The current legislation on the subject is presented as well as some local cultural elements that affects its fully accomplishment. Together with the reinforcement of technical and researching capabilities, a strategy is proposed to participate as Geoscientists and Citizens in creating a common link in a plural society in construction, by spreading the interest on environmental subjects from childhood. Some of the operative aspects of the proposals and the philosophical support of the suggested actions are also included.

1. INTRODUCTION

Colombia is a country submerged in a quite active environment, and is learning how to cope with it. Being the environment in a broad sense " that what surrounds ", this paper considers the role of the Geoscientists in helping to fulfil that necessity, in a country with all sorts of geohazards but also in communities with complex socio-economical conflicts in a nation in construction.

The applied strategies in fulfilling with this goal are summarized together with suggestions to improve the way in which the Colombians may survive to the environmental dynamics.

2. PHYSICAL ENVIRONMENT

2.1 Regions of the Country

Colombia located in the Northwestern corner of South America, is a country with contrasting physical features:

The southern and eastern parts of the country, about one half of the total area, have low densities of population, and correspond to the Colombian Amazonia and the Orinoquia Flatlands, respectively. Those areas comprises a belt region located at the eastern side of the Eastern Cordillera (Cordillera Oriental) that contains huge oilfields such as Caño Limón, Cusiana - Cupiagua oil complex (with reserves of about 2 billion barrels of oil), and the newly discovered Coporo oil field (with reserves of about 1 billion barrels). On the other hand, the majority of the population of the country live in the Andean Zone, with a quite different topography, inserted into the three local branches of the SouthAmerican Andes, known as Western, Central and Eastern Cordilleras; in this area are located the finest coffee crops of the world, being also the main cities of the country (Bogotá, Cali and Medellín) and the heart of the industrial activities.

In the West, nearby the Pacific Ocean, is placed the Pacific zone, with average rainfalls greater than 4000 mm/year, and some areas with up to 9000 mm/year.

At the North is located the Caribbean Zone, also having a proportion of the country population and the economy, and comprising the lower valleys and the flooding deltas of some of the most important river systems of the country (Magdalena, Cauca, Sinú, San Jorge and Cesar). There are also insular territories with some islands in both Pacific and Atlantic oceans.

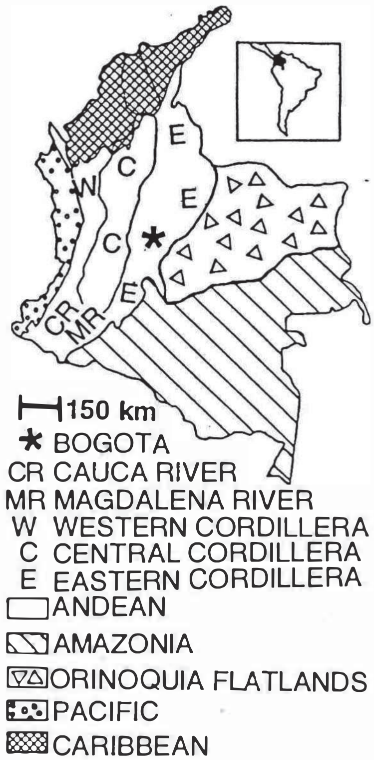

Fig. 1. Colombian Physical Regions

The different inland geomorphologic regions (Amazonia, Andean, Caribbean, Orinoquia flatlands and Pacific) reflex the complexity of the geologic and tectonic setting of the country (INGEOMINAS, 1988), and are presented in the figure 1.

2.2 Regional Geology and Tectonics

Kellogg and Vega (1995) summarize the different geologic studies of the three main Cordilleras, as follows : the Western Cordillera as part of a regional basic igneous complex (parts of Central and South America), including Cretaceous marine strata, ultramafic rocks, tholeiitic basalts, andesites, and quartz diorite intrusives of the Tertiary.

The Central and Eastern Cordilleras include in their southern regions Quaternary andesitic volcanic deposits covering Precambrian migmatites and Paleozoic metamorphics; in very general terms the Central Cordillera is regarded as Igneous-Metaphorphic and the Eastern as having sedimentary materials, with Cretaceous rocks of marine origin (INGEOMINAS, 1988), but also having igneous and metamorphic rocks in the Macizo de Santander.

In the three Cordilleras, the combination of geodynamics, climate, materials, slopes, rainfalls, and river action have produced all sorts of deposits and thick sections of weathered layers and residual soils, with very complicated engineering properties.

The tectonics of the region has been under detailed study during at least the last 25 years, and there is an active area because of the junction and interaction of the Nazca, Caribbean and South America tectonic plates, plus other "micro" features identified as the "Panamá-Costa Rica microplate" by Kellogg and Vega (1995) using Global Positioning System measurements, as part of the Central and South America (CASA) project.

Inland the traces of the surrounding energy exchange are evident, expressed as: topographical features, volcanic groups with 14 active volcanoes located in the Western and Central Cordilleras being part of the "Pacific Fire Belt", and marks of ruptures with many active faults capable of being displaced under the present state of tectonic stresses, being the source of destructive earthquakes.

The Neotectonic Map of Colombia (Paris & Romero, INGEOMINAS, 1993) has compiled information of active faults belonging to regional tectonic belts such as : the East Andean Frontal Fault, the Romeral and Cauca System Fault, and the Santa Marta and Bucaramanga Faults.

3. NATURAL HAZARDS

The hazards inherent to the physical location of Colombia are complex and has been described elsewhere (Forero-Dueñas, 1992) and are summarized in the table No. 1.

Among the regional hazards, the Seismicity is a constant threat to the populated Andean regions and a trigger to other destructive events. The figure 2 shows the Seismic Hazard Zonation of the country (ASE,1995). Suggestions about ways in which this hazard may be understood and studied are found in Forero-Dueñas, 1996c.

An example of a geohazard study is presented in Forero-Dueñas & Caro-Peña, 1996, with

Table 1. Natural Hazards in Colombia

HAZARD	MAIN POSSIBLE EFFECTS
VOLCANIC	Cities of Pasto (Galeras Volcano) and Manizales (Nevado del Ruiz Volcano).
SEISMIC	Main populated centres, Andean Zone.
LANDSLIDES	Andean Zone, Quaternary deposits.
EROSION	Most of the country.
FLOODS	Seasonal in flooding deltas. Torrential avalanches.
SPECIAL-MATERIALS	Many regions with Soils and Rocks having particularly - damaging properties related to : volumetric changes, compressibility, strength, etc.
CLIMATIC	Regional phenomena such as "El Niño", etc.

special reference to landsliding, standing out a Hierarchical approach coming from regional big-scale features, and ending up with local solutions.

As is shown, the whole country is under the threat of one or a combination of natural hazards, with some regional variations in the intensity. However, the country is improving the quality of the related studies and the knowledge of the physical media, and there is now an overall interest on the subject, leaded by institutions such as INGEOMINAS, the National Institute of Geosciences, Mining and Chemistry.

4. ACTIONS AGAINST THE HAZARDS

After painful and world-wide known tragedies, the Country is changing slowly the attitude towards the subject of natural hazards and the environment.

The turning point was indeed the destruction of the town of Armero, in 1985. In 1988 the Government created the National System of Prevention and Disaster Awareness, as a general logistic manager of the subject.

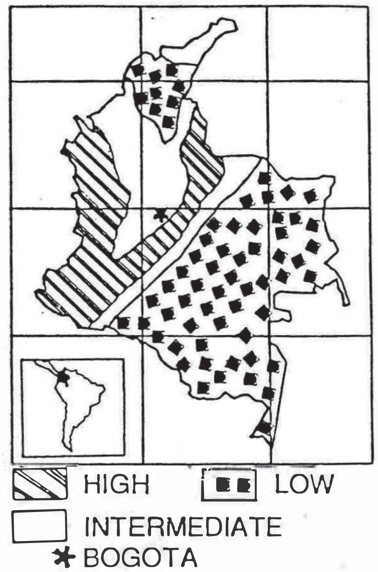

Fig. 2 Seismic Hazard in Colombia

The bulk of the technical studies in geohazards have been done by INGEOMINAS, though some other Institutes and consultants have collaborated. For every set of hazards in a given region, the goal is to make a zonation, defining safe and unsafe areas, and suggesting countermeasures.

INGEOMINAS, which is involved in multiple aspects of the knowledge of the earth, has also projects in the physical environment such as : ocurrence and forecasting of earthquakes and volcanic eruptions, evaluation of geological hazards and risks, seismic micro-zonation of urban centres, national seismologic and accelerographs networks, geoenvironmental evaluation and planning, and geotechnical behaviour of local soils and rocks, among others. As example of its role, the new version (1995) of the National Seismic-Resistant Constructions Code was produced having as main input hundreds of events and wave propagation characteristics, recorded for INGEOMINAS since 1990 with a modern satellite-operated seismologic network

In 1993, (by Law 99) was created the Environment Ministry, the public sector in charge of the environment and non-renewable natural resources management was reorganized, and the Environmental National System was organized.

The new structure of the so called Regional Autonomous Corporations, and the economic autonomy of the local administration in small towns, coming as consequence of our new Constitution (1991), have put a national interest on the subject of natural hazards and environment management.

The Law 99 of 1993 also defines the national environmental policy, under general principles which includes : sustainable development according to the Pact of Rio (June, 1992), protection of the country biodiversity, rights of the population to have a healthy and productive life in harmony with nature, definition of zones under special protection, human consumption as priority of use of hydric resources, the enhancement of the scientific research, landscape protection, disaster prevention as a matter of collective interest, and environmental protection and recovery as a multiple goal of : the Government, community, Non Governmental Organizations and the private sector.

The spirit of the Law 99 is intended to allow the community to participate in the actions and decisions with regards to the environment management. The Environment Ministry is after the conciliation between development and environmental conservation.

5. CULTURAL ELEMENTS

After near 180 years of independence from the Spanish, who arrived in 1492 and were expelled in 1819, Colombia is a nation still finding her own identity. The independent life of the nation has been marked by factors such as : the racial mixture, the richness of the natural resources, the natural hazards, the religion and multiple social conflicts arisen from the distribution of richness. The new Constitution of 1991, is the expression of a process of change still in progress.

The guerrilla warfare, appeared at the middle of this century, fighting against the official institutions, and a complex mixture of private forces and interests have generated a violence situation that produces victims every day. There is conflict in the country, and the search for a peace process in such conflictive environment is indeed a joint effort, in which all an every one of the citizens should contribute. A clear point is that the way in which we solve our internal troubles has to be with our own views without imposed policies from outside.

The Geoscientifics, working in a vivid geoenvironment, are then trying to organize the land use, to promote a better use of the resources and identify the natural hazards in such a complex social context. The importance of taking into account the man in any environmental topic is pointed out by Kates (1978) with reference to "natural" events, that are indeed natural, but the threat potential for human kind and its works is by definition human phenomena. If the final goal of a technical evaluation is to care about the people, the situation deserves that we have to make an extra effort to understand the local cultural and socioeconomic features (see Forero-Dueñas & Booth, 1995 and Forero-Dueñas, 1996 b), otherwise our efforts would be putting another ingredient of disruption to areas which need quite the opposite: to act rationally.

6. ANALYSIS OF FUTURE STRATEGIES

6.1 Proposals

From the scientific viewpoint, the needs of carry on with the research strengthening is obvious, and the multidisciplinary evaluation of the complex setting of the Country has to be continued with projects for each kind of hazard present. On the other hand, postgraduate training projects such as those coming from COLCIENCIAS, the Colombian Institute for the Development of Science and Technology, have to be continued and enlarged; each technical institution involved (as happens with INGEOMINAS) has short, medium and long term training programs that have to be consolidated. The technical, as opposite to the political, management of those organizations is an ideal that one day might be reached.

The country, as was already shown, has a good number of laws, decrees and regulations, so that if all of them were executed, almost everything should be working with a fresh sense of community participation under equitable and fair rules, in benefit of the Country development. However, an air of incredulity is also part of our national character, as a result of past experiences and the lack of clear short time social solutions. Several examples of the influences from power elites and unfairness in the treatment of almost everything are elements affecting the confidence of the general public on the official institutions.

What to do, as geoscientifics and citizens, to help in the situation ?. First of all is to accept the challenge, and go beyond "simple" technical matters. This is of course a controversial subject, but the local circumstances deserve that the scientifics also become engaged and contribute somehow. Let's approach the general public, and contribute to what might be called a Common Layer of Understanding, spreading in simple terms the interest for the study of environmental issues, geohazards and natural resources conservation.

The idea is simple : the real country, as opposite to the one of decrees, lacks of a common ideal and unity, that is indeed affecting the speed of overall development, so let's inject to our population, from childhood, the common language of the natural resources management. The idea is sane, as is a real need for any community, and goes beyond the physical reality if reaches, in the medium and long term, objectives of spread a sense of friendship and nationalism that helps the country to reach a dialogue channel and find her path afterwards.

6.2 Some Operative Aspects

The strategy proposed of a definite environmental education requires the participation of all the National Environmental System, Education Ministry, the Disaster Prevention Organization, the Media, and the population. Neither is a simple nor a short term matter, and requires to break complex historical barriers. The introduction of new values, in a process of Acculturation, may rise to some initial cultural conflicts and to adaptation leading to a modification of group identity (Duncan-Mitchell, 1979).

The spreading of the environmental layer should consider the different cultures, ethnic groups and world visions and goals of the different parts of the Colombian plural society. Specific "manuals" and definitions of terms should be produced to minimize cultural conflicts, but without lost the basic general idea of common environmental awareness with long-term objectives of national unity.

In the future, the cultural spreading, starting in childhood, will cover today's recognized biases in the people's assessments of geohazards and environmental risks. Among these biases, generated by the man's mental techniques of handling information, the style of the media covering and the ignorance, are (Tversky & Kahneman, 1973, 1974; Broadbent, 1985) :

- "Availability" bias : assigning higher probabilities to those occurrences which can most easily be brought to mind, according to past experience.
- "Anchoring" bias : an initial idea affecting the whole process of assessment; the order of consideration of alternatives affects the overall judgement.
- "Representativeness" bias : originated from the lack of knowledge about "background" information.

6.3 Philosophical Bases

The French sociologist Emile Durkheim used the term "anomie", to refer to several aspects of social participation where the conditions necessary for man to fulfil himself and to attain happiness were not present (Duncan-Mitchell, 1979); conflicting conditions where the individual had no morally significant relations with others, was a state of anomie. Probably the country is an example of that condition, where the norms go in one direction and the people's goals go in other.

The idea is produce a Colombian-Consciousness where the plain individual become increasingly aware of his position, acquiring a national cohesion in the face of the country problems. The situation deserves a National Consensus in the sense of produce, in the medium-term, a state of constructive agreement and harmonious collaboration in the population about the country's improvement.

John Locke in 1690 presents a theory of property in which man has a right to that part of nature with which he has mixed his labour, and "no man's labour could subdue or appropriate all", in a general agreement to respect to such rights in a "Social Contract"; J.J. Rousseau in 1762 argued that sovereignty resides in the community for there is in every man's will an element which stands for the good of the whole (Duncan-Mitchel, 1979). The Colombian situation might be deserving such a general agreement, but requires the participation of all an every one to create a society in which individuals are bound to one another by common commitments, avoiding the persistent social and economic segregation that generates rage.

The human "needs" analysis, other way to see the scope of the proposals, has been categorized by Maslow (in Risk and Rationality, 1980) in a strict ascending order as follows: starting with basic food, warmth and shelter, following by safety needs, then arriving to social needs as need for belongingness and esteem and finally reaching to self-actualization. Rowe (1977) has modified that hierarchy adding more categories (in the base he locates "value of life", in the middle "need for control over money", and in the top he adds "value of life quality").

It is then a model of ascending steps in a "need hierarchy" scheme that has been criticized (Risk and Rationality, 1980) as is argued that if you rush into one of the upper steps you can break all the scheme shortening the process. The suggestion of communicate across the interest on environmental -geoscientific matters agrees with it, so that if you propagate a feeling of belongingness to the population, across a common language and a sense of participation and mutual interests, you can then create a climate of unity and start creating the cultural conditions so that the everyone's needs might be fulfilled.

To diffuse this layer of unity, spreading a link between a plural society and the different national groups and regions, looks then for a National Evolution that might imply change, order and progress.

7. CONCLUSIONS

- Colombia is a country affected by all sorts of natural hazards, and being a dynamic society in construction, the cultural aspects must be also part of any environmental matter.
- The technical studies usually deserve a hierarchical approach starting from regional frames and ending up with detailed solutions. The cultural matters usually goes in the other direction, and to construct a country you should consider first individuals and groups and the ways to integrate them with a common dialogue.
- Given the particular circumstances of the country, a strategy is proposed in which the Geosciences and Environmental Sciences in general, may be playing a Social Function to create and maintain a group solidarity, a kinship sense, between the Colombians.

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As a part of a national campaign of some of the Colombian Students Abroad, we would like to state that WE ARE PROUD TO BE COLOMBIANS, land of work, future and hope.

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SHEAR MODULUS-TIME VARIATIONS OF A SILICA GEL

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As a main indicator of the ability of wet silica gels to sustain shear stresses, the shear modulus, G_{max}, of a sodium silicate gel was measured, in conditions of no evaporation and constant humidity and temperature. The transition from a sol to a gel was followed in a Pulse Shearometer, measuring values of the shear wave velocities. The gelation time was defined using simple geometrical constructions in the G_{max}-time curves. Alternative methods for defining such times are also described which use a precision balance, a rheometer and a thermocouple to follow gelation. The results have considerable importance modelling in engineering geology.

Keywords: sol, gel, gelation, low strains shear modulus, engineering geology.

INTRODUCTION

Amorphous silica gels are found in natural sediments and rocks, but very little is known about the extent of their Geotechnical role [1]. This paper describes some of the results of a research project in which the working hypothesis is that: silica, in the form of a colloidal material, i.e. an amorphous silica gel, may influence the geotechnical behaviour of soils and rocks in which they reside, providing them with properties that could respond dramatically to environmental changes, as many real rocks and sediments indeed do. The research attempts to present a systematic study of aspects of the subject.

The gels were produced in the laboratory using mixtures of sodium silicate solution. The polymerisation reaction involves the condensation of silanol, SiOH groups, to form siloxane, Si-O-Si bonds. The change from a liquid-like condition (a sol) to a semi-solid gel occurs when the siloxane bonds appear and extend sufficiently to form a load - carrying network.

A key factor in the ability of a gel system to start sustaining stress is the sol - gel transition. The study of this process has been achieved by different techniques, including the use of a Pulse Shearometer, to register the maximum shear modulii, G_{max}; the use of drying curves with a precision balance and a chronometer; the use of a Bohlin Rheometer to measure the changes of viscosity with time, and finally, the use of temperature changes that occur in the formation of these gels.

The research also includes complementary results and analysis concerning the rheological, and drying behaviour, of such systems. Some further aspects of this study are presented in accompanying papers [2&3].

GELATION

A gel is a form of matter which lies between a solid and a fluid. Among the different and rather diffuse definitions available, Almdal et al [4] (1993) say "a gel is a soft, solid - like material of two or more components, one of which is a liquid and is present in a substantial quantity". The definitions also specify the idea that a gel consists of colloidal seized (1 to 1000 nm), continuous three dimensional structures surrounded by liquid (often water), and that on a nanoscopic scale it is possible to follow a path through the solid phase from one boundary of the gel to the other, without leaving a continuous route. Gelation is the process in which this continuous structure is formed, changing from a sol, to a semi - solid gel.

Mechanically, the sol behaves as a conventional liquid, but the gel can resist shear stresses even though the gel is neither a conventional solid nor a conventional liquid. Under appropriate environmental conditions, the monomers of silicic acid enter into a polymerisation reaction. The result is that the oxygen bridges to other silicon atoms to form a siloxane (Si-O-Si) link, and as polymerisation progresses the system eventually reaches the sol-gel transition and a gel of silica is finally formed.

The so called Gelation Point or Gelation Time, tg, when the sol - gel transition is defined to have occurred, is the time when a recognisable elastic response occurs or the moment at which a sudden change in viscosity occurs, due to the fact that the material is no longer a pure liquid. Such changes in the mechanical properties have been used to help the identification of tg in a systematic way.

Percolation models can be used to represent gelation. These represent probabilistically the random Si-O-Si bond formation within the gel. The gel is modelled with a fixed lattice within which bonding develops and the gelation is said to occur at the percolation point, when a long-range connectivity suddenly appears [5,6&7]. Scaling relations in this theory include characteristic exponents; that for the elastic modulus varies from 1.65 to 2.6, and that for viscosity varies from 0.7 to 0.8, and such ranges are predicted for 3D percolation, as function of the degree of the chemical reaction [5]. For the tested gels such exponents are going to be presented in a following section.

THE APPROACH

In geomechanics there has been little research interest in the geotechnics of silica gels, and the practice of site investigation usually describes the recovered cores as having solid or liquid phases only. The reason for this is a mixture of both the engineering tradition and technical difficulty, for the fact is that gels, when present, are not easily recognised by the naked eye, unless they are massive, or even by traditional mineralogical or chemical analyses.

In geology and geotechnics there are references about the existence of silica gels, and among those Mitchell & Solymar [1] (1984) , and Butenuth et al [8] (1995) suggest for some specific geological settings a connection between gel properties and the geomechanical response in the field of the materials involved. The traditional study of silicates in geotechnical engineering has been connected with ground improvement techniques [9]. For that traditional usage, some of the techniques and results presented here to characterise silica gels can also be useful, but as already explained, this paper presents a quite different philosophy based mainly on the novel approach of Butenuth, de Freitas and Forero-Dueñas (in Butenuth et al. [8]), that the gels can be present naturally in the ground.

Rock and sediment can be represented as a "mechanical mixture", a composite, made up by some solid "hard" components (i.e. sand or silt sized mineral grains), held together by the action of a cementing agent, a silica-gel. Thus a given mechanical property of the total mixture is provided by the contribution of the solid plus the contribution of the gel. The sol-gel transition will help to clarify the possible role of "wet" gels in the mechanics of such composite geomaterials.

Forero-Dueñas, [10], describes a case in which an earthquake makes the materials of the Paez River basin, in Colombia, change from being stable and rock-like so as to behave as a fluid- like material so permitting the development of a catastrophic debris flow, and then after changing so as, to behave as a stable material again; such materials are located nearby the Nevado del Huila volcano and probably contain amorphous silica from volcanic inputs.

In that case, on June 5th 1994, the day before the earthquake, the geomorphology of the Paez River basin already showed physical characteristics of an active geoenvironment:

rounded slopes with scars of past landsliding, and river valleys containing the debris from such mass movements which itself had been incised by high energy events (debris flows and floods). As a consequence new flood plain deposits form the record of a recurrent instability, enhanced by environmental triggers such as high rainfall and the seismic activity of the region.

The day of the earthquake the apparently stable deposits changed, in a rather sudden way, after an earth shaking of a few seconds, from being apparently stable to a viscous-like material. However what was most surprising was that then, after flowing, the material started to regain its strength even supporting vertical slopes. Can this be an indication that the material was changing from a sol to a gel again, in a sort of natural in-situ cycle?. It is possible that the mechanism of strengthening due to drying is contributing, as shown by Forero-Dueñas et al [3]. Conlon [11] describes a similar approach (cohesion plus friction forming the overall strength) studying a landslide in a Canadian clay.

EXPERIMENTAL RESULTS AND DISCUSSION

Silica gels were produced in the laboratory using the following mixture : 10 cm^3 of sodium silicate solution, with a silica/alkali ratio by weight, of 1:3.375; a ratio of distilled water to sodium silicate solution by volume, of 7.5:1; and 27 cm^3 of hydrochloric acid (1 mole / litre) dropped at a rate of 1.5 cm^3 per minute.

Such a combination yielded a silica gel in about five minutes, having an almost neutral pH, far from the alkaline or acidic extremes, as required. The reasons for that requirement are related to the fact that the solubility of amorphous silica can be assumed constant (about 120 ppm SiO_2) at pH values below about 9 [12]; but at higher pH's, the solubility increases rather abruptly. In addition it was necessary to model the behaviour of gels that may form in pH values similar to those most commonly found in the ground.

A pulse shearometer (Rank Brothers, Cambridge, UK) operating at a shear wave frequency of around 200 Hz. was the main testing device. This equipment, shown schematically in Figure 3, was used to measure the shear modulus, G_{max}, at low shear strain levels, by propagating a shear wave in a sample of known dimensions.

It is a non-destructive technique, which has the great advantage of allowing consecutive tests on the same sample, to be run under exactly the same environmental conditions.

The values of the shear wave velocities, V_s, were recorded in the sol and gel states. By applying elastic theory, and measuring the density, ρ, with a Paar Density meter (resolution of 0.0001 g/cm^3), curves of the shear modulus, G_{max}, against elapsed time were produced. The measured typical value for the density of the tested silica gel was ρ= 1.031 g/cm^3.

The moduli is taken as equal to the square of the shear wave velocity times the density, as shown in Equation 1. These data are used as an indicator of the ability of the material to sustain shear stress. The measurements described were performed under truly controlled environmental conditions, in a closed vessel under conditions of no evaporation and constant temperature, and relative humidity. The temperature is controlled by connecting the shearometer chamber to a constant temperature water circulating system.

$$G_{max} = V_s^2 * \rho \quad (1)$$

As is shown in the upper part of Figure 1, a plot for 30°C, the sol stage is characterised by near zero values of G_{max} confirming that the sol behaves as a conventional liquid. As polymerisation continues the first values of G_{max} are noted and this may be taken as the first indication that a material with the mechanical properties of a gel has formed: with time this extends through the tested volume as the network of Si-O-Si bonds that constitutes the strength provider of the gel is developed.

After a given period, the shear modulii, $G_{max,}$ oscillates somewhat and then follows a fairly constant plateau value, that for some samples was followed for several months without any appreciable decay. At 30°C, typical values of G_{max} for the "wet" gel used are around G_{max} 15.3 kPa, obtained at times around 1.5 h. after the addition of the last drop of HCl, 1 mole/litre.

The start of the sol-gel transition was observed in detail, and a gelation time, tg, was defined by using the method shown in the lower part of Figure 1. This Figure highlights the first readings presented already in the upper part of Figure 1, and by using a simple geometrical construction tg is defined. Typical values of such time for the gel used are tg= 0.082 h or about 4.92 minutes.

COMPLEMENTARY TESTS

DRYING CURVES METHOD

As complementary tests, drying curves, temperature changes and viscosity changes were followed to monitor the sol-gel transition. For the drying curves, a Sartorious analytical balance connected to a computer was used; such a balance has a resolution of 10 μg., and includes a cylindrical weighing chamber with motorised doors. The data of weight changes for different times was recorded for samples of about 7.5 cm^3, poured on a Pyrex circular dish (diameter 5.6 cm, height 1.3 cm) while still liquid and allowed to set (sol-gel transition) while registering the drying.

Figure 2 presents an enlargement of the first section of one of the curves obtained from a series of tests, in which the weight loss was recorded as a function of time. In this case, the plots are presented in terms of the Normalised Mass Loss, NML. The Figure presents a simple geometrical construction to define the gelation time, tg, as the time about which the slope changes. This method was very useful, because the drying mechanisms of the material started to be clarified and also because a different way to predict the sol - gel transition was produced.

Before tg, the rate of drying is higher than after that time, as may happen when a liquid (a sol) is being dried compared to the slower drying rate of a semi - solid (a gel). This is a new method of defining gelation time, and enables drying behaviour to be related with rheology. Note that the times are similar to the ones obtained by means of G_{max} readings; in the shearometer the temperature was some degrees higher than the laboratory conditions surrounding the precision balance yielding a faster sol-gel transition.

TEMPERATURE CHANGE METHOD

A series of tests were performed recording the temperature changes that occurred while dropping the prepared solution of hydrochloric acid over the mixture of sodium silicate solution and distilled water. To do so, the tip of a thermocouple (Fluke - 52, resolution of 2 decimal places in °C) was immersed in the material, recording the temperature changes.

One of the results is illustrated in Figure 3. It shows that there is a net increase of temperature of about 1 degree, and that the gelation occurs in two stages. The first phase corresponds to an exothermic process in which the temperature rises; such a process starts from the beginning of the dropping of acid, reaches a maximum in about five minutes before the final dropping of acid, followed then by a plateau that marks the end of this phase. After that, the temperature starts falling about five minutes after the final drop of acid was introduced. This coincides with what has been identified as the gelation time, tg, both with the G_{max} and with the drying curves. The Figure also shows how the gelation time, tg, for silica gel may be estimated.

The second phase starts as soon as the temperature decreases towards its original level, which may coincide with the polymerisation sequence of monosilicic acid "monomers" that follows the initiation of gelation. Such an interpretation agrees with that proposed by Caron[13].

VISCOSITY CHANGE METHOD

As explained before, the theory describing the transition of a sol to a gel predicts a dramatic change in the viscosity at the transition from a liquid to a semi - solid. Following such arguments, a series of tests were performed using a Bohlin Rheometer, in which a non - contact motor applies a torque (stress) to a sample which is monitored by a measuring system; the resultant displacement is measured. A concentric cylinder (C-25) was used to hold the sample, and the test was run with a constant, fairly low, shear rate of $1.46\ s^{-1}$.

After several trials, it was found necessary to introduce 24 cm^3 of acid to the mixture used instead of the usual 27 cm^3, in order to obtain longer gelling time so as to allow the setting up of the experiment in the apparatus. For that reason, in this particular case the sol - gel transition occurred after about 27.5 minutes, but the interest was to demonstrate the significant change in the viscosity which occurs at the gelation point, and the gel system created by using such volume was considered to be similar to the formerly tested gels.

The results were successful, and the changes in apparent viscosity, η , were recorded as shown in Figure 4, highlighting the huge difference between a fluid - like sol, and a semi solid - like gel (where in fact the viscosity becomes "immeasurable large", according to the percolation theory).

To predict the changes of the different properties that occur during gelation, the percolation theory suggests Scaling Relations to model phenomena belonging to the same universality class [5,6&7]. The equations with the so called characteristic exponents, are in this case presented as a function of the time t, together with the gelation time tg, and have the next general form:

Shear modulus (Pa) $G_{max} \propto (t\text{-}tg)^p$ (2)

Viscosity (Pa.sec) $\eta \propto (tg\text{-}t)^{-k}$ (3)

The obtained values are near 1.5 for k and 1.2 for p (see Figures 4 and 5). Similar values of p and k were found using the percolation theory, by assuming that at the gelation time the critical degree of reaction was around 70%. The exponents obtained for this test are then below the lower value, for p, and over the upper value, for k, as predicted by 3D percolation [5], as a function of the bond fraction present.

These exponents are much closer to a percolation-like model than to the predictions from the classical Flory model where the exponents are fixed, being p=3 and k=0, both far from the experimental evidence. Consequently, for the silica gels used here the percolation model represents approximately the changes in the properties that occur at the gelation time:

$G_{max} \approx (t\text{-}tg)^{\wedge 1.2} * 11961.9$ (4)

$\eta \approx (tg\text{-}t)^{\wedge(-1.5)} * 0.08155$ (5)

CONCLUSIONS

The ability of wet silica gels of the type used here, to sustain shear stresses is proved. The sol stage was characterised by near zero values of G_{max} confirming that the sol behaves as a conventional liquid. When the first values of G_{max} is noted, the "gelation time", tg, is defined and the gel then extends through the tested volume. Such a structure is formed by a network of Si-O-Si bonds that constitutes the strength provider of the gel. It is only in the gel state that the sample can resist shear stresses, as is indicated by the finite G_{max}. After a given period of time, the shear modulii of wet gels climbed up to a maximum value and the plateau values in G_{max} seem to remained fairly constant, under a constant environment and no evaporation.

Complementary rheological tests, such as viscometry, have shown other characteristics of the sol-gel transition. In fact, at tg the viscosity of the silica gel suffers a dramatic increase indicating a sol/gel transition and the existence of a change from a liquid to a solid-like material.

The results show how, under a given set of environmental conditions, the tested gels preserved their ability to support shear stresses in such a "wet" state. They also show the dramatic differences in behaviour between a sol and a gel.

These data contribute to an understanding of the possible role of amorphous hydrated silica gel in the movement of earth materials. The percolation theory offers a suitable model to represent such a transition.

ACKNOWLEDGEMENTS

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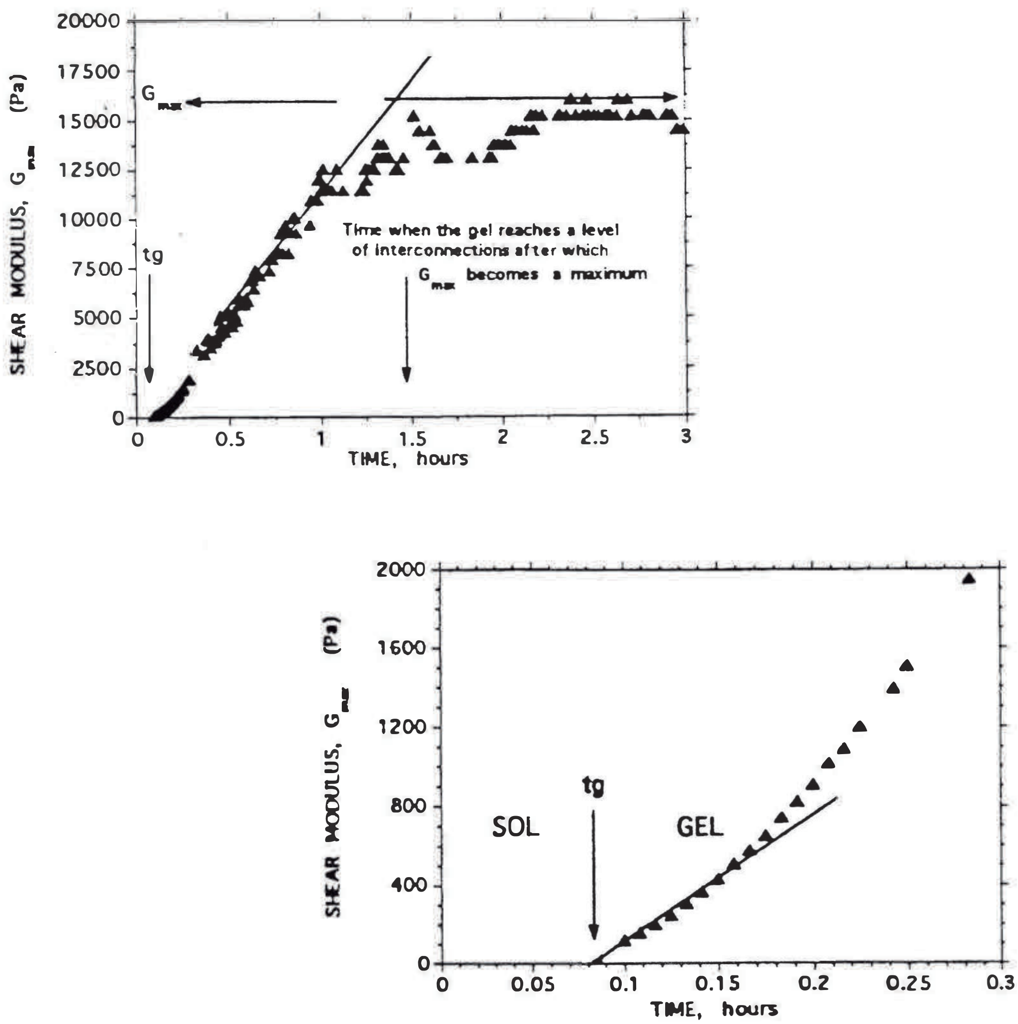

FIGURE 1. A typical shear modulus, G_{max}, time record for silica gel formation, at 30°C. In the lower part a detail from the first readings is shown. The extrapolation used for estimating tg is illustrated.

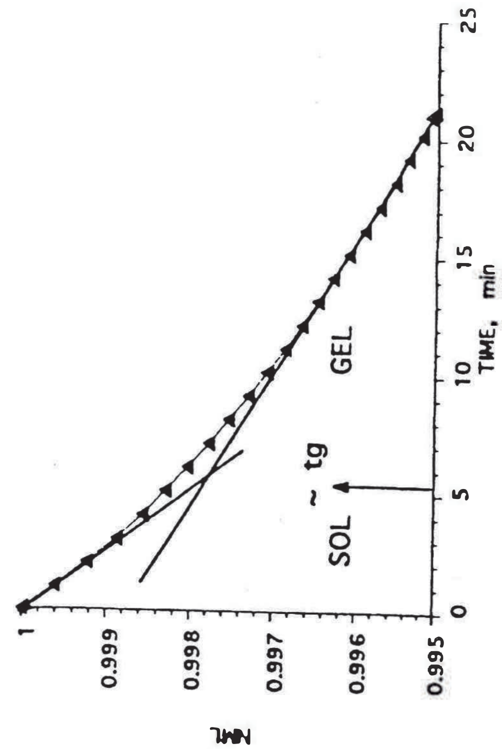

FIGURE 2. Normalised Mass Loss against elapsed time, at around 23°C. The approach for estimating the gelation time, tg, for the silica gel tested is shown.

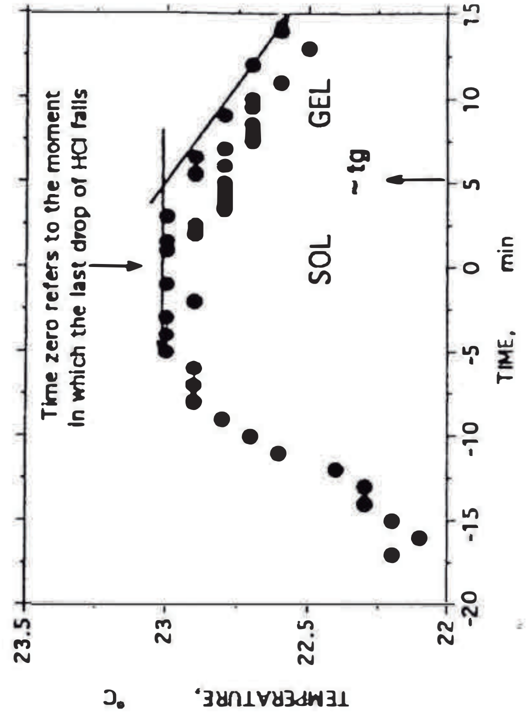

FIGURE 3. Temperature-time changes in the sol-gel transition. Another approximation for estimating tg for the tested silica gel is used.

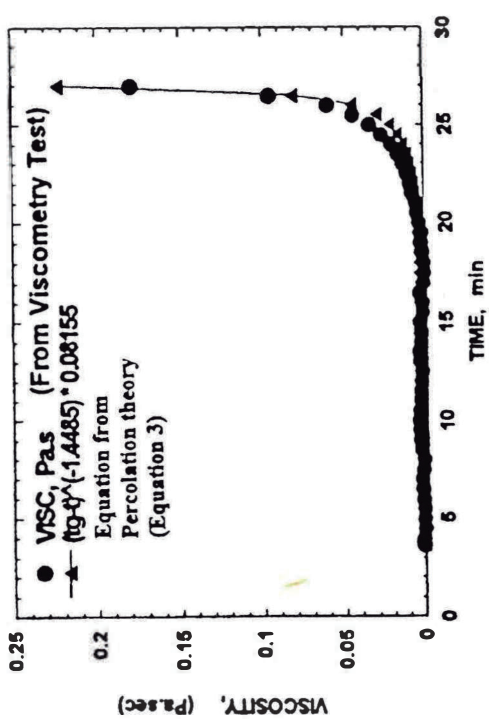

FIGURE 4. Viscosity-time data fitted to a percolation-like model, for the silica gel used.

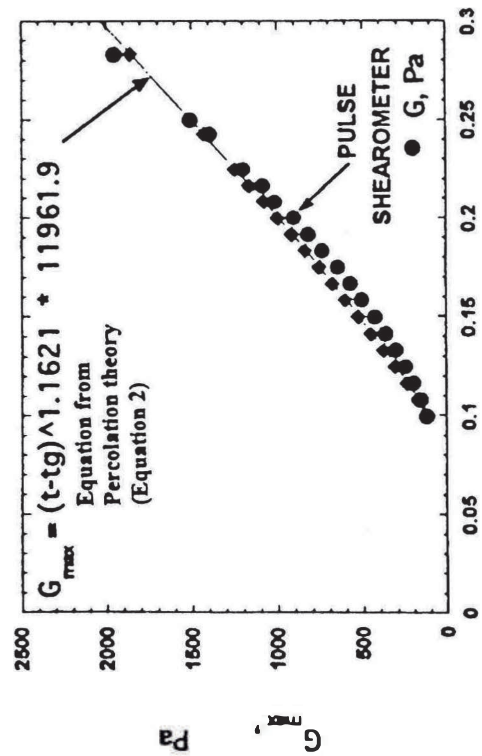

FIGURE 5. Shear Modulus, G_{max} - time data fitted to a percolation-like model, for the tested silica gel.

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INFLUENCE OF WATER CONTENT ON THE MECHANICAL PROPERTIES OF A SILICA-GEL

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The mechanical properties of silica gels having different water contents were studied by using elastic strain in uniaxial compression and hardness cone indentation. The results show how dramatically the strength of such a gel can vary as function of the moisture content. In compression, the values of initial tangent Young's modulus, E_o, can be as low as 0.0281 MPa for wet gels with about 95% weight of water and as high as 1.6108 MPa for samples with about 82.74 % weight of water fraction. A power law was found to approximately describe such variation. Similar trends were found with the cone indenter. The consequences for the modelling of the behaviour soils and rocks, where it is suggested that silica gels are present, are significant.

Keywords: gel, stress-strain modulus, stiffness, visco-elastic-plastic, engineering geology.

INTRODUCTION

In the field of Engineering Geology evidence shows that silicic acid gels can exist in some environments, such as those with inputs of active silica nearby volcanoes, which may act essentially as a provider of cohesive strength; a "cementing" agent. To establish the properties of such gels, a novel multidisciplinary research approach has been initiated. One key element in the observed behaviour of real soils and rocks is that moisture content variations induce considerable changes in the strength; for that reason the influence of this factor is the main issue in the characterisation of silica gels in the laboratory.

Silica is present in nature, both as deposits of silicate minerals (such as sands and clays) a weathering product, and by direct release from volcanic activity. The combination with water can produce monosilicic acid, $Si(OH)_4$. Under the correct combination of environmental conditions, the monomers of silicic acid, in the form of a sol, undergo polymerisation, with the condensation of silanol(SiOH) groups, so that oxygen bridges to other silicon atoms to form a siloxane (Si-O-Si) link. A polymerisation occurs, the sol-gel transition is reached and a gel of silica is finally formed. These gels may well follow all sorts of development according to their geological setting, and in some cases drying might occur, with consequences such as strengthening but also weakening by cracking. This paper presents a study of the effect of moisture on the mechanical properties of a silica gel. Accompanying papers demonstrate the ability of even "wet" weak gels, full of water, to sustain shear stresses[1] and the drying mechanisms of such materials [2].

In soil and rock mechanics it is important to appreciate the importance of the water content on strength. Barton [3], has shown that the uniaxial compressive and tensile strength of rocks (including sandstones, shales, gneisses, gabros, and amphibolites among others) can be reduced by half due to the effect of saturation. The basic hypothesis of this research is that silica gels may contribute to this effect. This has significant implications in the modelling of geomaterials in fields such as slope stability, foundations design, and in all the aspects related with the use of soils and rocks as an engineering material. This research attempts to measure the mechanical properties of silica gels in the laboratory as the basis for further discussion in the above areas.

RATIONALE

The facts which support the need to study the role of silica gels in rocks and their unlithified weathering products, such as sand and clay, come from sources of evidence:

CASE HISTORIES

It has been shown that silica gels can exist in natural sediments and rocks: Fieldes & Swindale [4] (1954), Naboko & Silnichenko [5] (1957), Bates [6] (1962), Degens [7] (1965), Colinvaux & Goodman [8] (1971), Kraskopf [9] (1979), Mitchell & Solymar [10] (1984), Pettijohn et al [11] (1987), Gluyas & Coleman [12] (1992), and Butenuth et al [13] (1995), among others. Further, it is a common occurrence for the strength of sediments and rocks to decrease significantly in the presence of water. These two areas of case history experience have been combined to produce a working hypothesis: that sediments and rocks can be considered as mechanical mixtures of mineral solids bound by a gel.

A similar model was described by Conlon [14] (1966), to explain the behaviour of an estuarine clay in Canada, in which a landslide had occurred. Conlon proposed that the overall shear strength of the clay could be described in terms of its frictional and cohesive components. Following these examples, Forero-Dueñas [15] (1996) has described landsliding in Colombia, and the possible relationship between this and the presence of silica gels now can be suggested.

THE COMPOSITION OF ROCKS

With the obvious exception of limestones, most rocks and their breakdown products contain a lot of silica. Most of the igneous rocks consist of silicates silicate minerals. The composition , by weight, of the earth crust is dominated by silicates, with oxygen 46.6 %, silicon 27.7 %, (compounds which are the base of silicates), and others 25.7 %: so that if taken together, the silicon and the oxygen comprise 4 out of every 5 atoms available near the earth surface. The SiO_4 tetrahedron (a three dimensional unit having silicon at the centre of a tetrahedron of four oxygen) is the basic building unit from which silicates are constructed.

COLLOIDS IN ROCKS AND SEDIMENTS

Many rocks and sediments contain ultra-fine material of colloidal particle size. The influence of such grain sizes upon the mechanical properties of these materials can be expressed in a variety of ways, one of which is "Activity" as defined by Skempton [16]. This describes the ratio of the water taken up by a clay to convert it from a "plastic" condition to that of a viscous fluid, to its particle fraction which is less than 2 micron in size. Its value is related to clay mineralogy, the clays being colloids amenable to identification. It is not unreasonable to imagine that silica gels could be associated with the clays; their presence, though, would not be revealed by the x-ray techniques used in clay mineral identification.

EXPERIMENTAL RESULTS AND DISCUSSION

The gels were produced in the laboratory, using with mixtures of sodium silicate solution, distilled water and dilute hydrochloric acid, in different proportions, details are given in Forero-Dueñas, et al [2]. The gels chosen for testing have a pH of about 7, away from the acidic or alkaline extremes, and a gelation time of around five minutes at laboratory conditions. Equation 1 describes the polymerisation of n molecules of monomeric silicic acid $Si(OH)_4$, on the presumption that such a process involves the condensation of silanol (SiOH) groups to form siloxane (Si-O-Si) bonds [17]:

$$n\,Si(OH)_4 = (Si\,O_2)_n + 2n\,H_2O \qquad (1)$$

It is also appreciated the formation of water as part of the chemical process. Such fact, can in principle have the advantage of help in preserving the moisture content of the gel, and hence its gel-like state (which also contributes to the strength, as shown in ref. [2]), by surrounding it with water; of course, if because of environmental circumstances the drying occurs, such gel-like state changes and then the strength increases. But on the other hand, the generation of water also may be having a negative side, related to the weakening effect on surrounding materials and the development of excess of pore pressures and instability. Such ideas require further development.

For the particular procedure followed in the preparation of the gels used, when the solution of sodium silicate is mixed with the rather dilute acid, an instantaneous reaction occurs forming silicic acid, and as a by product, the sodium salt of the acid used, sodium chloride in this case [18].

The mechanical properties of this gel have been studied by loading in uniaxial compression and by hardness indentation tests.

For the compression testing, the samples were cast in containers having different height - diameter, H / D, ratios, up to 2.11. Most of them were produced using two-pieces moulds (Struers, multiform, Denmark) with a smooth mounting cup and a specially designed removable base, having a D of 3 cm and an H / D of 0.85.

The weight fraction of "water" and "solids" of the gels when cast was calculated as follows: the weight fraction of "water" (FW)= Ww/Wg, and the weight fraction of "solids" (FS)= Ws/Wg, and the "water content" (w)= FW/FS; being Ww= weight of a unit volume of water, Wg= weight of same unit volume of gel, so that Wg= Ws+Ww, where Ws= weight of "solids" in the gel. For the gels made, their values when cast were FW= 95.05%, FS= 4.95%, and w= 1920 %.

To obtain the desired range of moisture contents, the samples were uncovered for different periods of time, under "laboratory conditions": temperatures varying from 20 to 25 °C and relative humidities from 40 to 60%. In all cases, the samples were initially covered for 2 hours, to allow the initial gelation process to develop and the formation of a similar initial structure within each specimen of gel. Such times were defined with the knowledge of the variations of the low shear strain shear modulii G_{max} with time, information provided by the pulse shearometer and presented in an accompanying paper [1].

The drying was accompanied by the unavoidable shrinkage of the samples. Scherer [19] explains such changes, as a result of the combination of polymerisation to form the gel (an increase in the number of Si-O-Si bridging bonds with time), and syneresis (the contraction of the gel network that results in the expulsion of pore liquid), as the common drying and ageing processes.

To obtain samples with a FS greater than 17 to 20 % was difficult, as the samples cracked around these moisture contents. It was possible to have a few dried pieces having greater values of FS, but this lost the control over the sample geometry. Such observations can be interpreted based on the results reported in an accompanying paper [1].

The equipment employed was an universal testing Instron machine, model 1122. Initially a series of loading uniaxial compression were performed, with a crosshead speed of 1 mm / min. Figure 1 presents two examples of the sort of stress-unit strain curves obtained.

In terms of strength the differences are astonishing, and the hardest samples, among them the one with FS= 17.76%, represented in Figure 1, had a failure load that exceeded the capacity of the load cell initially used.

Because of shrinkage, the specimens that were originally cast to have variable FS at constant H/D, actually became a suite of specimens of variable FS and H/D, and Figure 2 illustrates how they performed. There are also two results having higher values of H/D, produced to see the loading behaviour of such taller specimens. In first place the Figure shows that the driest samples are more brittle than the "wet" more ductile silica gels.

Whilst a clear relationship between FS and axial stress cannot be defined whilst H/D is also varying, it is pertinent to note that whilst H/D varies in an unsystematic way from low axial stress for H/D= 0.82 to high axial stress for H/D= 0.614, with higher values of H/D in between, the relationship between FS and axial stress is systematic and increases steadily from FS= 5.756 % to FS= 17.76 %, as axial stress increases.

Thus, although there are two variables, it is possible to say that FS is by far the most dominant. Figure 3 presents the Young's modulus, Eo, plotting all the data obtained on the basis that FS is the only variable and reveals a continuous curve that does not appear to reflect the H/D ratio of the specimen from which the data was obtained.

The curve of Figure 3 demonstrates the considerable effect that moisture has on Eo for a silica gel, and may be described by the Equation 2:

$$E_o \approx 177*(FS)^{3.1} \quad (2)$$

Such a large range in the stress-strain response as a function of the moisture content is in agreement with the reported behaviour of real sediments and rocks; however, in their case the differences are not usually that large, and it is worth recalling that silica gels will occupy a small fraction of the total volume of rocks and sediments. In fact Mitchell & Solymar [10], report a field case in connection with the Jebba Hydroelectric Development of the Niger River, Nigeria, in which time-dependent strength gains were observed in a sand ; in this case having just 1% of total amorphous materials available to participate in reactions leading to cementation, but enough to produce a noticeable change in the ground strength.

In the second series of experiments, cone penetration tests were performed, with the recording of load-displacement curves for samples of the silica gel with different moisture contents. The gels were cast in plastic containers (Azlon, D= 4.5 cm, H= 4.8 cm) and the variation in water content was produced in a similar way as with the specimens for the compression tests. The method of analysis is described by Sebastian [20].

The advantage of this method is that the unloading section provides information about the rheological nature of the material : if the load-unload curves coincide the material is elastic, if the unloading curve falls straight without any recovery it is perfectly plastic, and the intermediate cases denotes elastic plastic behaviour. Changes with strain rate denote viscous effects.

Some of the compliance curves, for the silica gels having different water contents are shown in Figure 4, for a steel cone with a tip angle of 90^0 indented at a crosshead velocity of 1 mm / min. It can be seen that the response of the gels is elastic-plastic; further tests have shown that the strain rate also induces effects on the response, indicating that the gels used possess complex visco-elastic-plastic properties. Again this agrees with the recorded complex response of real sediments and rocks. Also evident here is the strong effect of the water content. Three of the samples were indented up to the same maximum depth, 3 mm, and the driest one only was indented up to about 1 mm due to the damage that the indenter was causing in the specimen and the limitations in sample size due to shrinkage. However the four curves are a good example of the applicability of this method to the analysis of the mechanical response of "difficult " samples such as gels.

In Figure 4 the slope of the unloading curves is known as the stiffness, S,(with units of Force / Length). From the Figure it is clear that stiffness is a function of moisture content. This definition of stiffness agrees with the classic ones used in strength of materials, in which for example for a spring S is equal to the applied axial load divided by the induced deflection, or in torsion S is equal to the applied torque per radian twist [21]. In geotechnics, the term stiffness is used for referring to modulii, both Young's and shear.

The recorded maximum load and the area of a circle defined by the plastic height (Sebastian [20]) are the values used to calculate the Hardness (units of stress). Dividing the stiffness by the contact radius multiplied by two, it is possible, to calculate the reduced Young's Modulus, $E' = E / (1 - \nu^2)$, where E is the Young's Modulus, and ν the Poisson's ratio. The recorded results of stiffness, hardness and reduced Young's Modulus are presented in Table 1, for each of the values of Fraction of Solids, FS %. Again, these values correspond to a 90° cone, indented with a crosshead speed of 1 mm/min.

From the values of Table 1, the effect of water content on the mechanical response of silica gels used is evident. As an example, the unloading curves show that for high moisture contents the samples behave more elastically than the gels with lower water contents (i.e. higher FS); in this case the stiffness is greater and the samples response are found to be rather plastic.

Such findings, combined with the others presented in the accompanying papers [1&2], may be used to produce an engineering geology model of the likely field response of silica gels in the ground.

TABLE 1
Mechanical properties for silica-gels from cone indentation.

FS (%)	S (N/m)	H (MPa)	E' (MPa)
5.143	498.87	0.01641	0.0986
10.346	1328.72	0.05917	0.2953
11.052	3167.44	0.18435	0.7470
16.529	4053.03	0.95755	2.9802

FS= Fraction of solids: S=Stiffness: H=Hardness: E'= Reduced Young's modulus.

By comparing Figure 3 (from compression tests) with the values of reduced Young's Modulus from the Table 1 (from cone indentation tests), it is evident that the values are similar. It is tempting to use the Table to apply elastic theory, assume a value of Poisson's ratio and estimate the Young's Modulus; if that is done the two values (those from compression and those from the cone) come close, especially for Poisson's ratio near the upper theoretical limits ($\nu = 0.5$).

CONCLUSIONS

The subject of the existence of silica gels in natural geomaterials has been described, together with the likely influence of such materials in the ground. For silica gels, the high dependence on water content of mechanical properties such as initial stress-unit strain modulus, stiffness, hardness, and reduced Young's Modulus have been demonstrated, by means of compression and cone indentation tests.

The gels turns more brittle with the decrease of moisture content, in comparison with the more ductile behaviour of "wet" gels, as shown in the compression tests. The response of the gels is that of a complex visco-elastic-plastic, as is shown with the compliance curves. This agrees with the rather complex behaviour of real sediments and rocks.

The values of stress-unit strain Modulus calculated with compression tests and the Young's Modulus estimated with the cone indentation are within the same order of magnitude, and change markedly with the moisture content, following a power law, and for the gels used here has a value around 2 MPa for the Fraction of Solids, FS, around 18 %, prior to cracking.

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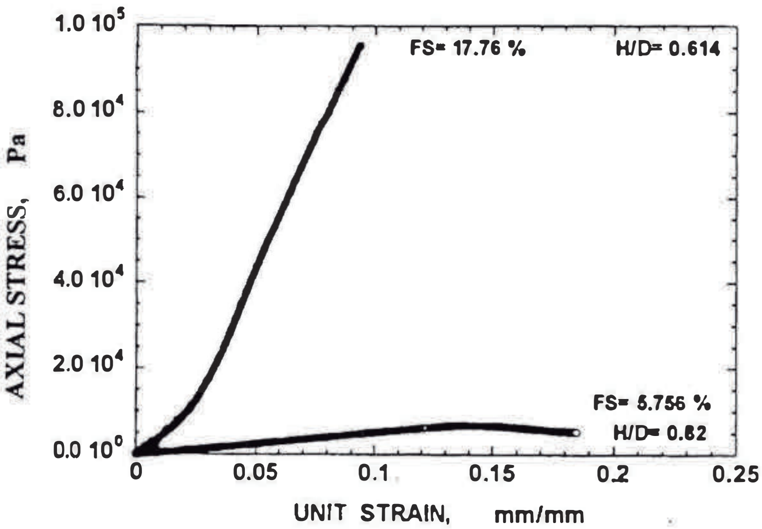

FIGURE 1. Two stress-strain curves for silica gels, from compression tests. FS= weight fraction of solids, %; H/D= height/diameter.

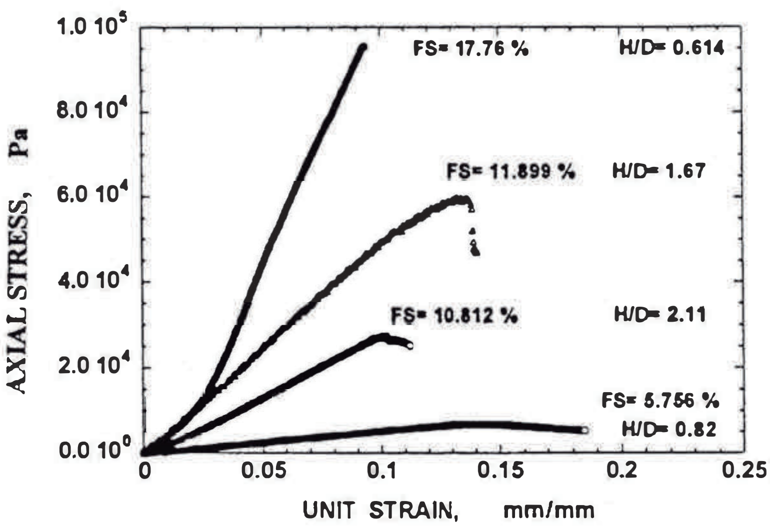

FIGURE 2. Typical stress-strain curves for silica gels, from compression tests, showing a range in H/D values. FS= Fraction of solids, %; H/D= height/diameter.

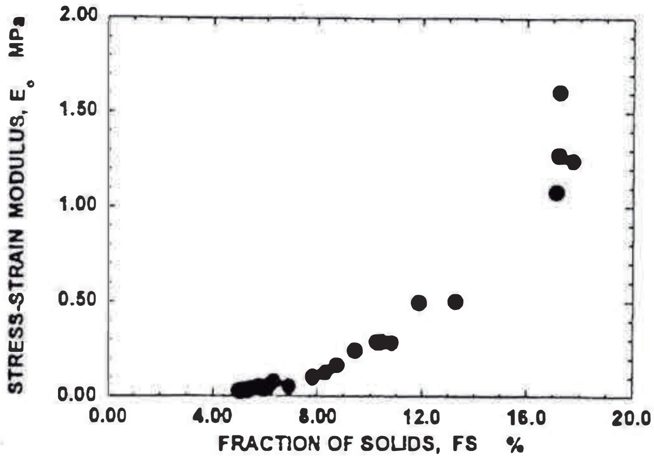

FIGURE 3. Stress-strain modulus, E_o, for silica gels, from compression tests.

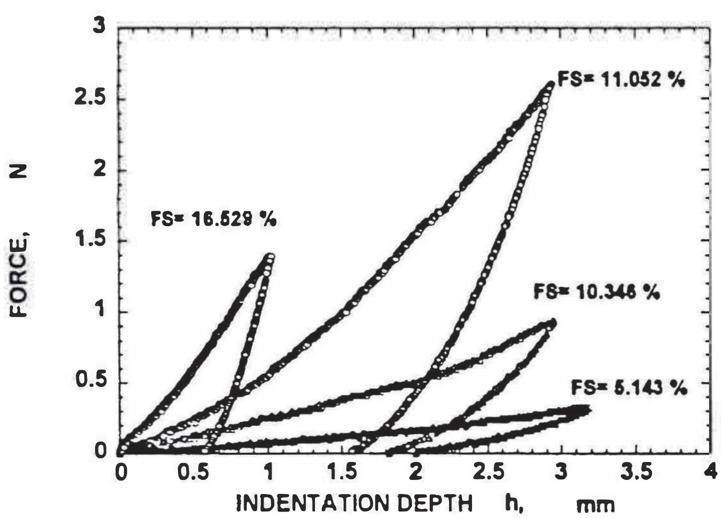

FIGURE 4. Compliance curves for silica gels, from cone indentation tests.