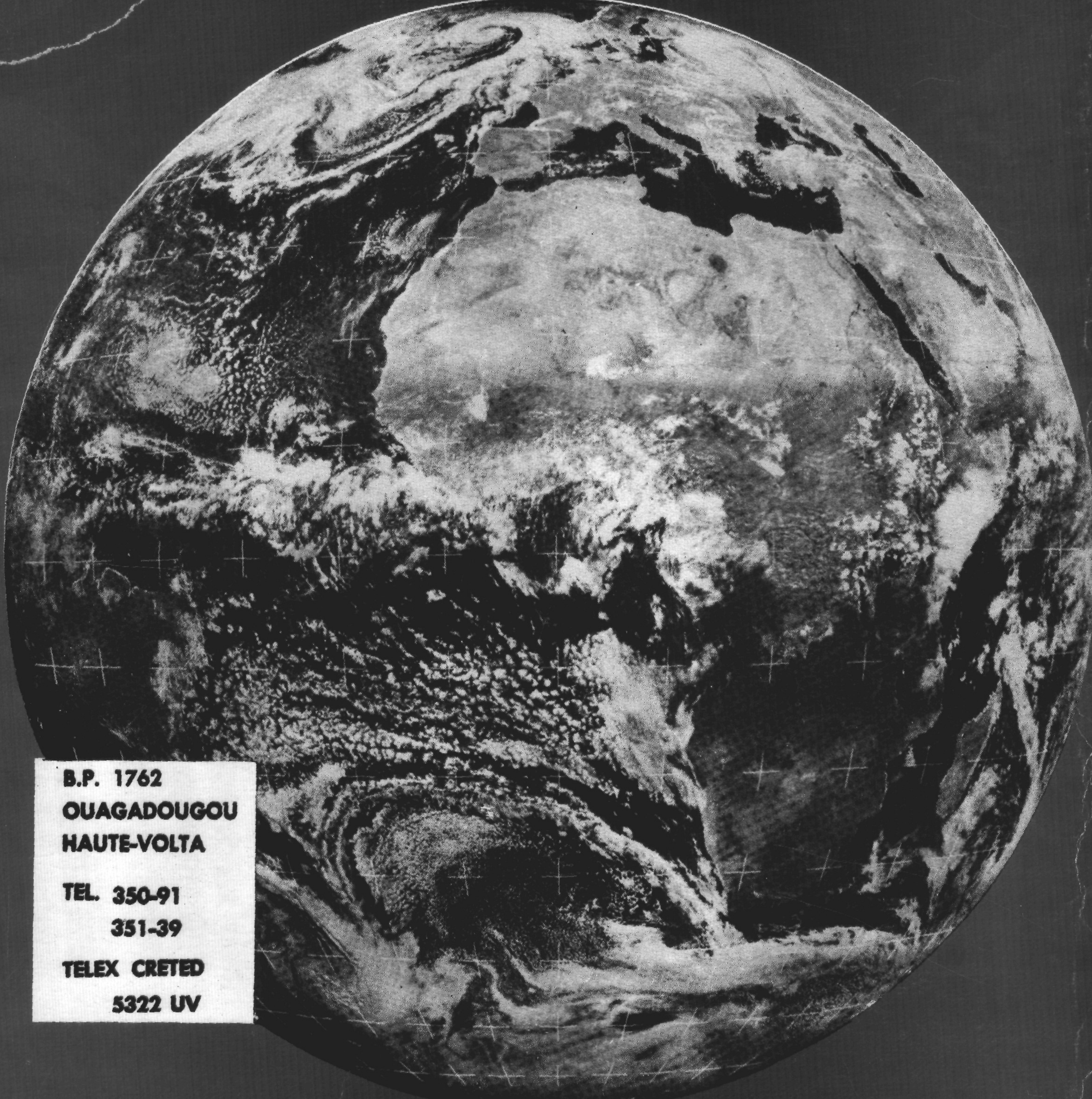

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THE INVESTIGATION ASSESSMENT AND DEVELOPMENT OF GROUNDWATER RESOURCES IN THE PROVINCES OF BOUGOURIBA, HOUET KENEDOUGOU AND PONI

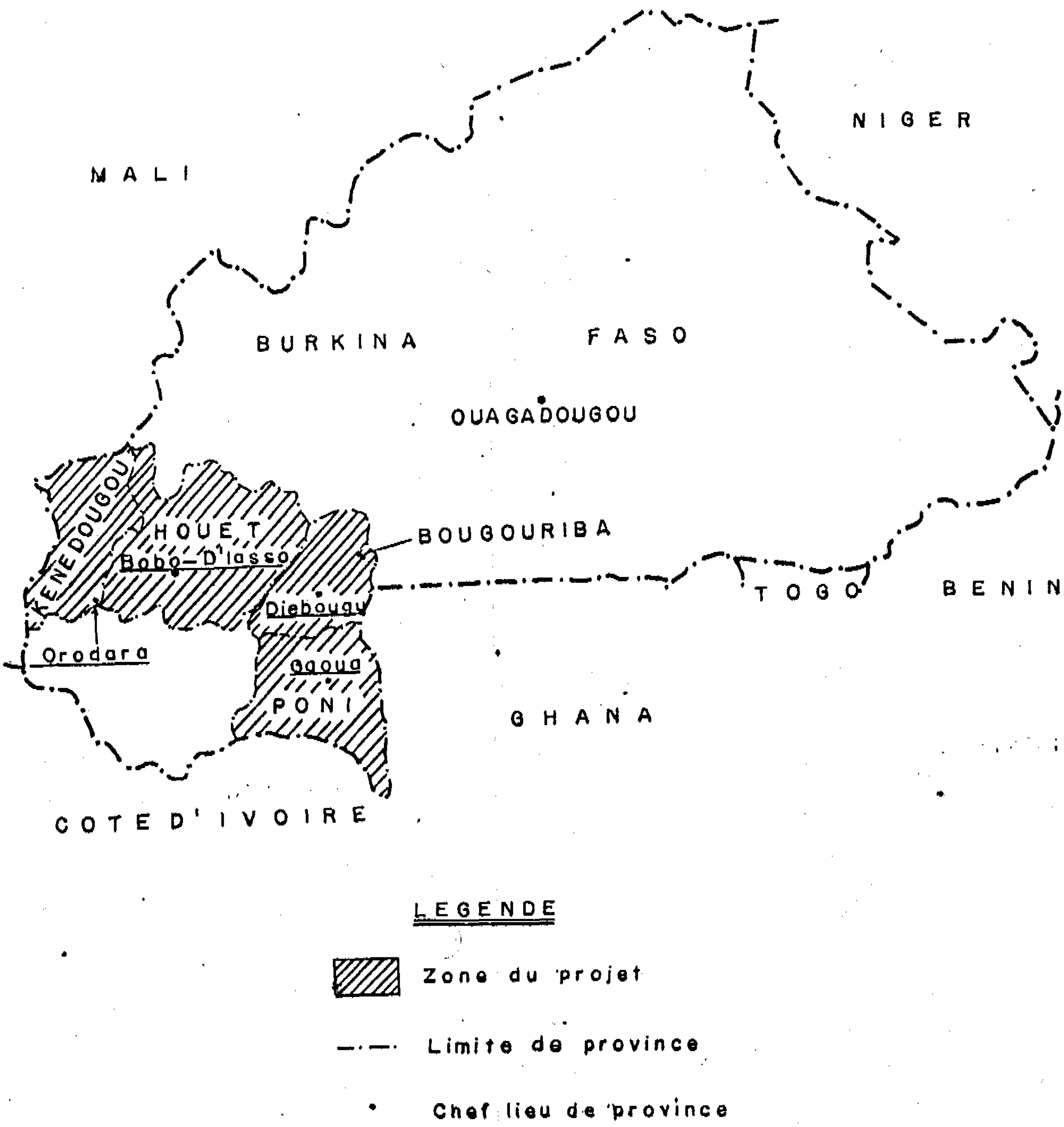
DECEMBER 85

PROJECT : HYDRAULIQUE VILLAGEOISE
US.AID N° 686-0228

BY M.S. KAMARA
APPLICATION EXPERT
GEOLOGY / HYDROGEOLOGY

REGIONAL REMOTE SENSING CENTER
OUAGADOUGOU - BURKINA FASO

Fig I. Situation de la zone du projet



THE INVESTIGATION ASSESSMENT OF GROUNDWATER IN THE GROUNDWATER IN THE PROVINCES OF KENEDOUGOU, HOUET BOUGOURIBA AND PONI

.../...

THE ASSESSMENT AND MANAGEMENT OF GROUNDWATER RESOURCES IN THE PROVINCES OF : KENEDOUGOU, HOUET, BOUGOURIBA AND PONI.

INTRODUCTION

Groundwater resources assessment discussed in this report concern the four provinces of :

- BOUGOURIBA (7,100 km2)
- HOUET (16,500 km2)
- KENEDOUGOU (8,300 km2)
- PONI (10,400 km2).

In this region of sub-arid climatic regime, there is a general lack of portable water for domestic and municipal supply. There a number of ways of supplying such water by : engine, driven pumps, from boreholes, shallo w wells, springs, rivers, dams and lakes. Of the many amternatives springs are widely regarded as the cheepest source of clean water, provided they are available. The main source of water in these areas has been through traditional shallow wells, most of the hand dug wells however are improperly constructed and use primitive water lifting devices such as buckets. This practice of traditional water supply is other unproductive, that is yields are very low, particularly during the dry period of the year. The goal of the present groundwater programme is to provide adequate good quality water for the majority of the population through machine dug wells, equipped with handpumps.

The future prospects of groundwater development is reflected in the facts as follows :

- the storage capacity of groundwater reservoirs generally far exceeds that of dam reservoirs ;
- the life time of groundwater reservoirs is much larger than that of dam reservoirs ;
- groundwater can usually be recovered and used at the site where it is needed ;
- groundwater reservoirs are less contaminated.

../..

On the primary constraints to economic and social development in the Soudano-Sahelian countries in West Africa is the difficulty encountered in developing reliable water supplies for the population.

In tropical arid regions, surface water supply is not usually available on a permanent basis, while in humid regions it is always contaminated. As a result groundwater is usually the only permanent and save source of water.

However the search for groundwater and its development in these regions raises a number of problems. Rùral populations have suffered from various diseases related to polluted water on one hand, while deficiency of water sapply has led to famine and lost of cattle on the other hand.

Recent technological advancement have improved the methodology and technique for the exploration and development of groundwater. These have raised considerable hopes for the future of the drought affected countries. The governments of the countries concerned, with the support of multilateral and bilateral agencies are engaged in large programmes for groundwater development.

It is in this same vein of thought that the rural water programme for the provinces of Bougouriba, Houet, Kenedougou and Poni, all in the Westorn part of the country, was concieved.

The occurrence and behaviour of groundwater in this semi-arid terrain are related to a number of fractors which could be grouped into three broad categories, relating respectively to : geology/pedology, morphology and climatology.

Subsequent, chapters of this report will treat each of those topics by province.

GEOGRAPHICAL LOCATION OF THE STUDY AREA

The provinces of Bougouriba, Houet, Kenedougou and Poni are situated in the South-Western Section of the Country, Burkina Faso. The areal extent of this project area is approximately estimated to represent 15 % of the whole territory. With a total population of 920,000 inhabitants.

../..

It is a region characterised by wet and dry climatic regime which alternate every six months. Mean annual rainfal range between 950 mm in the north and 1150 mm to the South [Renard J.1973] [ASECNA 1966. R. MOLLARD FONTES . 1983 and GUINOS 1984].

With references to the works of Tams Report, ASECNA, CIEH, provided in the annex of this report, the climatic parameters of temperature,humidity, evaporation and evapotranspiration are typically Sahelian. High temperatures through out the year with occassional drop in values during the wet season.

Generally landforms tend to be angular in shape, and soils are usually light colored and low in organic content. The high PH of soils favours solution and downward movement of silica, sometimes resulting in duripans. The soils are not strongly weathered. Saline soils may occur in the basins where shallow water table exists.

There are two major groupes of geological formations in the project area is indicated on the geological map. These consist of : - the precambrien crystalline basement rocks and the younger sedimentary rocks.

The assemblages of granites, schists, and rocks of the greenstone formation are of different structural components. In these crystalline rocks groundwater is less abundant and often reserves are localised. Aquifer development is due to tectonic fracturing giving rise to secondary porosity. Sedimentary rocks of the younger formation consist principally of varities of sandstons (Bandiagara sandstone, Koutiala sandstone, Bobo sandstone with dolomitic limestone and quartz veins, Sotuba sandstone (see stratigraphy of the rocks.

2.1.1 - OBJECTIVE AND SCOPE OF STUDY

In the assessment and management problems of groundwater resources in the project area, the applicability of methods to evaluate aquifer is an important component of the programme. Methodology serves as the basis for planning the developpement of water resources. The relevant questions to be solved in such evaluations are those posed as follows.

../..

- How widespread (the areal extent) is the area ?
- What are the lithological thicknesses ?
- Homogenous or inhomogeneous aquifer ?
- Are the aquifers continous, or discontinous due to the excessive stratification ?
- Where and when does recharge occur ?

These basic situations form the components of the practical problem for the evaluation of groundwater resources in the project area.

The management problem of groundwater however is one important task encountered during its exploitation. It should be carefully protected against over - exploitation and contermination by pollutants. Undesirable side effects such as deplection of the groundwater reservoir, deterioration of the water quality and subsidence of the land must be considered. The primary goals of the programme is to address these questions and propose suitable solutions.

The procedures by which the study of the groundwater potential in the project area is accomplished are :

a) Determining and verifying computed hydrological parameters.

b) Verifying boundary conditions of the water - bearing beds under exploitation.

c) Fore casting the extent of lowering of the watertable and the development of a cone of depression with time, under influence of continuing water with drowal.

d) Assessing the influence of groundwater exploitation on water and salt balances in the basins.

e) Study of the interrelationships between surface and ground waters.

f) Planning and design of groundwater level networks. This is useful is assessing the relative importance of economic efficiency, social well being regional development and environmental quality.

.../...

These are some of the research investigations considered as the principal goals that will be examined, in accordance with the data available. The influence of water development on the total water balance in a representative basin whould be assessed, particularly when this development is concentrated in localised areas, with consequent lowering of groundwater levels of large area. Small dispersed rural water - development installations like some of the villages of the study area do not influence appreciably the groundwater regime and the water balance.

3.1.1 - METHODOLOGY

The groundwater regime is commonly influenced by both natural and artificial factors. Predictions of the influence of artificial factors on the system can be made only if the natural environment all factors have first been defined. Thus the forecasting process is complex, involving first the definition of how the groundwater regime changes under the influence of natural factors then the influence of artificial factors. The predicted conditions are thus an expression of the influence of all factors on the dynamics of the groundwater system.

In the study of groundwater regime in the provinces of Bougouriba, Houet, Kenedougou and Poni at becomes necessary to compile summary maps that permit presentation of the observed results for the study area. The scale of the maps depend on the complexity and character of natural conditions in the basins and the accuracy required for the problems solution. A scale for this 1:200,000 is considered appreciable for this project ; based on the fact that the thematic data base of the project area are available at this scale. Considering also the time limitation for a detail work, this scale could be adequate.

The procedures to be followed are as follows :

This will present depth to water level, changes in separate regime elements (water levels, chemical composition of water) in respect too both time and space.

- Synthesizing maps ; this represents interpretative results. The result will be a partition of the basin(s) according to the types of groundwater and balance formations. The main elements of this balance (percolation of precipitation, evaporation from the water table local recharge of groundwater). The geological and lithological characteristics are compiled from observations wells (well log data).

From maps of the groundwater contours compiled on a large scale, estimates of groundwater flow would be made. The helerogeneity of water bearing formations is appraised and the hydraulick connection of groundwaters with rivers is determined.

CLIMATOLOGICAL PARAMETERS

ANALYSIS AND INTERPRETATION OF CLIMATOLOGICAL PARAMETERS AS IMPORTANT CONTROLLING FACTORS IN THE EVALUATION OF GROUNDWATER REGIME

Climatic conditions are important in groundwater occurrence, especially such factors as rainfall and evaporation, which are always to be considered jointly in a given geographical area. This is especially true in many hard rock terrains, where geological, pedological conditions are not optimum and where a certain concentration of rainfall within a short span of time or a certain level of runoff is necessary to offset the effects of evaporation and thus permit some water to infiltrate and recharge the aquifer. On the other hand evaporation can draw heavily on the groundwater stored in the weathered layer. For an example it has been found in several areas of West Africa extending between Mali, Cameroon and Nigeria that the weathered layer over unweathered hardrocks becomes seasonally deplected of groundwater at the end of the dry season ; if the thickness of the weathered layer is less than 12-15 meters. Observations carried out in the four provinces of Bougouriba, Houet, Kenedougou and Poni show that most of the traditional hand-dug wells are subjected to this seasonal fluctuation.

The assessment of groundwater potential depend largely on the climatic data of the region. The main climatological data considered in this report :

a) Average annual rainfall in milimeters corresponding to a period of record of ab ut 30 years

b) Average annual temperatures for the same period of record

c) Average annual humidity

d) Evaporation and evapotranspiration

e) Aridity Index.

A major constraint in the climatic data assessment lies in presenting the information in a way that conveys the essential features of the climate without involving such a mass of information that interpretation becomes difficult. The main problem is that not only are seasonal or annual totals and averages important, but also temporal variation, both seasonal and year to year.

.../...

For this study most of the reported information was extracted from a variety of publications produced by government agencies, regional and international agencies. The detail description of the climatic factors is beyond the scope of this present work. The reader is therefore refered to the annex for finer details.

4.1.2.1. - Climatic parameter 1 - Rainfall

According to Church 1974 the general movement of the two air masses controls the climate in this part of West Africa. The rains and lower average temperatures arrive in conjunction with the northward movement of the maritime tropical air masses that reach the northerly limit of 21°N in July or August.
In January, the tropical continental air masses move south bringing with them the hot, dry dusty to about 5° to 7°N.

The average annual rainfall in the region ranges from about 500 m in the northern part to about 1000 mm in the Southern limits of the project area. The rainfall in the region in general has a summer Uni-modal peak. The rains generally begin in June and end in September or October. The rainy season is longer in the project area than in the northern part of Burkina Faso.

For rainfall distribution over the entire country, refer to map on opposite page.

As listed in the Bibliography points of references for sources of data include :

- Tableau climatologique Edition Août 1972
- Aperçu sur le climat de la Haute-Volta, 2ème Edition- Janvier
- Savanna Regional Water resources and Landuse - Vol. 3.

4.1.2.2. - Rainfall data analysis

With references to following : rainfall data from : selected number of stations.
Average annual rainfall in millimeters 1955 - 1984.

.../...

Average annual rainfall 1965-1984.

The fluctuation of rainfall has been analysed for the period 1955-1984, as indicated in the isohlet map.

There has been a general decrease of rainfall for each decade of rainfall over the entire region. Summarily, the project area is characteristed by this general decline of rainfall. In the Hounde area, an average of 960 mm of rainfall is recorded and Batié to the South East 1.138 mm ; Orodara 1.123 mm and Diebougou 1.022 mm.

Considering the main drainage basins of the region particularly the Black Volta, basin, the Bougouriba basin the Poni Kamba basins an estimate of annual average, rainfall are 1,60 mm, 10.10 mm and 1.100 mm respectively.

4.2.1. - Climatic parameter 2 - Temperature

The periods of record of temperature values are usually ten years. Absolute monthly maximum and minimum temperatures are shown on the table. The avera values vary slightly, average annual minimum and maximum are 21°C and 33°C respectively. At Bobo-Dioulasso and at Diébougou avera annual temperatures recorded are 27°1C and 27°7C respectively. The histogram shows the average temperatures between 1961-1980 with two minima and two maxima peaks ; corresponding to the het and wet periods of the year :

4.3.1. - Climatic Parameter III - Relative Hymidity

The effects of relative humidity are implicit in the aridity index of the region. Aridity index is the fined by the expression

AI - 100 X R /ETP

where :

R = is the average annual rainfall

ETP = is the average annual evapotranspiration potential

100 - are values which can exist in an area.

Relative hymidity annual averages show the following values for Boromo 52 % and Beregadougou 58-59 %. The annual average humidity for the study area approximates 50 %, for the months of May-October inclusive. This period coincides with the wettest time of the year.

.../...

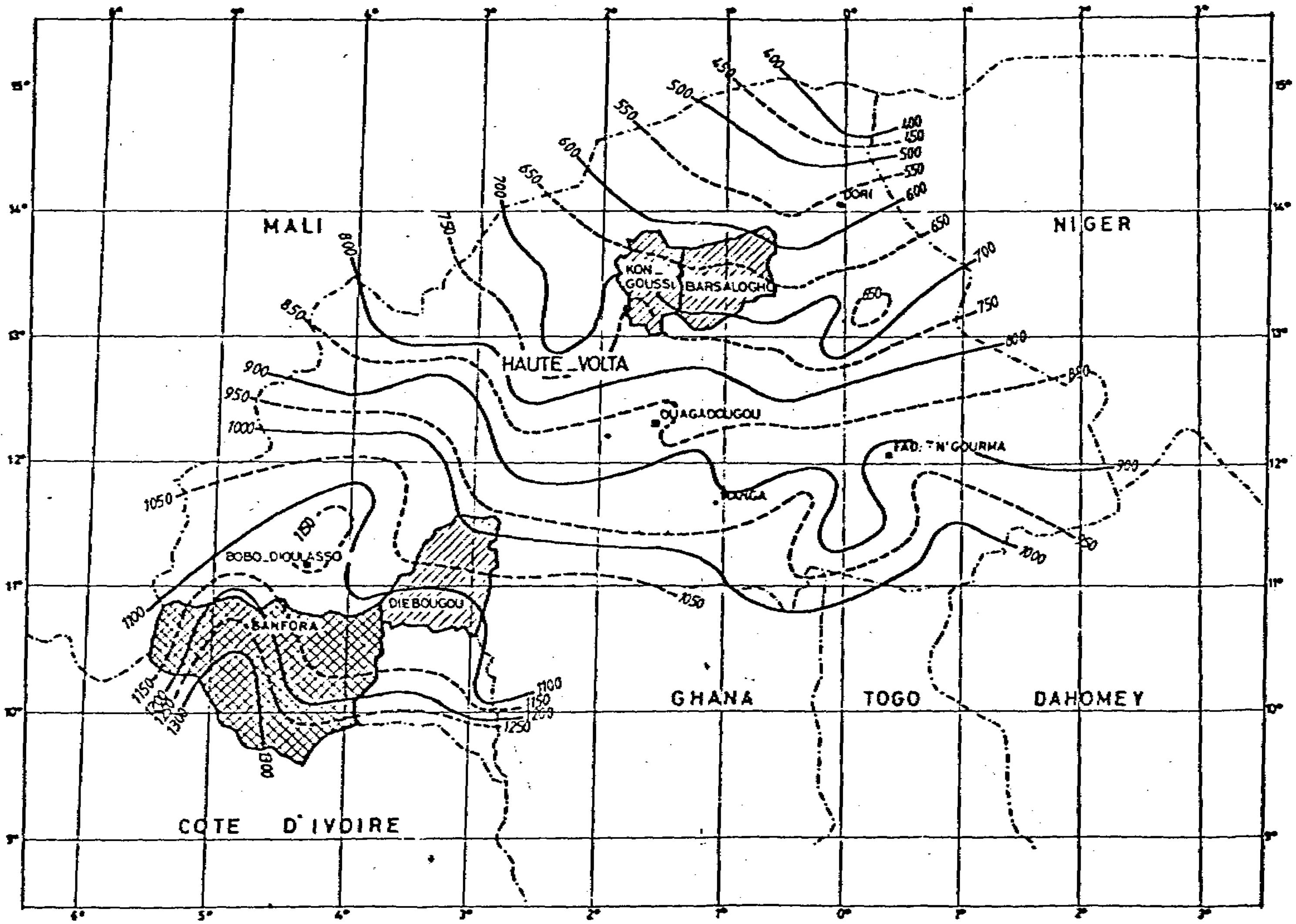
4.4.1. - Climatic parameter IV - Evaporation

With reference to the works of L. LEMOINE and J.C. PEAT. 1972, annual evapotranspiration has been calculated, using the TURC Formula for the areas of Bobo-Dioulasso (1,876 mm) Gaoua (1,876 mm), and Gaou (1.980 mm) For Bobo-Dioulasso, and Gaoua, annual averages recorded are1,780 (Gaoua) and 2,600 mm (Bobo-Dioulasso). The highest peaks occur during the hot season, while lowest peaks occur in the wet season.

4.4.2. - The purpose of Climatological Data

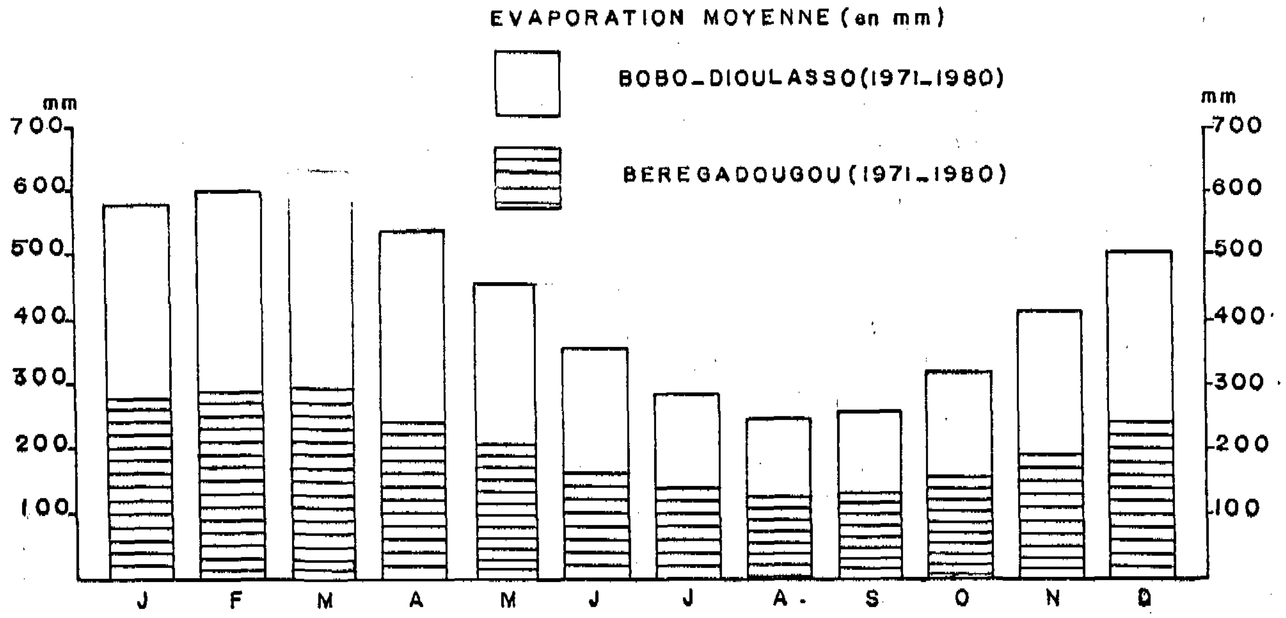
The collecting and collation of climatological data for groundwater ressources survey serve a useful purpose in the water budget analysis of the study area. The data are chosen to give the best combination of length of period of record and spatial distribution of the observation points throughout the project area. The long-term averages and the fluctuations are indicative of whether the climate is changing permanently or temporarily. It is important project planners be informed of the climatic situation inorder to design their projects accordingly.

Plan de situation - Isohyètes
(Isohyètes de la période 1961_1970, d'après ASECNA)



Echelle 1: 4 000 000
0 40 80 120 160 km.

Planche 1.1


EVAPORATION MOYENNE (en mm)
BOBO_DIOULASSO (1971_1980)
BEREGADOUGOU (1971_1980)
mm
700
600
500
400
300
200
100
J
F
M
A
M
J
J
A
S
O
N
D

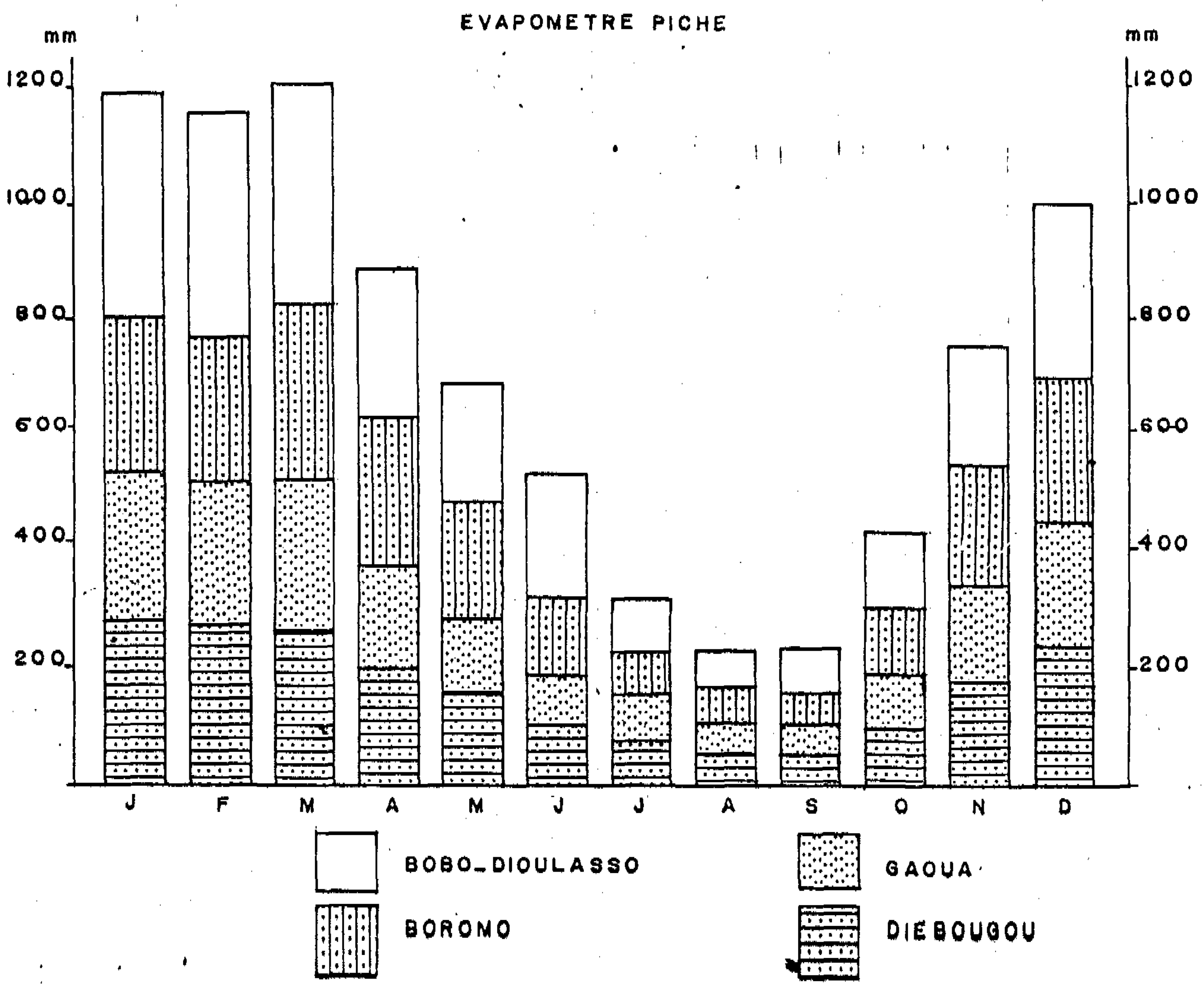
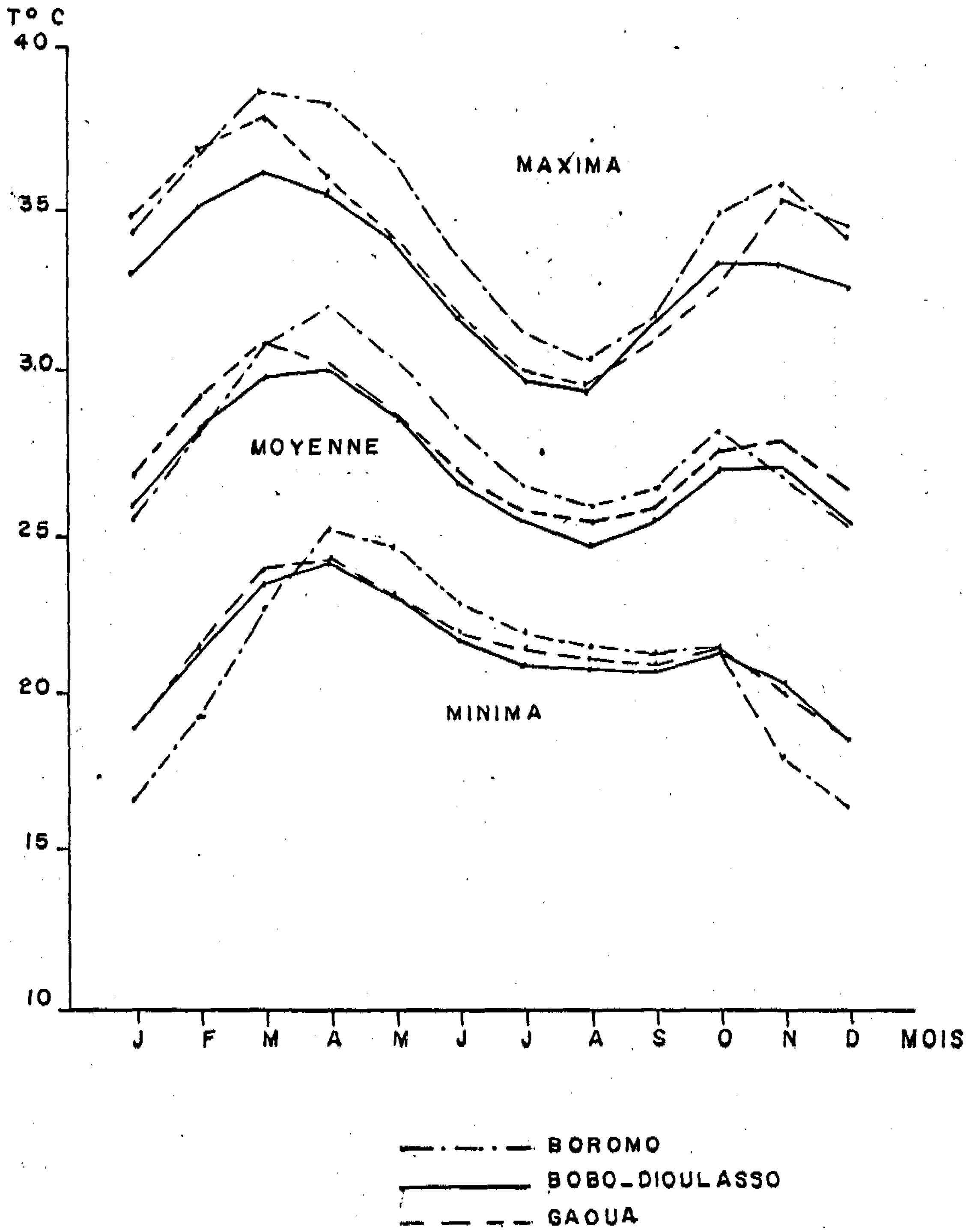

EVAPOMETRE PICHE
mm
1200
1000
800
600
400
200
J
F
M
A
M
J
J
A
S
O
N
D
BOBO_DIOULASSO
GAOUA
BOROMO
DIEBOUGOU

Fig 2. MOYENNE DES TEMPERATURES SOUS ABRIS
(Period 1961 _ 1980)



MORPHO-PEDOLOGICAL PARAMETERS

5.1.1. Morphological Parameters

The topography an area plays important aspect in the assesment of groundwater regime in an area. Its influence on the groundwater regime can be studied by analysing the following criteria ; degree of relief or ruggedness and depth of erosional downcutting or degree of draining of the area. The degree of draining of the an area is usually related to the density of the river net-work and to the depth of its down cutting. The greater the density of the river network and the deeper the down cutting, the more complete the drainage system provided for the discharge of groundwater.

The density and down cutting of a river are in turn dependent upon structural - orographic conditions. The ruggedness of the relief of an area increases the surface run-off (due to greater gradients), there by discouranging the recharge of groundwater and consequently decreasing the amplitude of water-level fluctuations. Conditions of groundwater recharge in drained areas may be further aggravated by usually deep seated groundwater.

5.1.1. Classification of Landforms according to TAMS

Macro - Relief	P. Land forms	S. Land forms
I. Flatlands	Depressional non - riparian	Basin, interior drainage and playas. narrow bohomland narrow/wide stream bottoms.
II. Undulating/Rolling	Planar surfaces	Plains/Plateaus Pediments
III. Hilly Lands	Upland Plateaus mesas	
	Slope systems	Escarpments • Valley/gorge • Isolated hills • Smooth slopes • Smooth steep • Angular gentle • Angular steep.

5.1.3. General description of the Landform systems

These are characterised by gentle smooth slopes (generally under 4 percent). It is the most widely spread type of landform in the project area. Slopes in excess of 10 % are usually short and represent abrupt changes between two general base levels. Prominent slopes range up to 3 %. The Landscape is not strongly or so frequently dissected by deep and steep sided drainages that it loses the dominant aspect of level topography.

Parallel and denderitic drainage patterns closed basins playas, and intermittent or remuant lake beds are common topographic features. Drainage may also be sparse or moderately intricate with braided or meandering streams. The typical drainage patterns of the surrounding uplands usually terminate or change abruptly their boundary.

5.1.3.2. Undulating and Rolling Land

This class is characterised by moderate smooth, slopes in simple systems of slopes and drainages. Slopes are predominantly over 4 % and generally under 16 %. They merge smoothly into one another except along major drainages. Parallel drainage patterns are common on erroded terraces and outwash plains falling in this class.

Simple denderitic drainage patterns are typical of undulating or rolling macrorelief developed on extensive plateaus, plains, and uplands.

5.1.3.3. Hilly Lands

In hilly land, moderate to steep slopes 16 % or greater, tend to merge smoothly from pitch to pitch and ridges tend to be round. The relief pattern is irregular and consists of a moderately complex system of major and minor ridges.

Drainage patterns may be complex and may extend to tertiary levels. Escarpments and cliffs are generally minor components of the landscape ; depending upon parent rock stratification. Abrupt slope changes may be common in areas where certain landforms predominate, ie buttes, terraces, and mesas.

5.1.3.4. Planar surfaces

These are secondary landforms that are flat in general aspect. This includes several landforms that may have slopes of less than 4 % that are erosional remnants of a former landscape. Included in this category are :

a) Plains - flat landscapes that are not highly dissected by deep cut streams or erosional features.

b) Plateaus and Benches

Flat areas associated with plateaus and benches where these plateaus and benches are extensive enough to be mapped as units.

c) Pediments

Gentle slopes controlled by bedrock structure in old erosional areas. They are included in the areas between the plateaus and outcrops where the slopes immediate to the erosional remnants are steep, but the overall aspect is very gently sloping to nearly flat between the plateaus and outcrops.

PEDOLOGICAL PARAMETER

5.2.1. In the most general terms, the major soils units in the area described in TAMS report 1978, - 1980, ATLAS de la Haute Volta, 1975, "Etude pédologique de la Haute Volta Ouest-sud (J.m. Reefel et R. moreau 1969) and l'étude pédologique de la Haute Volta region Ouest Nord (J.C. Leprun et R. Moreau 1968), as tropical ferroginous soils of varying depth and often indurated. Les fertile but having better physical properties are the ferraltic which occupy a relatively small percentage of the study area. Many of the lower, flater areas and some of the river basins (Black Volta, Bougouriba) and depressions have both hydromorphic and vertisols. Along the sides of the plateaus and buttes are colluvial soils of various depths, and in the rivers and basins are deposits of colluvial soils that are less well developed than some of the vertisols and hydromorphic soils.

Only the main categories of soils are treated in this report.

5.2.1.2. Feraltic soils

These are very old, deeply weathered red to yellow clayoy soils, almost uniform throughout the profile without distinct horizons. They are rich in sesquioxides and have poor chemical and good physical internal soil properties. They are characterised by the presence of latice day minerals of the kaolinite group, a stable friable soil structure and a low content of silt.

5.2.1.3. Ferroginous soils

Red or reddish soils, rich in sesquioxides. They are generally loss deep, loss permeable, more susceptible to erosion and often more fertile than feraltic soils, through the higher content of weatherable minerals and high values of cation exchange capacity and base saturation. However, the alternating wef and dry seasons cause a contrasting soil climate, thus restricting the agricultural potential. Also, their higher content of alterable ferroginous materials may give rise to liberation of iron and frequently to formation of iron crusts desaturated non concretionary, and concretionary soils reworded, and indurated soils as well as ferroginous soils with hydromorphic properties.

5.2.1.4. Hydromorphic Soils

These soils are characterised by seasonal or permanent water-logging resulting in formation of gley or pseudo gley in at least one of the subsurface horizons. Their physical properties and or location in low lying areas are responsible for their poor external an internal drainage. Some of these soils are fertile and have relatively high agricultural potential. Among numerous associations with other soils, the one with juvenile soils are riverine and lacustrine alluvium is most widely distributed. Their reclamation may necessitate control of the water level. Due to the gentle sloping of the landscape thick soils are developed.

5.2.1.5. Concretionary soils

Developed mainly on medium topographical positions and particularly on argillaceous sandstones of the Bobo - Banfora areas. The terrain is seasonally wet and has perched water table in the rainy season. The conspicuous features of these soils are numerous ferroginous concretions, frequent exposures of iron pan and boulders, imperfectly drained A and B horizons,

5.2.1.5. Moderately well - drained soils on sandstones

These soils occur notably on the sedimantary lithology of the Bobo - Dioulasso, and Banfora escarpments. Derived from sandstones they are either deep and non-concretionary or with varying depths of concretionary soils underlain by concretions or pan. The A horizon is light textured and overlies a medium textured B horizon. In the summits there are exposures of iron pan and shallow soils with sandstone brashes.

5.2.1.6. Moderately well drained soils on Granites

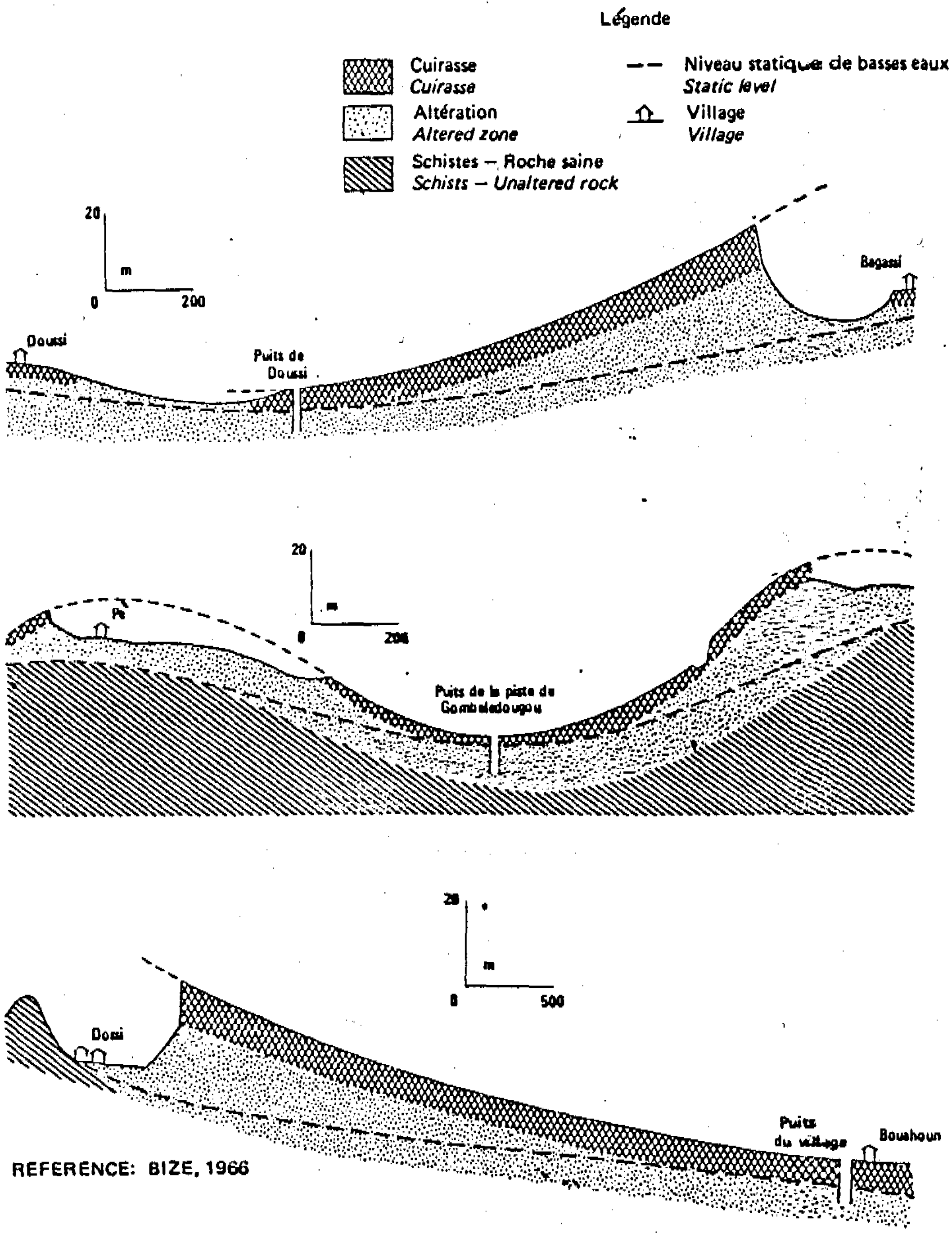
They have a wide range of characteristics. Their most common feature is the light textured A horizon and medium textured B, which is soft when wet, but hard when dry. There is an abrupt increase in the clay content below 18-24 inches depth. However, some of the soils are heavier, stoney, and highly concretionary below 24 inches.

5.2.1.7. Shallow ironstone, rocky or brashy soils :

Vary according to the geology and topography of their location. The shallow iron pan soils are found scattered in almost all upland areas and generally occur in the summits. The iron pan is 4 - 10 feet thick underlain by the parent material. Other soils of this group are severely eroded in either shallow or very brashy decomposed parent material. Included here are also light and coarse - textured shallow lithosols and rock outcrops.

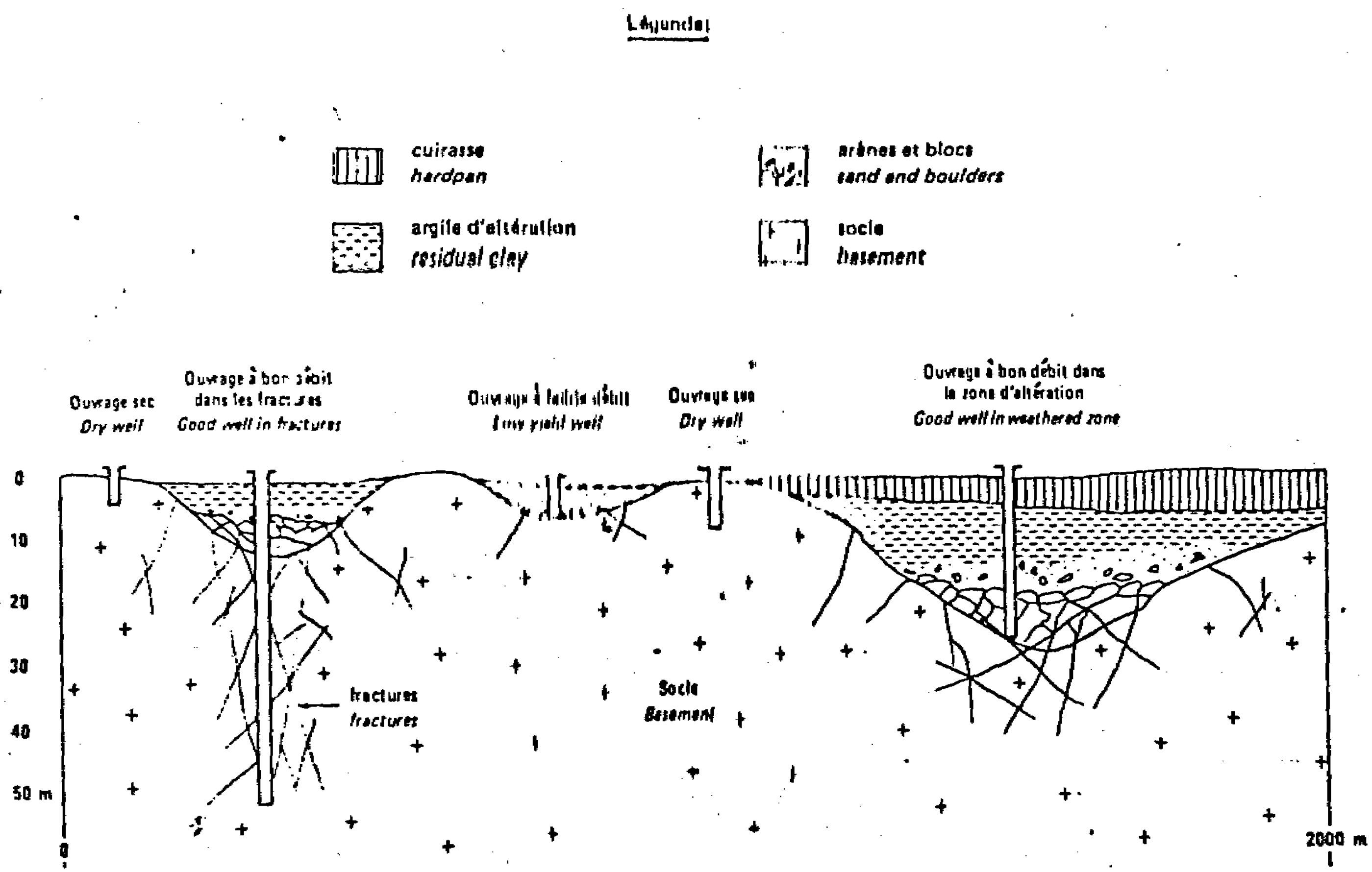
The role of soils in groundwater storage. Summarily, the ground and subsurface soils play an important quantitative and quatitative part in the mainland water balance. The characteristics of the ground surface regulate the rainwater distribution into its two hydrological components : runoff and infiltration. The natural retention ability of the aquifer provokes provisional storage, which fixes a partial regularization of the flow rates. The two flow components in the hydrologic cycle : the rapid overland flow and the deffered and more intricate flow into the groundwater body (infiltration - groundwater flow - discharge - rivers - oceans).

The study of the groundwater regime in the project area take into consideration the variable soil factors influencing the potential yield of aquifers, the transmissivity and permeability.



REFERENCE: BIZE, 1966

Figure 13-3. EXEMPLES DE CUIRASSES AQUIFERES CERCLES DE HOUNDE.
EXAMPLES OF AQUIFERS IN CUIRASSES, VICINITY OF HOUNDE.

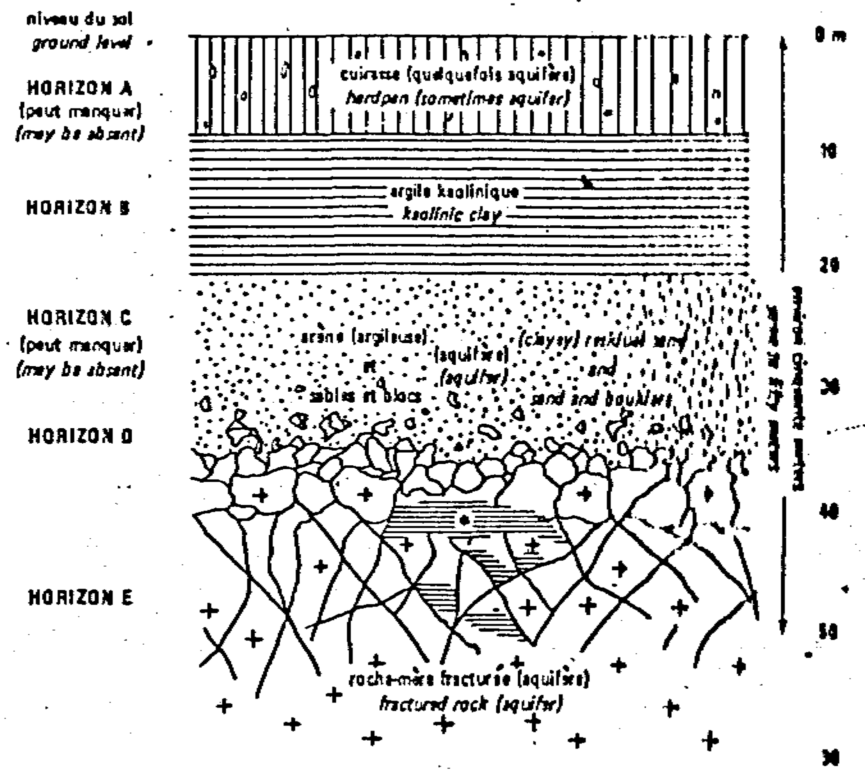


REFERENCE: TAMS – AGRICULTURAL DEVELOPMENT GROUP, 1978.

Les zones aquifères sont les arènes et blocs de la zone d'altération, et les fractures.

Groundwater occurs in basal sands and boulders of weathered zone and in fractures.

Figure 13-2. COUPE TYPIQUE DES ZONES AQUIFERES DANS LE SOCLE.
GROUNDWATER OCCURRENCE IN BASEMENT, TYPICAL CROSS-SECTION.



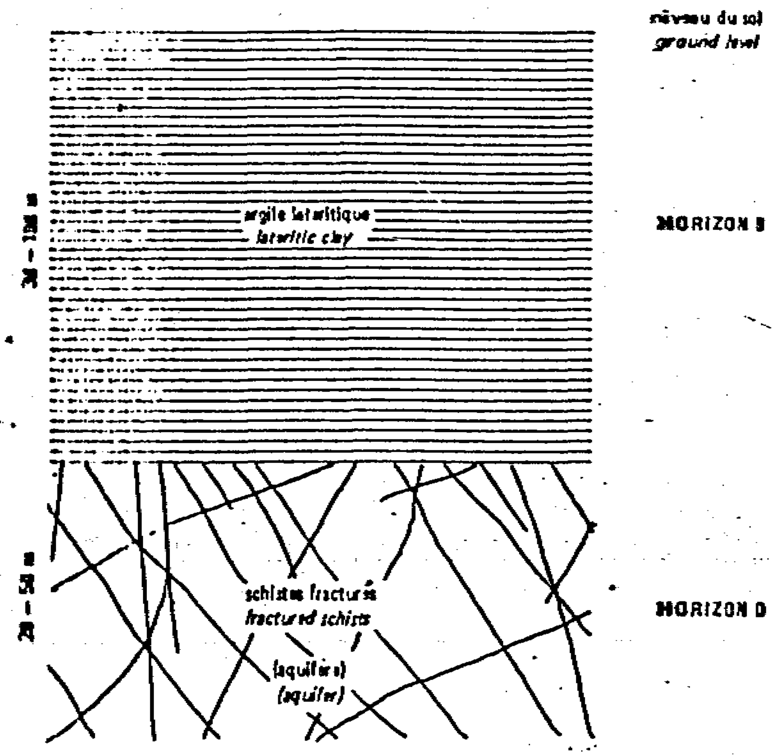
*argile d'altération
residual clay

les meilleurs sites pour puits et forages sont de part et d'autre de l'argile d'altération qui occupe le centre de la zone altérée.
best location for wells is apart from the residual clay in the center of the altered zone.

Figure 13-1a.

ALTERATION DES GRANITES ET GNEISS ET L'EAU SOUTERRAINE.

WEATHERING AND GROUNDWATER OCCURRENCE GRANITE GRANITES AND GNEISSES.



les meilleurs sites pour puits et forages sont dans la zone fortement fracturée.
best location for wells is where fracturing is dense.

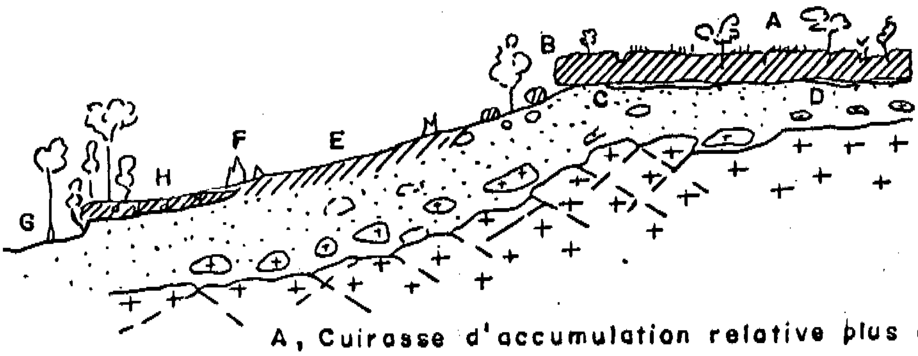
REFERENCE: TAMS – AGRICULTURAL DEVELOPMENT GROUP, 1978.

Figure 13-1b.

ALTERATION DES SCHISTES ET L'EAU SOUTERRAINE.

WEATHERING AND GROUNDWATER OCCURRENCE IN SCHISTS.

RELIEFS CUIRASSES



A, Cuirasse d'accumulation relative plus ou moins fissurée

B, Rebord avec sourcins et eboulis

C, Zone tachetée

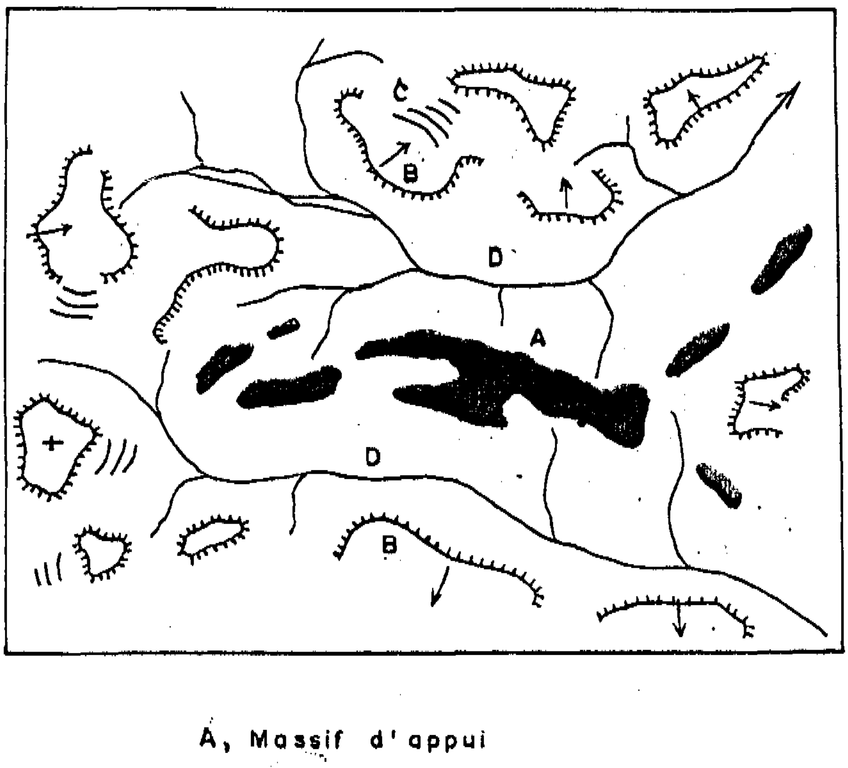
D, Reseau de circulation souterraine

E, Versant cimente faconne en glacis

F, Termitieres éventuelles

G, La plaine et son marigot H, Cuirasse d'accumulation absolue

PAYSAGE CUIRASSE(BURKINA FASO)



A, Massif d'appui

B, Couronne de grandes cuirasses tabulaire

⟶ Pendage

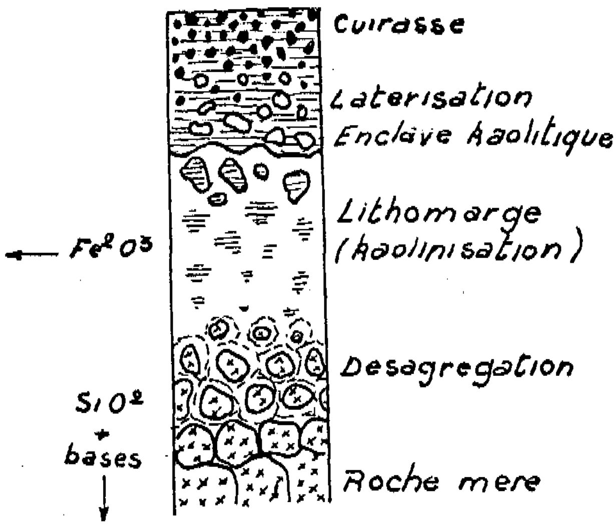
+ Horizontalité

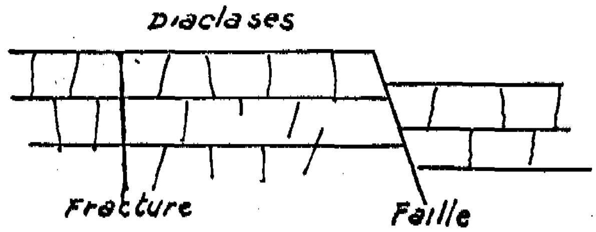
C, Petites cuirasses d'accumulation absolue

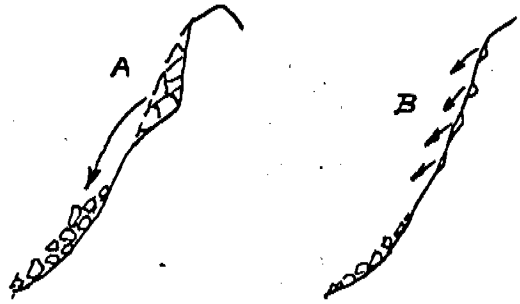
D, Depression peripherique

ALTERATION et EROSION

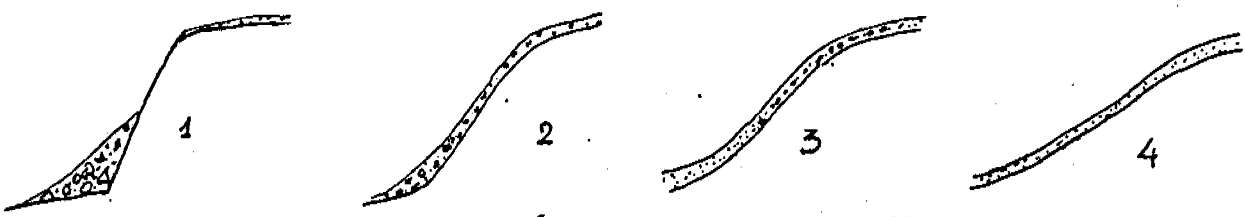
Sol lateritique



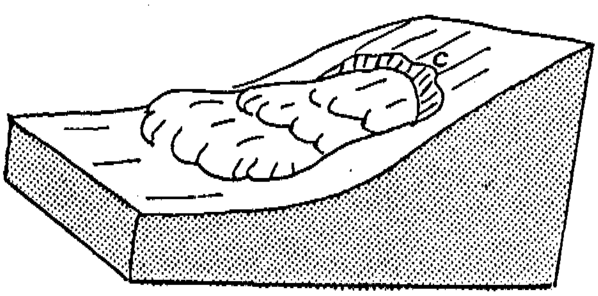




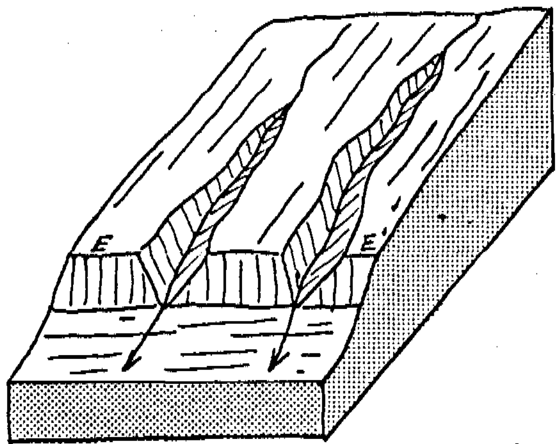
Eboulement (A) et Eboulis



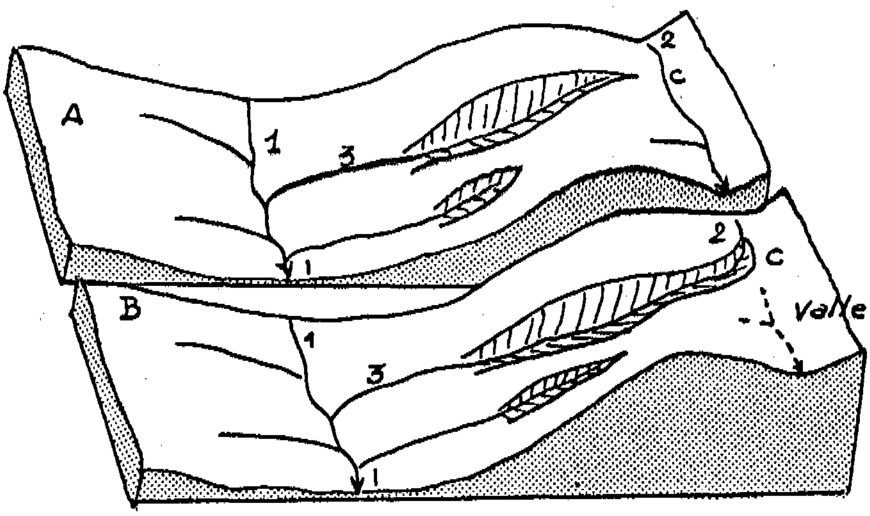
Evolution d'un versant (Recul du point d'inflexion et Amenuisement des debris)



Coulée boueuse - C Cicatrice d'arrachement



Recul d'une rupture de pente par erosion régressive
E E' Escarpement initial



capture par recul de tête

C Coude de capture

6.1.1. GEOLOGICAL PARAMETERS

A number of factors of geological significance influence the ground-water environment during very long periods of time ranging over geological epochs. Among these are the geological history of evolution of the porous medium in which the groundwater occurs, epeirogenic and orogenic movements of the earths crust, mechanical and chemical weathering, and the internal heat of the earth.

In the provinces of Bourgouriba, Houet Kenedougou and Poni, These geological factors will be discussed, and their influence on the ground-water regime of the area.

6.1.2. REGIONAL GEOLOGY

The geology of the area in the regional context can be grouped into two main groups namely :

- Sedimentary Rocks
- Crystalline Formations.

a) Sedimentary rocks (Precambrian A. TAMS 1978-80) Precambrian A Sedimentary rocks are present in the extreme south border of Burkina Faso and this formation extends northern Benin. The Pan- African orogeny, 550 ± 100 million years ago caused; folding and metamorphism of these rocks. Also, precambrian a sedimentary rocks, consisting primarily of sandstones and shales, unconformably overlie the precambrian C and D in western upper Volta. Many of the NNE trending dolerites were intruded into these sediments during this episode the Later Hercynian orogeny produced the Atacora mountains of Benin and also produced folding, fracturing and faulting of the basement rocks.

b) The Crystalline Rocks

These rocks have been grouped into the crystalline formations of the precambrian D ; and the younger precambrian C, or the Birrimian system.

The crystalline formations of the precambrian D, are the most ancient formations. These are predominantly granitic rocks, migmatites, gneiss and leptynites. The precambrian D was folded and metamorphosed (mesozonal to catazonal) during the Liberian orogeny 2,600 M.Y.B.P.

The younger precambrian C, or the Birrimian system, consits of volcanics, pyroclastics, volcano- clastics sandstones, and shales, with epizonal metamorphism present. The oldest Birrimian groups of rocks (2,300 m.y.B.P.) was followed by a granitization phase (2,170 m.y.B.P.). After the deposition of sandy sediments, the Eburnean orogeny (2,100-2000) m.y.B.P.) was accompanied by syntectonic to late tectonic granitic intrusions (1,950 m.y.B.P.). The latest phase of Eburnean (1,750-1, 500 m.y.B.P.) consisted of alkalic intrusives.

6.1.3. STRATIGRAPHY AND TECTONICS

Precambrian sedimentary

Alluvium
Bandiagara sandstone
Koutiala sandstone
Toun shale
Red sandstone
shaly dolomitic sandstone
Dolomite
Sandstone with quartz lenses
Sotoba sandstone
Basal sandstone

a) The Basal sandstone :

This formation, outcropping in the Bobo-Dioulasso area makes contact with the Birrimien schists or with the granito-gneiss in the vicinity of Dingasso.

The basal sandstone has an average thickness up to 10 m - 200m. It is usually coarse textured with conglomerate facies and cross bedding. The Basal sandstone is less well consolidated and cemented than some of the sandstone formations. It is typically an epicontinental deposit noted for its cross bedding indicative irregular depositional period.

b) The sotuba sandstone :

It has an estimated average thickness between 100-300 m, overlying the basal sandstone in the Bobo-Dioulasso area. In the areas around Kongoba it forms a contact with the birrimien schist. The sotuba sandstone is characterised by green minerals giving a schistose structure. It had compacted and highly fractured.

c) The Bobo-Dioulasso Sandstone

This formation has an average thickness of 100 m - 400 m thick. The sandstone is sub-divided into the following three members :

- Sandstone with quartz lenses
- Argillaceous - dolomitic - sandstones ;
- red fine - grained sandstone

The sandstone with quart lenses are of various sizes. The formation has a total thickness of about 300 m. This elevation corresponds to the vast lateritic plateau region of Bobo-Dioulasso. It is notably outcropping in the Orodara region where numerous wells have been implanted.

Dolomitic sandstones, shows lateral variations in facies, and could be clearly observec in the Tiara and Souroukoudinga areas. The red fine-grained sandstone formation show high potential of groundwater reservoirs. It is homogeneous, compact, and in part subquartzitic.

d) The Toun Shale

This sedimentary formation as estimated thickness, averaging between 90 -300 m. It contains alternating argillaceous and arenaceous facies. Jasper beds and or dolomitic intercolations mae present but localised. In many areas, there has developed a carapace.

e) The Koutiala sandstone

This sandstone formation is similar in its homogenity to the red-fine red sandstone. It is approximately 10-200 m thick and considerably cross bedded. The formation is characterised by its thin bedding, fine-grained, and slightly kaolinitic. The few shale layers present generally weather into lateritic irostone (ref. Carte geologique de Bobo-Dioulasso 1968).

f) The Bandiagara sandstone

It has a thickness of 50 - 600 m ; heterogenous and considerably cross bedded like Koutiola sandstone, and the basal sandstone. The formation is characterised by silicified intercalations of quartz pebble conglomerate and quartzite.

g) The Lateritic Cover

Lateritic cover is presen over much of the project area. The indurated lateritic caps extensive plateaus, buttes and in some areas for escarpments.

The description on the development of laterite its formation is beyong the scope of this report. The role of indurated laterites in the formation of tropical relief is so foundamental that it merits mentioning.

In general the induration occurs after exposure of lateritic horizons as a result of erosional striping of topsoil. This striping may be confined to breaks of slope along valley sides but may commonly occur over wider areas, leading to the formation of lateritic tablelands, mesas, bench or terrace like features, and cliffs, which vary in extent and depth.

The alterites often attain thicknesses of several meters masking the underlying bedrock. The alteration is so intense that the bedrock is not recognizable.

6.1.3.1. <u>The Basic Intrusions</u>

In general, doleritic intrusions occur as sills, necks or dikes in Burkina Faso. Many of these intrusions are considered to be of permain age associated with the Hercynian orogeny.

In the precambrian A rocks west of Bobo-Dioulasso, sills or necks of doleritic gabbro intrude into various levels of the sandstone formation.

Their mineralogy is usually labradorite, augite, pigeonite, olivine and quartz. The most common accessory minerals are biotite magnetite and illmenite. Contact metamorphism is associated with these formations.

6.1.3.2. <u>The crystalline basement rocks</u>

In Burkina Faso, Duceillier 1963 used a depositional tectonic classification to distinguish the following facies of the syntectonic granites :

- granites and biotite - amphibole grandiorites.
- porphyritic granites
- two-mica granites
- biotite, muscovite and epidote granites.

Syntectonic and post tectonic granites occur in the region as very large concordant or subconcordant batholiths, often hundreds of square kilometers in area. They are characterised by a metamorphic aureole and by abundance of intra both olithic migmatites. Very often those granites intrude into the Birrimian formations.

The geological parameters discussed in this section is generalised type.

A study of the surface and subsurface distribution of rocks and of their character, thickness and depth below land surface is prerequisite to an understanding of the occurrence and movement of groundwater in the project area. An analysis of these parameters and their relevance to groun water regime is the subject of the subsequent chapters.

Table 5-1 (cont.)

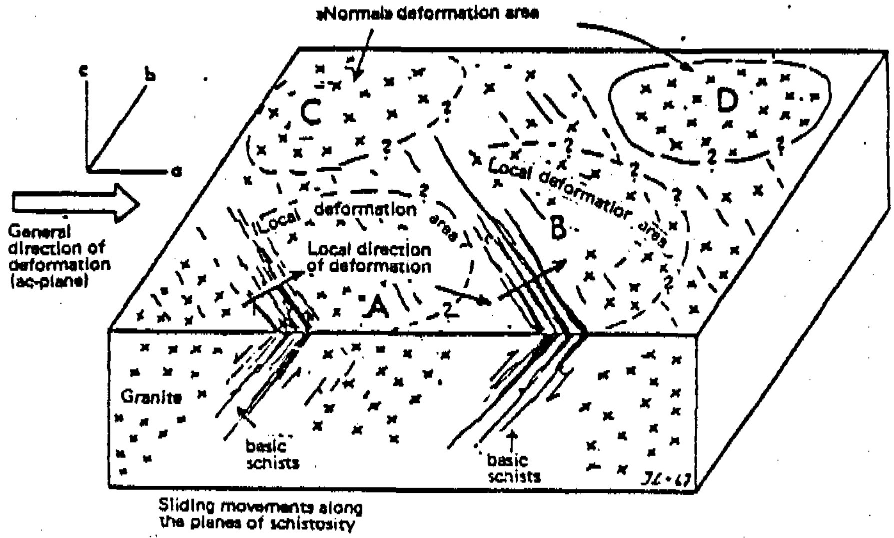
Upper Birrimian *Birrimien Supérieur* Lower Birrimian *Birrimien Inférieur*	Upper Birrimian *Birrimien Supérieur* — Riziam gp.* OR Lower Birrimian *Birrimien Inférieur* — Dacola gp. Birrimian, Undifferentiated *Birrimien Indifférencié* * Ducellier's classification: No distinction between Upper & Lower Birrimian		METAMORPHIC FORMATIONS *FORMATIONS METAMORPHIQUES* Precambrian C *Précambrien C*
	Pre-Birrimian Migmatites *Migmatites Antebirrimien*	Dahomeyan *Dahomeyen* Djougou-Agbandi group (Gneiss with muscovite, two micas, leptite, etc.) *Groupe de Djougou-Agbandi (Gneiss à muscovite, à deux micas, leptynites, etc.)* Kandi-Olé group (Gneiss with biotite, with biotite & amphiboles, leptite, etc.) *Groupe de Kandi-Olé (Gneiss à biotite, à biotite et amphibole, leptynites, etc.)* Badagba group (Quartzites) *Groupe de Badagba (Quartzites)* Kouandé-Anié group (Orthogneiss with biotite or with biotite and amphibole) *Groupe de Kouandé-Anié (Orthogneiss à biotite ou à biotite et amphibole)* Dérouvarou-Kabré group (Orthogneiss with pyroxene, pyroxenites, amphibole-pyroxenites, etc.) *Groupe de Dérouvarou-Kabré (Orthogneiss à pyroxène, pyroxénites, amphibole-pyroxénites, etc.)* Pira-Chra group (Migmatite) *Groupe de Pira-Chra (Migmatites)*	Precambrian D *Précambrien D*
Dixcove Granite Cape Coast Granite Dolerite *Dolérite* Gabbro *Gabbro* Norite *Norite* Serpentine *Serpentine*	Microgranites *Microgranites* Alkaline Syenites *Syénites alcalins* Post-tectonic Alkaline Granites *Granites postectoniques alcalins* Dolerites *Dolérites*	Post-tectonic Undifferentiated Calc-alkalic Granites *Granites postectoniques calcoalcalins, indifférenciés* Syntectonic Undifferentiated Calc-alkalic Granites *Granites syntectoniques - calcoalcalins, indifférenciés* Peridotites *Péridotites* Serpentines *Serpentines*	IGNEOUS FORMATIONS *FORMATIONS ERUPTIVES* Variable Ages *Ages Variables*

Table 5-1. Rock formations in the Project Area.
Les formations rocheuses dans la zone a l'etude.

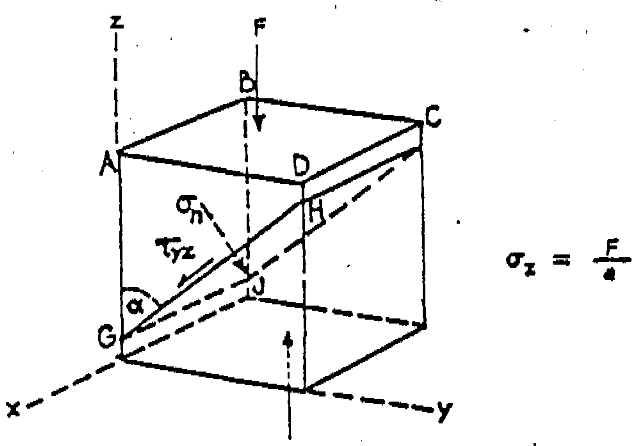
SEDIMENTARY FORMATIONS / *FORMATIONS SEDIMENTAIRES*

GHANA	UPPER VOLTA: Western Upper Volta / *Haute Volta occidentale*	UPPER VOLTA: Eastern Upper Volta / *Haute Volta oriental* — Stable Zone / *Zone Stable*	UPPER VOLTA: Eastern Upper Volta / *Haute Volta oriental* — Mobile Zone / *Zone Mobile*	BENIN: Stable Zone / *Zone Stable*	BENIN: Mobile Zone / *Zone Mobile*	Era
Alluvium	Alluvium			Alluvium		QUAT. TER. — Ceno.
	Continental Terminal			Continental Terminal		
				Upper Cretaceous of Northern Benin *Crétacé Supérieur du Nord Benin*		CRET. — Meso.
Obossum tillite (Upper Voltaian) *Tillite d'Obossum (Voltaïen Supérieur)* Obossum (Lower Voltaian) *Obossum (Voltaïen Infér.)* Oti (Lower Voltaian) *Oti (Voltaïen Inférieur)* Basal quartz sandstone (Lower Voltaian) *Grès-quartz de base (Voltaien Inférieur)*		Cambro-Ordovician sediments; Voltaian Oti shale *Cambro-Ordovicien; schistes argileux de l'Oti - Voltaïen*	Upper Buem *Buem Supérieur*	Cambro-Ordovician sediments; Voltaian Oti shale *Cambro-Ordovicien; schistes argileux de l'Oti - Voltaïen*	Upper Buem *Buem Supérieur*	SILUR. / CAMBR. — Paleozoic / *Paléozoïque*
				Dapango Sandstone *Grès de Dapango*		
Lower Buem (Age relationship with Voltaian is uncertain) Niveau inferieur de Buem	Bandiagara Sandstone *Grès de Bandiagara* Koutiala Sandstone *Grès de Koutiala* Toun Shale *Schistes de Toun* Bobo-Dioulasso Sandstone: *Grès de Bobo-Dioulasso:* with dolomitic limestone; *à calcaires dolomitiques;* with quartz lens; *à yeux de quartz;* argillaceous-dolomitic sandstone; *grès-schisto-dolomitique;* red sandstone *grès roses* Sotuba Sandstone *Grès de Sotuba* Basal Sandstone *Grès de base*	Gobinangou Sandstone *Grès de Gobinangou*	Lower Buem folded facies; weak metamorphism *Niveau inférieur de Buem, faciès plissés; métamorphisme faible*	Gobinangou Sandstone *Grès de Gobinangou*	Lower Buem folded facies; weak metamorphism *Niveau inférieur de Buem, faciès plissés; métamorphisme faible* Kandé Series *Série de Kandé*	Precambrian A / *Précambrien A*
			Atacorian folded and metamorphic facies; quartzites *Atacorien - faciès plissés et métamorphiques; quartzites*		Atacorian (mica schists, quartzites, granitized mica schists) *Atacorien (micaschistes, quartzites, micaschistes granitisés)*	
Tarkwaian *Tarkwaïen*	Tarkwaian *Tarkwaïen*					

NOTE: Both upper and middle PreCambrian noted in literature for Atacorian.



Sketch of anisotropic steering and local deviation of a hypothetical post-crystalline deformation. (Larsson, 1967).



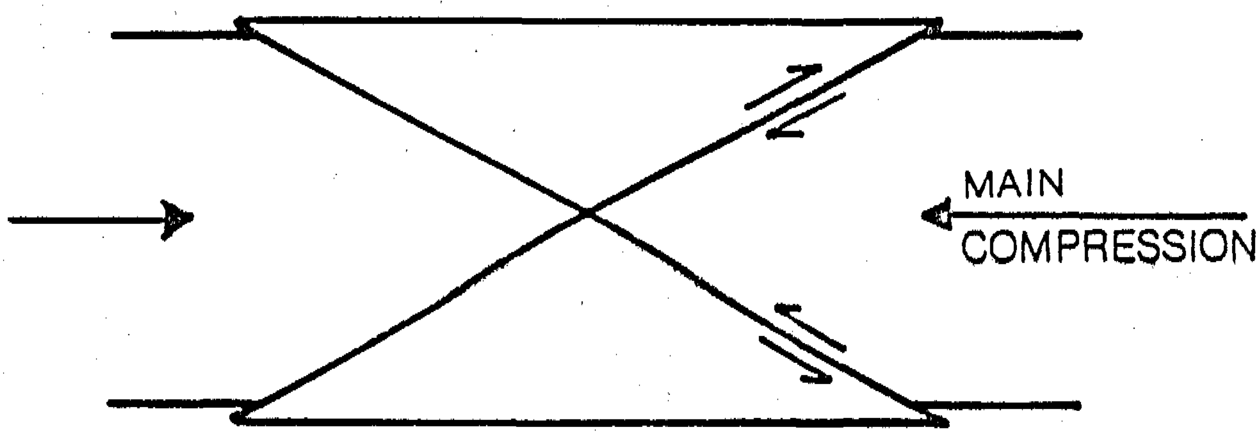
$\sigma_z = \frac{F}{a}$

Normal and shear stresses acting on external and internal surfaces of a small unit cube subjected to a compressive force F (adapted from Price, 1966).

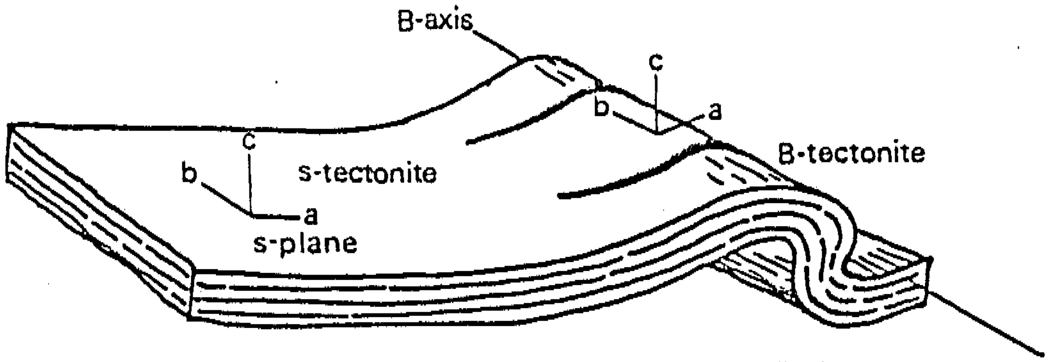
Shear fractures are the result of differential movement of rock masses along a plane. They are commonly observed in the field. They can range in length from many kilometres to tiny fractures observable in the hand specimen or under the microscope. If two intersecting shear planes develop under the same stress conditions, they are called conjugate shear fractures (Figure 2.1.2.13).

Price (1966) has shown the relationship of fractures to the axes of principal stress (Figure 2.1.2.14-16).

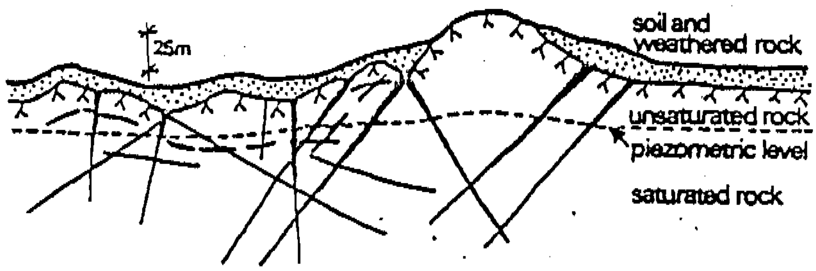
Case (a) is illustrated in Figure 2.1.2.14. The greatest principal stress σ_1 is horizontal and the least principal stress σ_3 is vertical. If movement is significant the fractures are termed thrusts (overthrusts). This case is illustrated by the fracturing of a granite area in southeast Sweden. The thrust zones are filled with fault gouge, often granular with relatively high hydraulic conductivity.



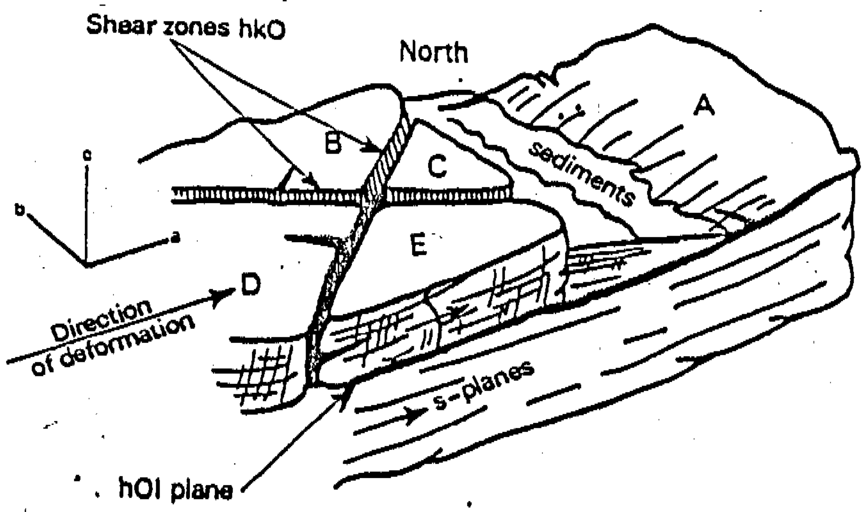
Conjugate shear fractures (Adapted from Price, 1966).



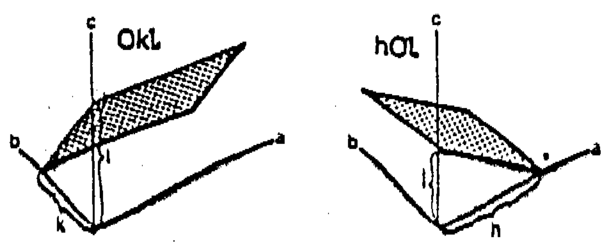
Generalized sketch of the development of s- and B- tectonites (Larsson,1968).



Typical water-bearing fracture zones in hard rock.



Brittle deformation model, modified by anisotropic steering due to schistosity (Modified from Larsson, 1967).



Examples of the use of indexes to define planes in relation to the axes. (Larsson, 1967).

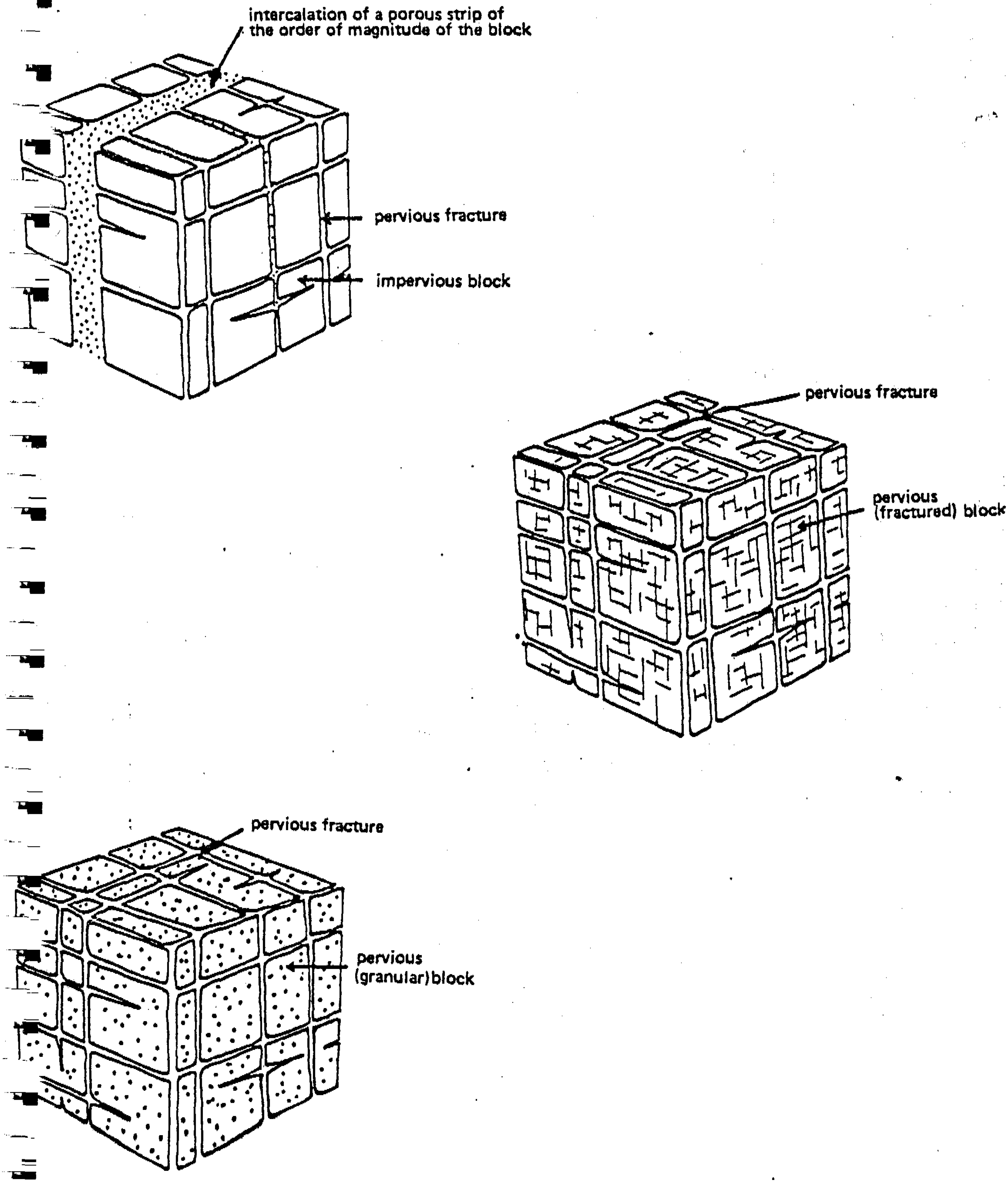
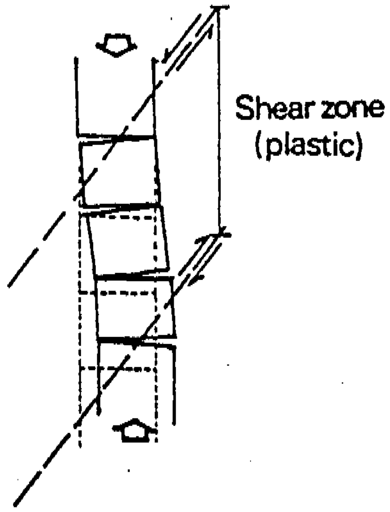


Figure 3.3.6.3 Double permeability-storativity systems.



[illegible] Development of a shear zone by uniaxial compression.
(after Lundgren,1978) (Reprinted by permission).

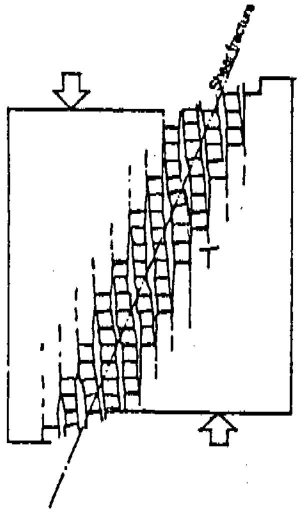


Figure 2.1.2.29 Development of a shear zone (macroscopic scale).
(After Lundgren, 1978)(Reprinted by permission).

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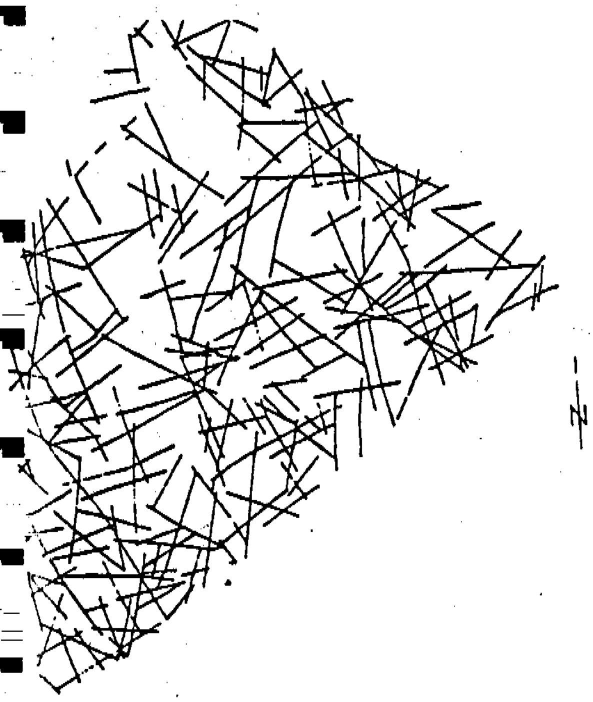


Figure 2.1.2.31 Fracture pattern in granite of Banfora, Upper Volta. (Engalenc, 1978)

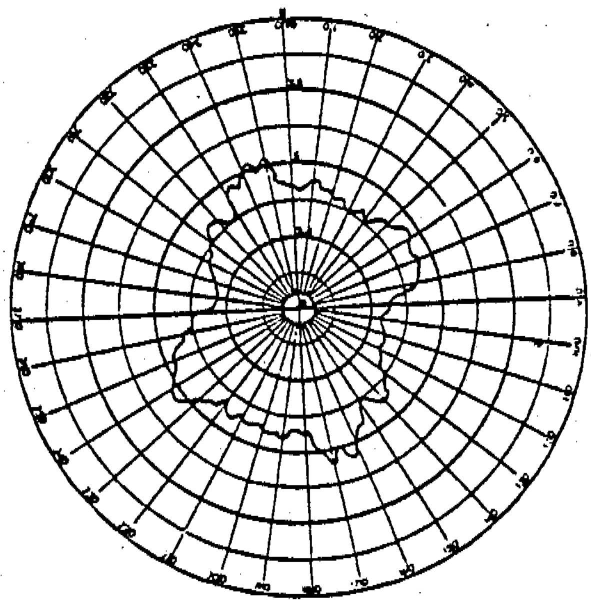
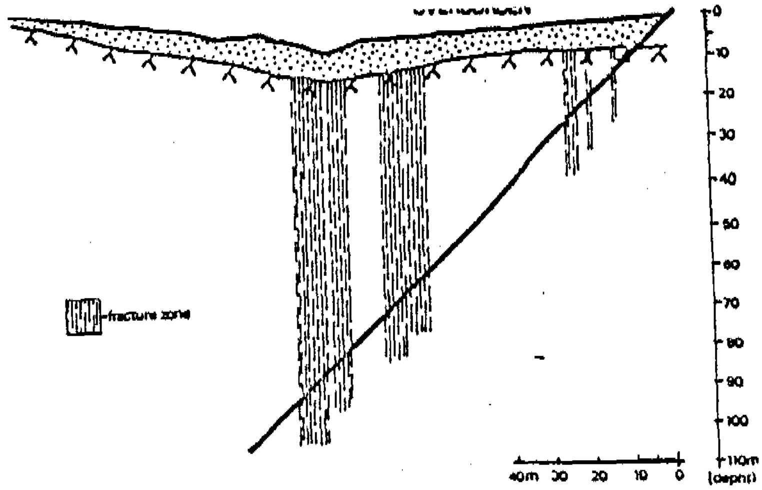
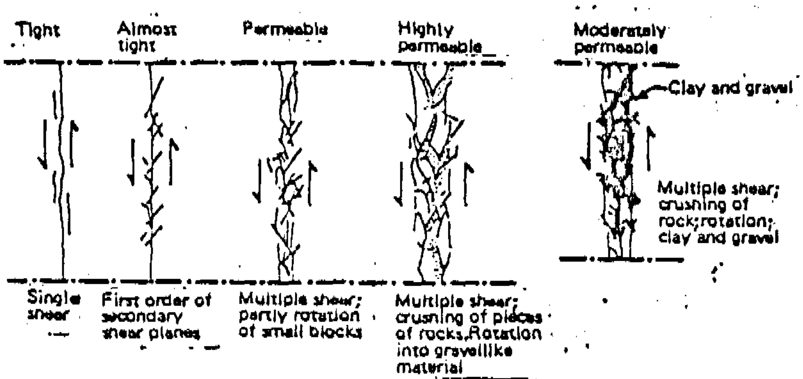


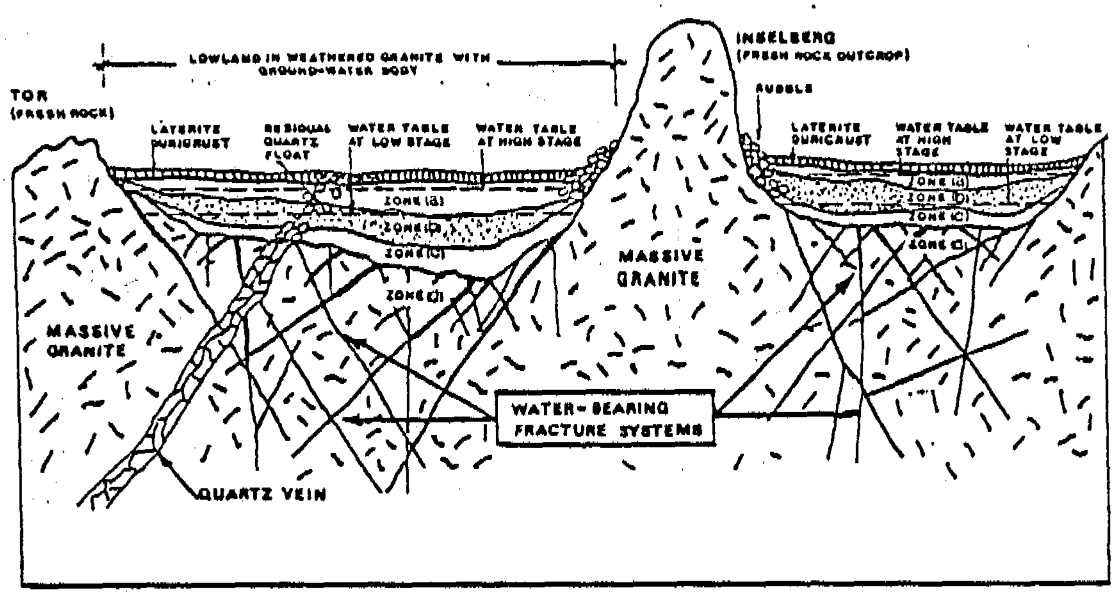
Figure 2.1.2.32 Measurement (stereographic projection) of fracture pattern in Figure 2.1.2.31 (Engalenc, 1978).



Model of rock fracturing due to brittle deformation.



Different stages in the development of shear fractures and permeability.



Sketch of lowlands of weathered granite forming ground-water bodies and separated by uplands of unweathered, massive granite. Laterite duricrust: Hard ferruginous carapace passing downward into ferruginous clays and ferruginous concretions.

Zone (a): Sandy clays and clayey sands. Commonly concretionary and kaolinitic. High porosity but low permeability.

Zone (b): Altered massive clays, commonly plastic, in which stable primary minerals may be preserved in their original form. High porosity but low permeability.

Zone (c): Rock progressively altered upward to a granular, friable layer of disintegrated crystal aggregates and rock fragments. Low porosity but appreciable permeability.

Zone (d): Fresh fractured rock with water-bearing fractures.

HYDROGEOLOGICAL PARAMETERS

6.2.1. Needed research

Forced by the necessity of solving pressing groundwater supply problems in the sudano sahelian countries, much valuable groundwater investigation programmes have been initiated. Many organisations national, regional, and international make information on groundwater available to the public through investigation. The public consists of individuals who use water as well as those who are concerned with exploration, development of supplies, distribution and chemical quality.

By information is meant :

- raw data, such as observations on groundwater levels ;
- interpretations, such as on quantity, distribution, sources of replenishment, and discharge in areas of concern,
- knowledge of foundamental principles and relationships.

It is necessary to keep track of groundwater withdrawals, to inventory the storage, and, in places of need, to know the physical facts concerning the voloume of groundwater in storage, its occurrence, replenishment, relation to adjoining surface water, and its state of contamination, if any. A critical examination of all information should be made befor it is used in analyses.

The investigation therefore involve the collection, synthesis and interpretation of data, so that for various areas one can define the enviroment in which groundwater occurs, and the flow system of the groundwater body or bodies. The enviroment includes the geometry of the aquifer system (area, depth, thickness, and extent of waterbearing beds), its storage and transmission properties (effective yield and permeability of the formations), and the chemical composition of the water and the aquifer materials

The flow system covers such things as the hydraulic boundary conditions (nearby sources of inflow, or boundaries of impermeable rock), hydraulick head distribution (water-level contour maps) water imput (recharge) and response of the system to physical and chemical changes.

6.2.2. The concept of the groundwater regime

The concept of the groundwater regime is based on the fact that the local occurrence of groundwater is not merely a product of chance, but the consequence of a finite combination of climate, hydrologic, geologic, topographic, ecologic and soil forming factors that together form an integrated dynamic system.

The integration of this factors for the provinces of Bourgouriba, Houet Kénédougou and Poni would provude some in sight into the functioning of the total system and thus serve as an indicator of local conditions of groundwater occurrence.

It is therefore possible to evaluate the general potential of the project area by appraising factors listed above as practical and then by interpreting the local regime on the basis of known relationships among the factors and their effect on the regime.

6.2.2.1. EXAMIN CRITERIA FOR GROUNDWATER POTENTIAL RECHARGE AND DISCHARGE

The functioning of the groundwater regime

The potential for recharge to the groundwater regime in the project area is dependent on the amount and pattern of annuel precipitation in relation to the potential for evaporation and to the occurrence of any surface or subsurface inflow from adjacent areas. Most of this potential recharge is commonly intercepted by the soil veneer and eventually returned to the atmosphere through processes of evapotranspiration or dissipated through the surface runoff. The amount that actually contributes to groundwater recharge varies seasonally and from year to year.

Although perhaps difficults to quantify, it generally represents a comparatively small part of the total potential recharge. Similarly, ground water discharge may be difficult to quantify because of temporal variations especially if it occurs at a number of scattered locations, either at the land surface in the form of springs, gaining streams lakes ponds, or at depth through permeable formations.

Thus the relationship between recharge and discharge under natural conditions is often obscured and not readily apparent from field observations. However, useful guide-lines that are generally applicable to specific problems areas can be drawn from the practical experience accumulated through field study of ground regimes in a variety of natural environments.

Guide Lines (main criteria) for consideration are as follows :

a) - In a relatively undeveloped areas long term average discharge from a ground water reservoir can be presumed to be in equilibrium with long-term average recharge.

b) As a consequence of (a), it follows that a large volume of groundwater discharge at the landsurface is proof of corresponding high recharge to the system.

c) The potential for recharge in an area as determined, for an example, by observing precipitation, should not confused with actual recharge. The two are related only in that actual recharge cannot exceed the potential for recharge. Thus semi arid areas characteristically receive low recharge because of low potential for recharge, but humid areas do not necessarily receive high recharge unless rocks underlying the land surface are highly permeable.

d) Surface - water discharge represents both run - off and ground - water discharge. The later can be approwimately equated with the low flow natural discharge less inflow of streams not originating in the area.

e) A groundwater reservoir tends to fill at least to the level of the lowest outlet regardless of aquifer characteristics usually, this level corresponds to the lowest point at which an aquifer is exposed at the land surface in a groundwater basin. The occurrence of discharge at such a location is good evidence of saturation below that level. The absence of any discharge at such a location indicates subsurface drainage, in which case well data are needed to determine the local level of saturation.

f) With drawal of water from a groundwater reservoir through development (usually construction of wells) will reduce groundwater discharge by a corresponding amount. With drawal in excess of recharge removes water from storage and eventually will deplete the available supply unless recharge is increased artificially.

6.2.2.2. <u>Examine criteria for potential groundwater bearing materials and movement</u>

The watertable (unconfined condition) or the piezometric surface (con fined condition), as defined by the levels at which water stands in wells, slopes in the general direction of ground-water movement. The slopes of the water-table or piezometric surfaces afford some clues, therefore, concerning the nature of the water movement of the aquifers and the water bearing materials. Thus during the initial appraisal of the groundwater in a new area, when quantitative data are lacking or in aqequate, qualitative relationships may be inferred from the following guide lines :

a) A steep gradient of the watertable or piezometric surface generally indicates low permeability unless high recharge is obvious.

b) A low gradient in humid regions probably indicates high permeability.

c) A low gradient in arid and semi-arid regions is probably more indicative of low recharge, and thus low discharge, than high permeability.

d) An aquifer having materials of low permeability will probably exhibit high gradient unless recharge is very low.

e) An aquifer having materials of high permeability will generally exhibit a low gradient.

f) Permeable materials comprising aquifers that are deeply incised by stream channels will tend to drain laterally over great distances unless recharge is very high.

g) moderately to slightly permeable materials comprising aquifers that are deeply incised by stream channels will tend to drain laterally a comparatively short distance from the point of incision unless recharge is very low.

The foregoing guide-lines would be modified if the aquifer appears usually thick or thin within ghe area under consideration or if it varies appreciably in thickness from one part of the area to another.

6.2.2.3. Evaluation of Groundwater Potential in the Project Area.

General Aspects

The occurrence and properties of groundwater, its origin, movement and contained chemical constituents are dependent on the geological framework, that is, the lithology distribution, thickness and structure of permeable, semi-permeable and impermeable rocks and sediments through which it moves.

In all the groundwater investigations the principle must be recognised that nowhere has the groundwater porous material been found in a homogeneous way. This applies to areas with igneous, metamorphic and sedimentary rocks.

The subject of groundwater evaluation will be considered in this report in two parts as follows.

- Evaluation of groundwater potential in the sedimentary formations.
- Evaluation of groundwater potential in the crystalline formations.

6.2.3.1. Groundwater Potential in the Sedimentary Formations

The method most commonly used to correlate aquifers, aquitards and aquicludes is based on a tudy of well records and examination of samples of drilling cuttings. Well log data on some of the areas drilled in the sedimentary formations of the project area, have provided useful information on the thickness and location of formations ; water levels and depth, discharge and head of water yielding beds.

The water level data has provided records of short term changes and long-term fluctuations of storage within the groundwater reservoirs. Reoognised uses of data on groundwater levels include the following :

a) to identify areas of detrimentally low or high water levels.

b) to facilitate prediction of the groundwater supply outlook for the future by showing the time-rate of change in groundwater storage.

c) to provide information of evaluating water yielding properties of groundwater reservoirs.

d) to appraise the relationship of water level fluctuations and pumping, precipitation, and other factors.

e) to aid in estimating the base flow of streams.

Culled from TAMS report the following are the groundwater potential of the various sedimentary formations :

- The sedimentary formations of precambrian A, age described by Palausi (1959) are summerised below :

- The Basal sandstone : is generally porous and permeable ; however, where the beds have been recrystallized by circulating groundwater in fractures the formation is considered impervious.

The Sotuba - Tandiagara sandstone is, inspite of its compaction, relatively porous and permeable, with an important interstitial permeability. This sandstone complex is important to the feeding of the hydrographic net work on the plateau of Bobo-Dioulasso.

The Bobo-Dioulasso sandstone contains a very important and exploitable groundwater resource. Springs emerge in numerous sites from this sandstone with yields of several m^3/sec. At Bobo-Dioulasso the Kou springs discharge water at approximately 2 - 4 % m^3/s.

The toun shale is impermeable and groundwater circulation in fractures in this rock is considered rare.

B Influence de la nature des roches sur les débits.

Cette étude ne tient compte d'aucun facteur hydrogéologique local.

Nature des roches	*	Debit au developpement en m^3 — Faibles: $0,400 < Q < 2$	Faibles: $2 \leq Q \leq 5$	Bons: $5 \leq Q \leq 10$	Bons: $Q > 10 m^3$	
Grès roses	5	5	5	I	I	I7
Grès schisto-dolomitiques	2	2	8	0	0	I2
Grès à galets de quartz	I3	6	22	5	6	52
Grès de Sotuba	4	7	7	I	I	20
Roches grenues, granite, granito gneiss	25	26	24	2	I	80
Schiste (birrimien)	9	I6	I6	0	0	4I
Roches vertes	4	9	8	I	0	22
TOTAL Grès	24	20	42	7	8	77
TOTAL Socle	42	53	48	3	I	I43

C - Profondeur des venues d'eau

Seules les venues d'eau notables ont été prises en considération dans le tableau ci-dessous.

Nature des roches	Profondeur des venues d'eau (m): < IO	IO X 25	25 X 40	> 40
Grès	0	46	I5	55
	0	2,800	2,230	I,904
Granito-gneiss	I*	44	I2	4
	15,I40	I,979	I,480	0,756
Schistes	I	IO	8	I
	0	2,229	I,687	3,400
Roches vertes	0	II	5	3
		2,239	I,900	I,500
Total	0	III	40	I3
		2,3II	I,454	I,386

46 nbre de cas

2,800 debit m^3/h

c-3 Epaisseur de l'altération

La variation de l'épaisseur de l'altération avec la nature de la roche peut être illustrée par le tableau de comparaison ci-dessous.

Nature des roches	Nombre de forages	Epaisseur de l'altération (m)			
		< 10	10 - 20	20 - 45	45 - 70
Grès	72	41,66 % 30	36,11 % 26	22,22 % 16	0 % 0
Roches grebues	7,33 % 109	7,33 % 8	16,51 % 18	50,45 % 55	25,68 % 28
Schistes	27	0 % 0	18,51 % 5	51,85 % 14	29, 8
Roches micro-grenues	59	3,38 % 2	15,25 % 9	69,49 % 41	11,86 % 7
TOTAL	264	37	58	126	43

C-4 Influen e de l'épaisseur de l'altération sur la productivité

Nature des roches	Epaisseur en m			
	< 10	10 - 20	20 - 45	> 45
Grès	30 2 640	13 2 836	17 2 769	1 5 140
Granito-gneiss	2 1 030	12 1 903	33 1 563	8 1 275
Shistes	0 0	1 0,476	14 2 311	4 1,531
Roches vertes	1 3,300	7 1,957	12 1,670	1 1,800
TOTAL (socle)	2 0,543	19 1,93	59 2,404	12 1,445

30 —— nbre de cas

2 640 —— débit en m3

D Evolution du debit en fonction de la profondeur du forage et de la nature des roches

Pour minimiser l'effet de la denivelée, cette étude a été faite en regroupant tous les forages situés à des côtes sensiblemen

	Grès			Granito - Gneiss			Schistes birrimiens			Roches vertes					
	P≤30	40<P<50	P> 0	P≤30	30<P≤50	P>50	P ≤30	30<P≤50	P>50	P ≤ 30	30 < P ≤ 50	P>50	P 30	30 P 50	P 50
Débit moyen	2 090	3,879	5,069	3,I00	3,547	3,240	2,800	3,466	3,554	0	3,683	2,464			
Nombre de forages	* 2	28	26	* 2	I6	I0	* I	6	7	* 0	8	3			
Pourcentage	3,57%	50 %	46,43 %	7,I4%	57,I4%	35,72%	7,I4%	42,86%	50 %	0 %	72,72 %	27,28 %			

* Non representatif

A côtes sensiblement égales le debit augmente progressivement avec la profondeur pour un aquifère greseux homogène jusqu'à plus de I00m

Pour les roches vertes et les granito-gneiss et dans les mêmes conditions de côtes égales, il augmente lentement jusqu'à près de 50m puis / tombe brusquement pour devenir nul à une profondeur voisine de 65 à 70 m dans le cas général.

S'agissant des schistes birrimiens le debit peut croître jusqu'à un peu plus de 60 m mais baisse moins rapidement au delà pour devenir nul presque à la même profondeur que les granito-gneiss.

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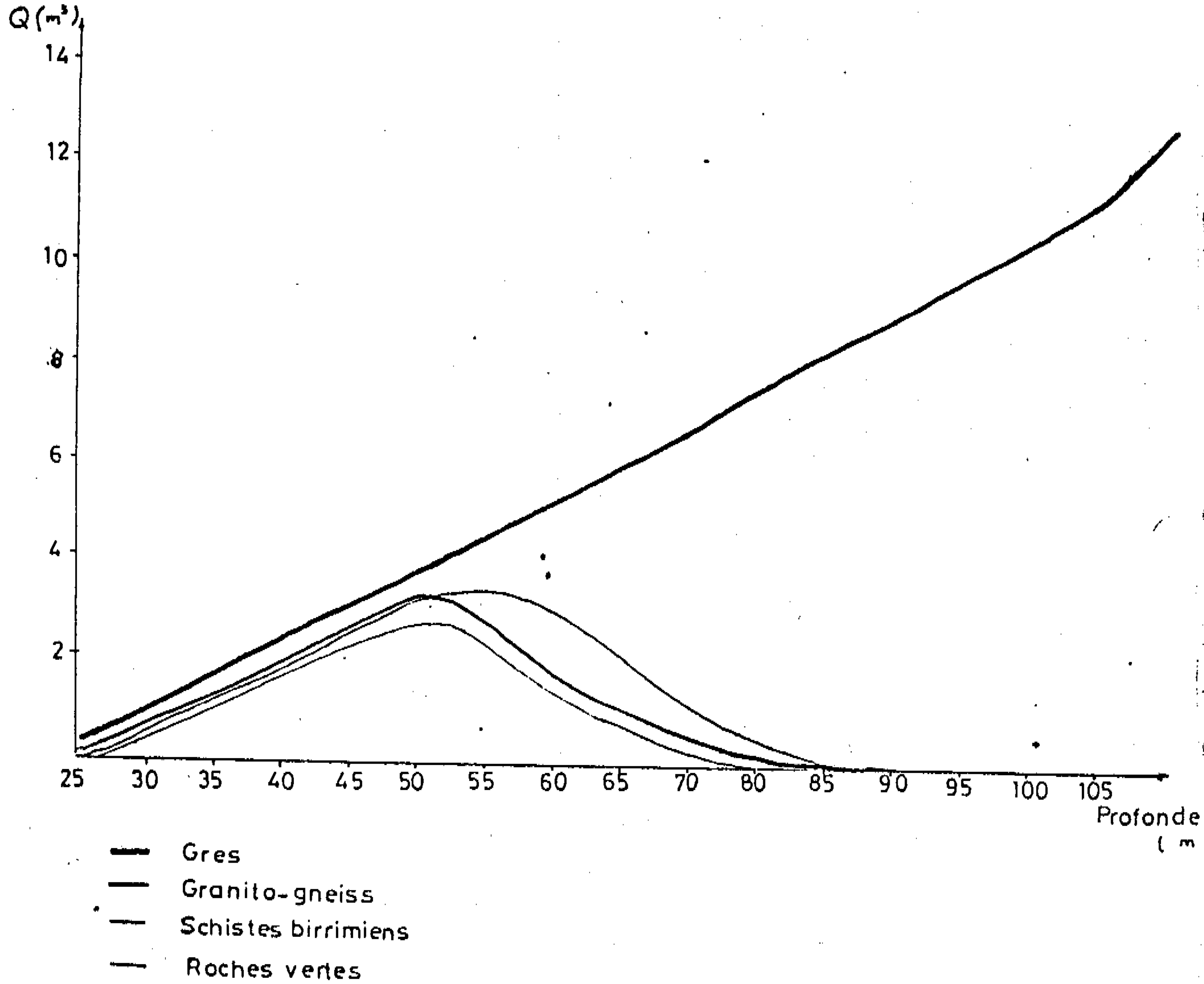
EVOLUTION DU DEBIT EN FONCTION DE LA PROFONDEUR DU FORAGE ET DE LA NATURE DES ROCHES



However, groundwater flowing in fractures in the overlying strata (Koutiala and Bandiagara sandstones) is important and often forms, at its base and at the top of the toun shale, some very important suspended aquifers.

The Koutiala sandstone is considered permeable when it has not been recrystallized by water circulating in fractures and joints. The retention of vadose water by these rocks depends upon the degree of fracturing.

The Bandiagara sandstone is not porous or permeable, but an important net work of fractures and joints allows abundant groundwater circulations near and on buiffs indicate resurgent points of water bearing layers (often at the contact between the underlying toun shale and the overlying sandstone).

Summarily, the permeability in all these formations would be greatly enhanced by the presence of fractures, joints and faults.

The Bandiagara sandstone is more jointed than the Koutiola and basal sandstone. Jointing in the toun shale is less important than in the sandstone formations. Dolomite and sandstone are the best aquifer rocks, and the shales are the poorest.

Differences in well yield on the various sedimentary formations tend to reflect differences in degree of weathering or fracturing rather than inherent differences of mineralogy or fabric within the rock.

Observation of geological cross section on the sedimentary basins, namely in the Djissara, Dianssaga and maomi areas. show the following sequence.

- indurated carapace - fractured and permeable
- middle transition zone is concretionary and irregular with a certain interstitial permeability resulting from fractures.
- clayey layer, less permeable.

It is therefore not suprising that local (traditional) shallow wells situated in laterite are known to dry up during the dry seaqon, thus a constant yield is not expected from these wells.

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6.2.3.2. Rocks of Project Area

a) General and local rock parameters

The crystalline rock (hard rock) terrains comprise of a great variety of igneous and metamorphic rocks. But from the hydrogeological point of view they are rather homogeneous in two aspects. They have virtually no primary porosity as do sandstones and other sedimentary rocks. They have a secondary porosity due to fracturing and weathering, which permits the flow and storage of groundwater. The storage capacicy of unweathered hard rocks is restricted to the interconnected system of fractures joints and fissueres in the rock. Such openings are mainly the result of tectonic events.

Weathering process have considerable influence on the storage capacicy of hard rocks. Mechanical distingration, chemical solution and deposition, and the weathering effects of climate and vegetation bring about local modifications of the primary rock and its fractures. This action can imply either and increase of the original fracture pattern of the rock. The transition zone between the weathered layer and the underlying fresh rock can function as a reasonably good aquifer, depending on the porosity of this zone.

FRACTURING IN INTRUSIVE ROCKS

Fine - grained rocks such as aplites generally show a dense pattern of fractures. In such rocks individual fractures usually are very limited in areal extent. On the other hand coarse grained rocks such as granites generally develop fractures up to hundreds of meters long. These fractures usually are widely show weak cohesion among the individual crystals. Therefore the rock body is brittle and may fracture easily with applied stress. Depending on the local tectonic framework, granitic rocks may be maghly fractured white in the same region basic rocks as diorites and gabbros will be less fractured (Larson, 1968).

METAMORPHIC ROCKS AND FRACTURING

The degree of metamorphism seems to determine the strength

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of the rock against fracturing. In India characteristic high-grade metamorphic rocks (charnokites) show almost no fracturing. But lewer grade metamorphic rocks of as biotite gneisses, which crop out close to charnokite bodies, have normal to heavy fracturing. This seems to be a general condition. Extremely low-grade metamorphic rock as schists are often heavily fractured.

To the hydrogeologist the importance of fracturing in the rocks, is the development of a fracture porosity. This means that open fractures lying below the groundwater level can store water.

The type of deformation in the crystalline rocks of the study region cannot be discussed in detail, however references have been made to schematic diagrams to give an insight to some fracture systems (Tams Report 1978).

Effect of weathering in the crystallin rocks and the development of groundwater aquifers offers the hydrogeologist important dues to aquifer regime.

Although there is a considerable potential range in the thickness, areal extent and physical character of the weathered layer from place to place, the typical profile begining with the fresh host rock at the bottom and progressing downward from the land surface may be summerised as follows.

Zone a) Sandy clays or clay sands often concretionary. Generally no more than a few meters thick.

Zone b) Massive accumulation of secondary minerals (clays) in which some stable minerals may be preserved in their original form. Its thickness may reach yp to 30 meters. High porosity but low permeability.

Zone c) Rock which is progressively altered upward to a granular friable layer of disintegrated crystal aggregates and rock fragments. May range in thickness from a few metres to 30 metres.

Zone d) Fractured and fissured rock. May range from a few tens to several scores of meters in thickness. Low porosity but moderate permeability of fracture systems.

.../...

In most places zone (a) is essentially a continum with the C. horizon of the soil profile. The B horizon is commonly the most compact part of the soil profile and is the locus of most intensive deposition of nodules and/or layers of ferruginous and/or aluminous laterites in humid and sub-humid tropical environment (laterization and pedogenic regime).

Where the climate is semi -arid or wet dry-tropical (calcification pedogenic regime). The B horizon is the locus of deposition of modules and/or layers of calcium carbonate know locally as Kankar, calich croute calcaire, calcrete or hardpan, indicating at last temporary groundwater discharge.

To contain significant aquifers with exploitable groundwater the weathered layer must attain a minimal areal extent and thickness and have sufficient porosity and permeability to store water and to yield it to wells from season to season. Extensive and thick weathered layers are likely to contain the most viable and productive aquifers.

Many productive wells, where groundwater is developed for rural water supply, livestock or samll scale irrigation, tap aquifers in zone c) of the weathered profile which averages of about 10-20 m in thickness.

6.3.1. - CASE STUDIES OF GROUNDWATER POTENTIAL IN THE FRACTURED AND WEATHERED CRYSTALLINE ROCKS OF THE PROJECT AREA.

Well log data from the villages of Werewere (Gaoua) Kampti Oualkoye, Zinkapoko and Bondigui all on granito-gneiss and schist terrain, have revealed striking resemblance of the general discription given above. Most of these rocks are inherently impermeable. However, facturing or faculting as indicated on the lineament map of Burkina Faso, (TAMS report - 1978) have produced secondary porosity and permeability in the rocks. Moreover, the increased weathering within these fracture zones have increased porosity and permeability. Weathering in some of the basement rocks, as observed from profiles of traidtional dug wells in the areas of Yergeresso, Tondohso, Kotedogo, Bodialindaga and Yalasso, have resulted in lateritic cover, which serve as potential shallow aquifers. The highest well yields in these basement rock terrain occur in either the fracture zones or in the residual weathered horizon (course materials such as sand and gravel beulders.

The Igneous and metarmorphic basement rocks of the Birrimian, which are refered to as the Precambrianc, consists of a great thickness of isoclinally folded, metamorphosed sediments intercalated with metamorphosed taff and lava. These formations do not form a continous and extensive aquifers as the sedimentary formations. Groundwater accumulates in weathered depressional areas within the basement separated by outcrops of unaltered or unweathered rock. Because the aquifers lack continuity, in a given basement area, it is difficult to predict the chemical character of the groundwater.

The basement rocks weather primarily into sandy, sandy argillaceous and argillaceous soil horizons and in places into indurated lateritic ironstone horizons, (observations from Copper and Gold prospections in the Gaoua and Hounde areas) The depth of the residual weathered material range from a few to several tens of metters. Perennial water reserves within the weathered zone occur where this zone is over 10 meters thick, but yields are very low.

.../...

Quartz veins weather into quartzitic pebbles (well log data observation) and course textured material which constitute petrographic discontinuities which act as drains within the weathered clay zone.

The schistose rocks weather uniformly into a clayey soil and favourable aquifers are present only where there is fracturing. The weathering profile is simpler than that of the granite or gneiss. There is essentially a cleyey phase of the basement level which is generally not too permeable (Benamour 1973). Well yields range from 0-20 m^3/h and average 8. Depths range 25-70 meters and average 40. Aquifer transmissivities are in the 10^{-5} to 10^{-4} m^2/s range.

The weathered prfile of the granitic gneissic rocks vary from the Schist formations. The Upper laterite tronstone horizon A may serve as a shallow aquifer, however, it may or may not be present in discrete horizon. Horizon "B" composed of Kaolinitic clay and horizon "C" composed of Clayey residual sand, also may be absent. Horizon "D" the basal weathered zone which consists of coarse sand boulders and fractured bedrock, and horizon "E", the fractured bedrock are important aquifer horizons.

TYPICAL WELL YIELDS AND DEPTHS IN THE GRANITIC-GNEISSIC ROCK FORMATIONS

Horizon	Well yields (m3/h)			Well Depths	
	Range	Average	Exceptional	Range	Average
A and C	0 - 5	0 2	10	5-30	15
	0 - 10	4	20	30-70	40

Source ... TAMS Savana regional water resources and landuse, 1978.

In those granitic-gneissic terrains that are not deeply weathered, water can circulate freely in the highly fractured zone of the upper surface of the basement. Benamour (1972) notes that the highest groundwater yields in granitic gneissic rocks are obtained in the fractured zones.

The Dolerites, as dikes and sills, provide obstacles to groundwater circulation.

The dolerite dikes form underground dams and the sills provide a wall or a roof for an aquifer sheet. The rarity of fractures and joints in the doleritic formations help to maintain their impermeability.

Summarily, the hydrogeological significance of the degree of weatherin and the intensity of fracturing in both the sedimentary and the crystalline rock formation contribute to the storage capacity of the aquifers, the water yield potential and the chemical quality of the groundwater reservoirs. Where the weathered layer is thin or absent, as it happens in the Kampti Doudou areas, all the groundwater movement and storage occurs in the open fractures (Geophysical survey - "Inventaire des ressources en eau" - IWACO - 1978).
Also in such areas, surface drainage networks are commonly aligned along the fracture system in the underlying granitic - gneissic formations. Relatively little recharge to groundwater in such fractures takes place by direct infiltration from rainfall. Rather recharge occurs chiefly by infiltration from streams where these cross or closely follow open fracture traces. Percolating water moves down the hydraulick gradient through open fractures and discharges through springs at points where the traces of closed clay-filled fractures intersect stream channels, or where masses of impervious unfractured rock interrupt the continuity of open fracture systems.

Where thick weathered layers are well developed (Black Volta Basin) (Vallée du KOU area) as is the case in the lowland peneplains, virtually all percolating water must necessarily move through the weathered layer before it can enter deeper fracture systems in the unweathered rock. Thus, shallow groundwater is commonly stored transiently in the weathered layer, as evidenced in the study of machine dug wells and the traditional wells of the area.

In the crystalline rocks of the lowland terrains, the areas of weathered hard rock groundwater bodies tend to be relatively small ; with surface areal extent only few kilometers. Many of such bodies are contiguous with the valleys of fairly through flowing streams which may be either ephemoral or

.../...

perenial. Other basins may lie in systems of interior drainage with a central discharge sump or pan. There may be several independent groundwater systems developed in lowlands of weathered rock. Moreover, enven beneath peneplains of relatively large areal extent and seeming continuity subsurface interruptions or disontinuities of unweathered and unfractured rock may occur. These divide the weathered rock as well as contiguous underlying fracture systems, into fairly small "cells" each of which functions as an independent hydrologic unit in so far as the recharge and discharge of shallow groundwater and the areal distribution of water quality are concerned.

The hydrogeological characteristic discussed in the text of the provinces of Bougouriba, Houet, Kenedougou and Poni are summarised in the tables that follow.

T A B L E

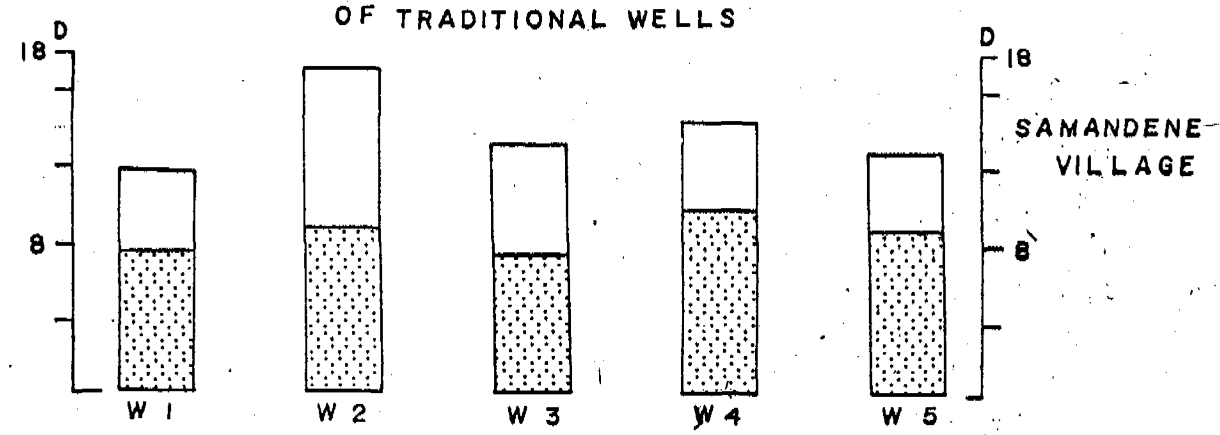
POSITION OF TRADITIONNAL WELLS (HAND AND WELLS)
RANDOMELY SAMPLED DEC. 1985

NAME OF VILLAGE	WN	LW m (meters)	DW m (meters)	DMW m (meters)	TNW	WYP + Ve -Ve	UT o.1 house hold
DANDE 1	LW 1	4.40	8.70	1.00	1	+ Ve	1
	LW 2	4.00	6.20	1.00	2	- Ve	1
	LW 3	4.10	9.20	1.30	3	+ Ve	1
	LW 4	4.80	8.60	1.50	4	- Ve	1
DANDE 2	LW 1	4.60	8.00	1.10	5	- Ve	1
	LW 2	4.70	7.80	1.30	6	- Ve	1
	LW 3	4.40	6.20	1.00	7	- Ve	1
	LW 4	4.80	6.80	1.00	8	- Ve	1
	LW 5	4.00	5.70	1.00	9	- Ve	
DANDE 3	LW 1	2.60	5.30	1.00	10	- Ve	1
	LW 2	2.10	4.40	1.20	11	- Ve	1
	LW 3	3.40	5.60	1.20	12	- Ve	1
KOTEDOUGOU	LW 1	4.60	5.80	1.00	14	- Ve	1
	LW 2	5.40	7.80	1.10	15	- Ve	1
LANFERAKOURA	LW 1	5.10	6.80	1.50	16	- Ve	1
	LW 2	5.40	5.90	1.00	17	- Ve	1
DARSALAM I	LW 1	0.50	9.10	2.00	18	- Ve	1
	LW 2	6.40	10.20	1.50	19	- Ve	1
PADEMA	LW 1	5.00	11.70	1.50	20	- Ve	1
	LW 2	4.80	11.10	1.50	21	+ Ve	1
	LW 3	6.20	12.20	1.00	22	+ Ve	1

CONTD

NAME OF VILLAGE	W N	L W m	D W (m)	D M W (m)	TNW	WYP	U.T.
PENI	LW 1	20.30	20.50	1.00	23	- Ve	1
	LW 2	11.70	19.20	1.00	24	- Ve	1
	LW 3	21.40	22.20	1.50	25	- Ve	1
	LW 4	21.45	22.60	1.30	26	- Ve	1
SAMANDENI	LW 1	3.90	7.70	1.50	27	+ Ve	1
	LW 2	8.30	8.70	1.00	28	- Ve	1
	LW 3	5.60	7.50	1.00	29	- Ve	1
	LW 4	4.40	9.80	1.00	30	+ Ve	1
	LW 5	4.00	8.60	1.00	31	+ Ve	1
SEGERE	LW 1	6.90	11.60	1.50	32	+ Ve	1
	LW 2	7.60	12.40	1.20	33	+ Ve	1
TAGA	LW 1	6.70	10.80	1.25	35	- Ve	1
	LW 2	7.80	10.30	1.20	35	- Ve	1
TOUGOUKOURA	LW 1	7.90	10.60	1.00	36	- Ve	1
	LW 2	6.80	11.50	1.00	37	- Ve	1
	LW 3	6.90	11.00	1.20	38	- Ve	1
TOUSSIANA	LW 1	16.20	16.40	1.30	39	- Ve	1
	LW 2	6.80	9.90	1.50	40	- Ve	1
	LW 3	10.00	12.20	1.30	41	- Ve	1
	LW 4	10.40	11.60	1.10	42	- Ve	1
	LW 5	11.40	11.80	1.20	43	- Ve	1
ZONGOMA	LW 1	3.70	5.50	1.60	44	- Ve	1
	LW 2	3.90	6.10	1.40	45	- Ve	1

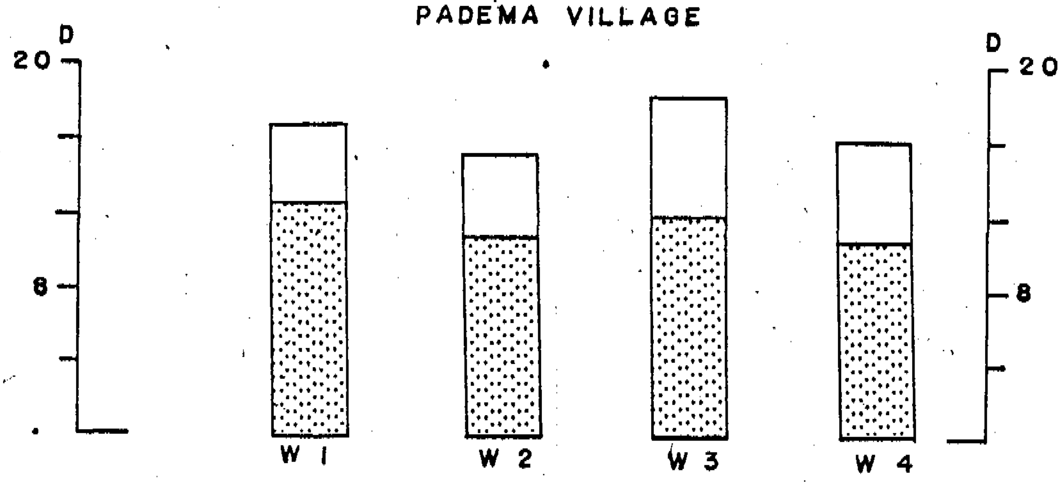
MORPHOLOGICAL CROSS SECTION AND PIEZOMETRIC PROFILES OF TRADITIONAL WELLS



1cm= 4m

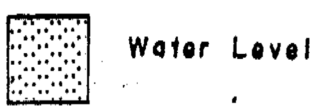
D = depth in metres

PADEMA VILLAGE

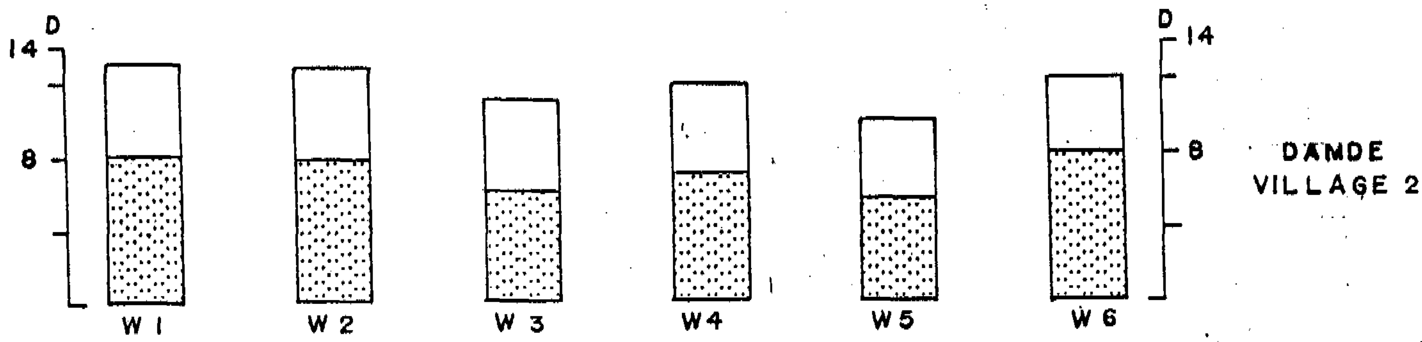


1cm = 4m

D = depth in metres



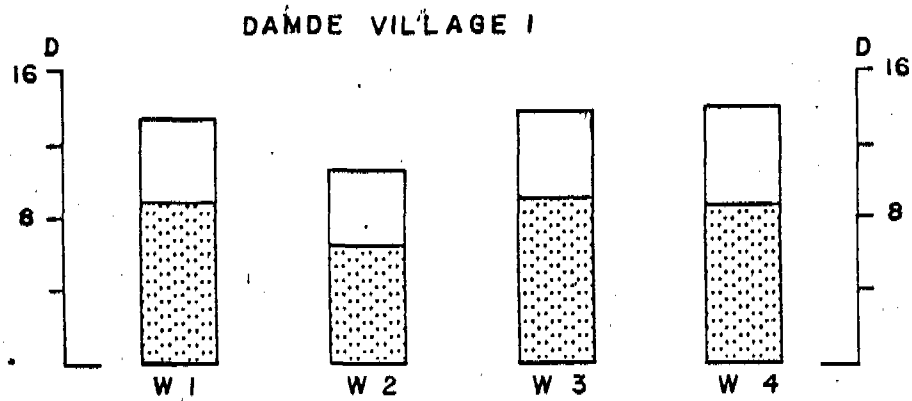
MORPHOLOGICAL CROSS SECTION AND PIEZOMETRIC PROFILES OF TRADITIONAL WELLS



lcm = 4m

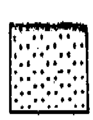
D = depth in metres

DAMDE VILLAGE I



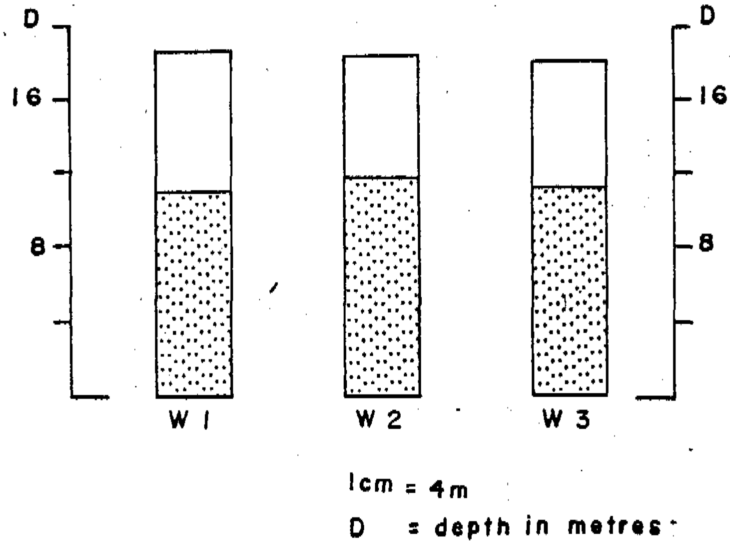
lcm = 4m

D = depth in metres



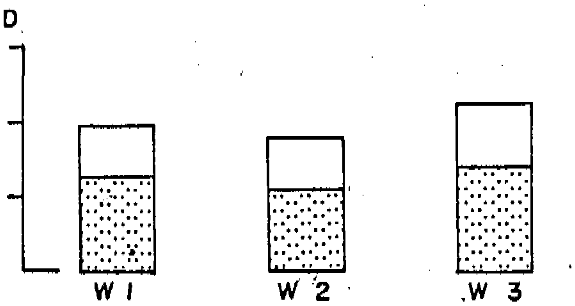
Water Level

MORPHOLOGICAL CROSS SECTION AND PIEZOMETRIC PROFILES OF TRADITIONAL WELLS



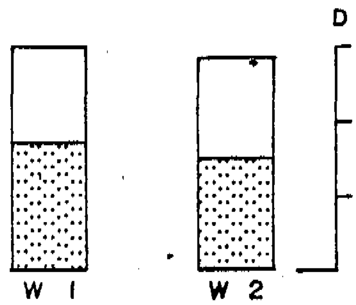
TOUGOUKOURA VILLAGE

DAMDE VILLAGE 3



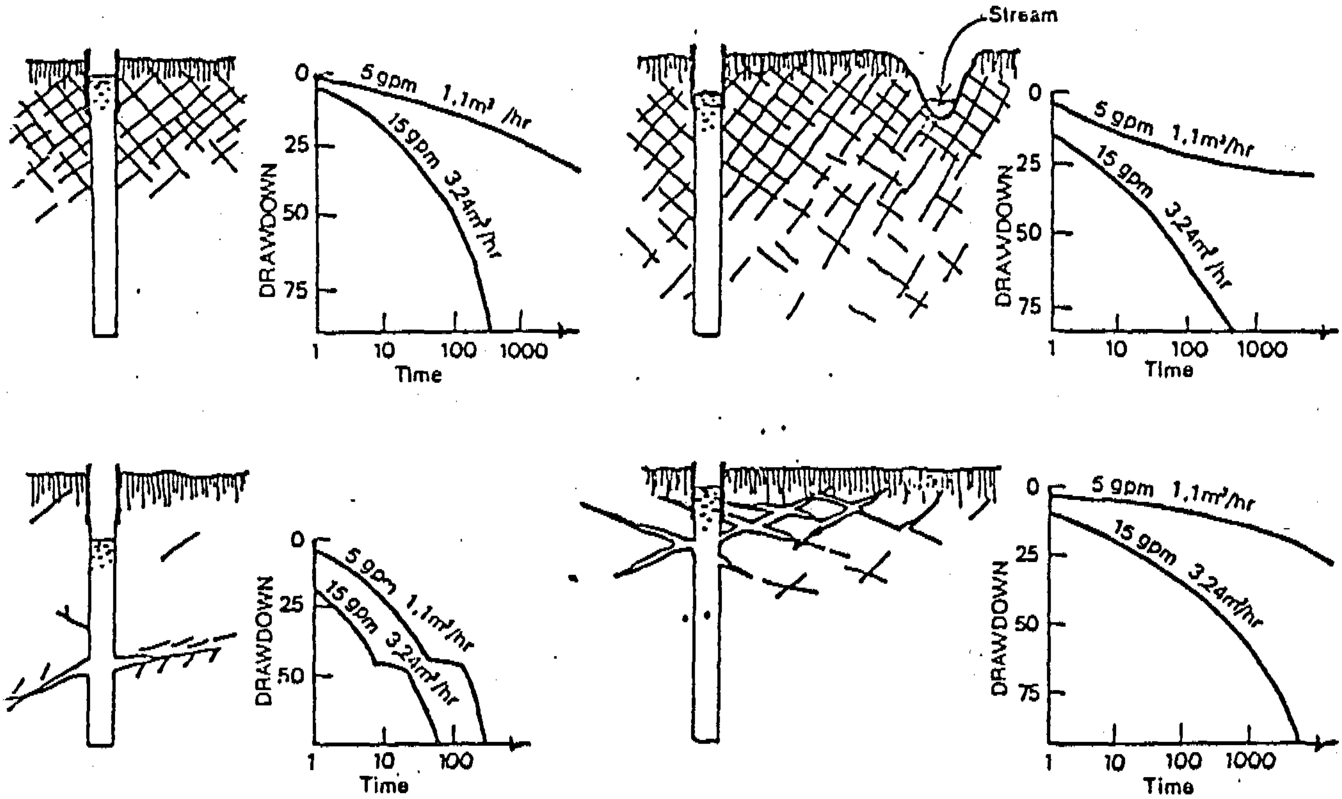
1cm = 4m

LAMFERAKOURA

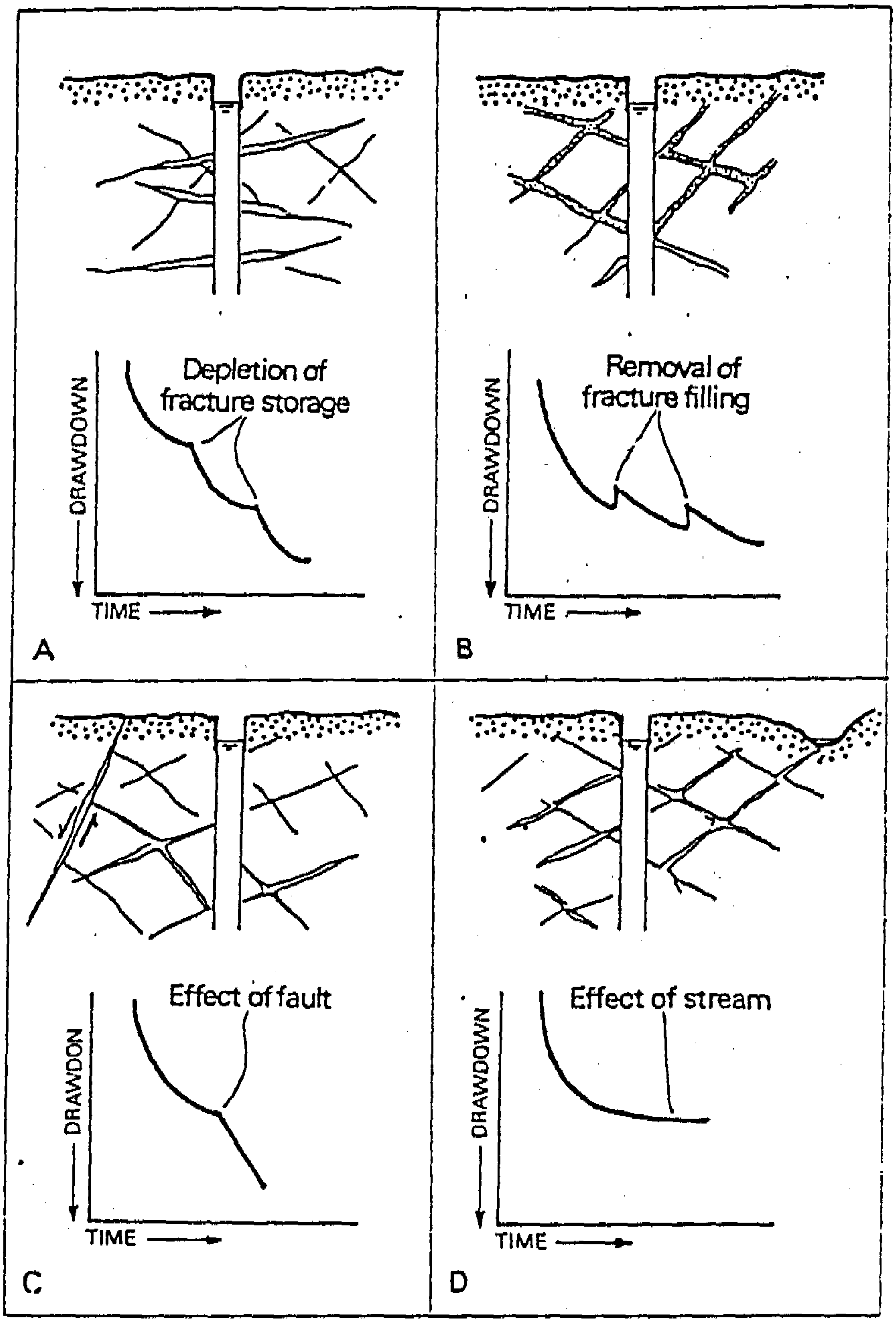


1cm = 4m

D = depth in metres



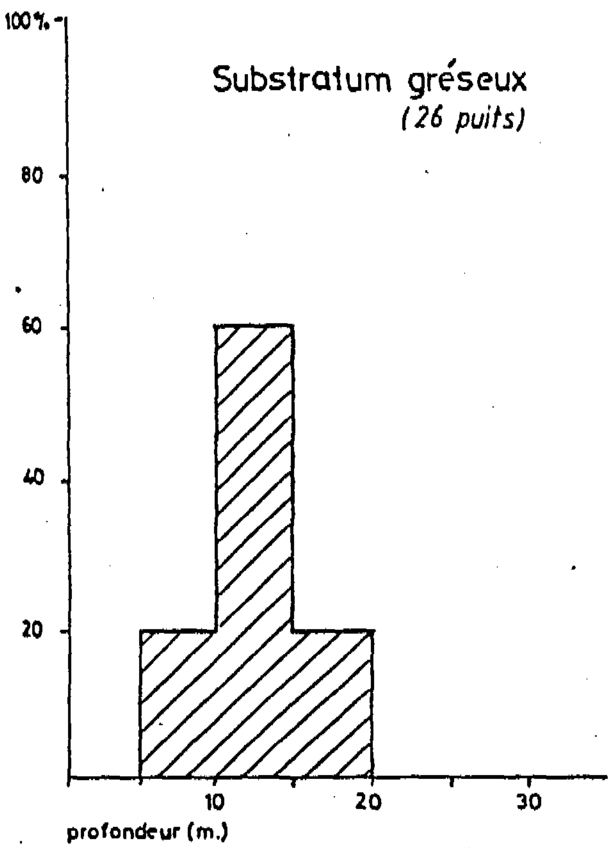
Hypothetical drawdown curves for wells in fractured crystalline rock at various pumping rates, a) Production from small, near-surface fractures; b) Production from extensive and widespread fracture system; c) Production from large but limited fracture; d) Production from large and shallow fractures that drain overlying weathered rock or soil (Modified from Davis and DeWiest, 1966).

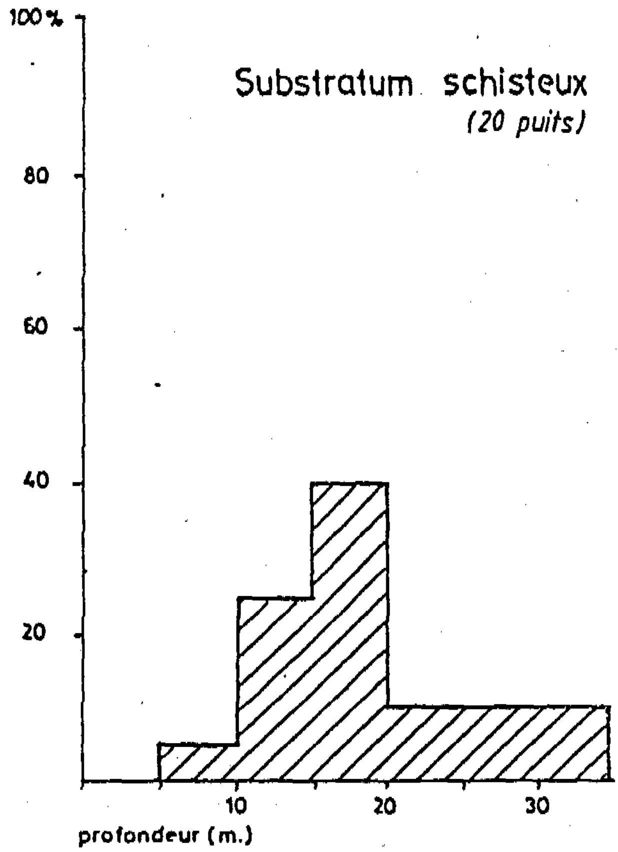


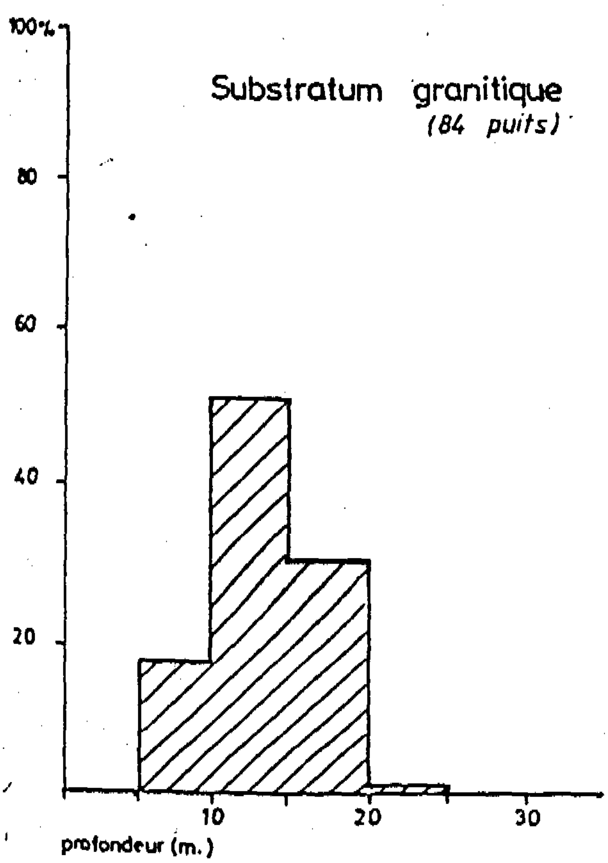
Hypothetical drawdown curves for wells in fractured crystalline rocks in response to fracture characteristics and local structure.

A) Production from large but limited fractures
B) Production from large fractures partially filled with fine-grained material
C) Production from large fractures with tight fault zone as an impermeable boundary
D) Production from large fractures with a nearby source of recharge from a surface source.
(from Davis and DeWiest, 1966) (Reprinted by permission of John Wiley & Sons).

Histogrammes de la profondeur mésurée des puits modernes dans les différents substratums hydrogéologiques







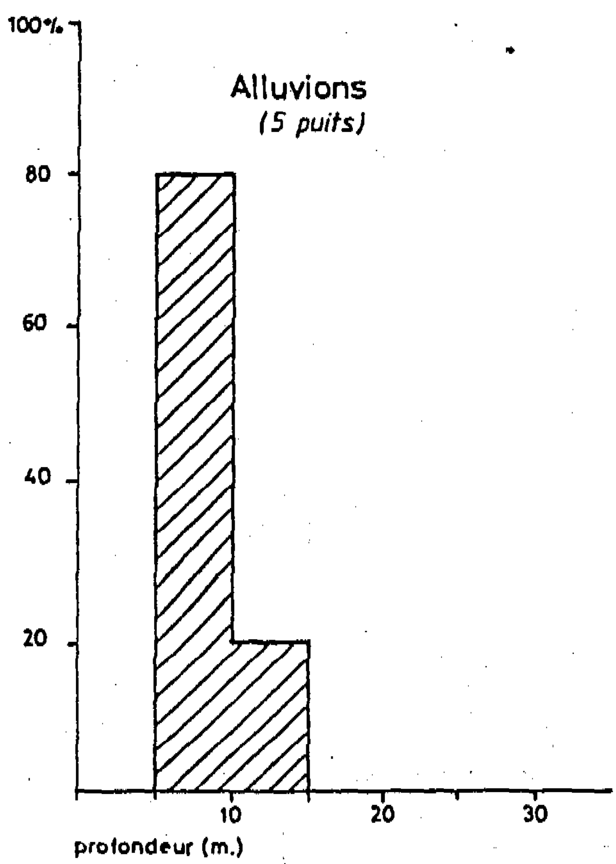


Planche 4.4

6.4.1. Hydrochemical characteristics of the Project Area

6.4.1.1. General Aspects

The major dissolued components in groundwater are positive ions of chloride (CI^-), sulphates ($SO4^2$), nitrates ($NO3^-$), bicarbonate (HCO3) and silicic acid. In addition there may be varying levels of ammonium and flouride ions.

The chemical quality of groundwater tends to be quite variable from place to place and even from season to season. This result in part from the compartmentalisation of rock formations into discrete groundwater basins or cells each of which may have an independent recharge - discharge regime.

Groundwater regime tends to be best in regions where seasonal recharge from rainfall is applicable and there is active groundwater circulation. Conversely, the quality tends to be poor where recharge is small or sporadic and evaporation rates are high, concentrating and accumulating salts in the residual groundwater. Commonly in the semi-arid, and arid regions of the topics and subtropics where the annual rainfall is small, the groundwater in hard rock terrains is often of poor quality with total dissolved solids greater than 3000 mg/l. Water containing from 3000-5000 mg/l of dissolved salts may still be usuable for livestock and for irrigation.

Locally, even within the same climatic belt, there can be considerable variations in water quality from one point to another. These variations can be attributed to different rates of recharge and discharge within neighbouring groundwater cells and to local chemical differences in the host rock and its weathered products.

Also within the same water groundwater basin, recharge areas tend to have lower salinity than discharge areas, where salts are concentrated by evaporation. In many closed basins in semi-arid or arid regions, the water contain 10,000 mg/l or more of total dissolved solids and hence be so saline as to be unsable.

Available analytical data on groundwater quality in some of the areas IWACO. Inventaire des ressources en Eaux - Burkina Faso 1978) is shown in the table.

Using de Piper diagram the result are as follows :

- high % of HCO_3 in the granitic rocks.
- high % CI^- and SO_4^2 in the sandstone terrain. Very poor mineral content in the aquifers

Diagramme d'analyses hydrochimiques

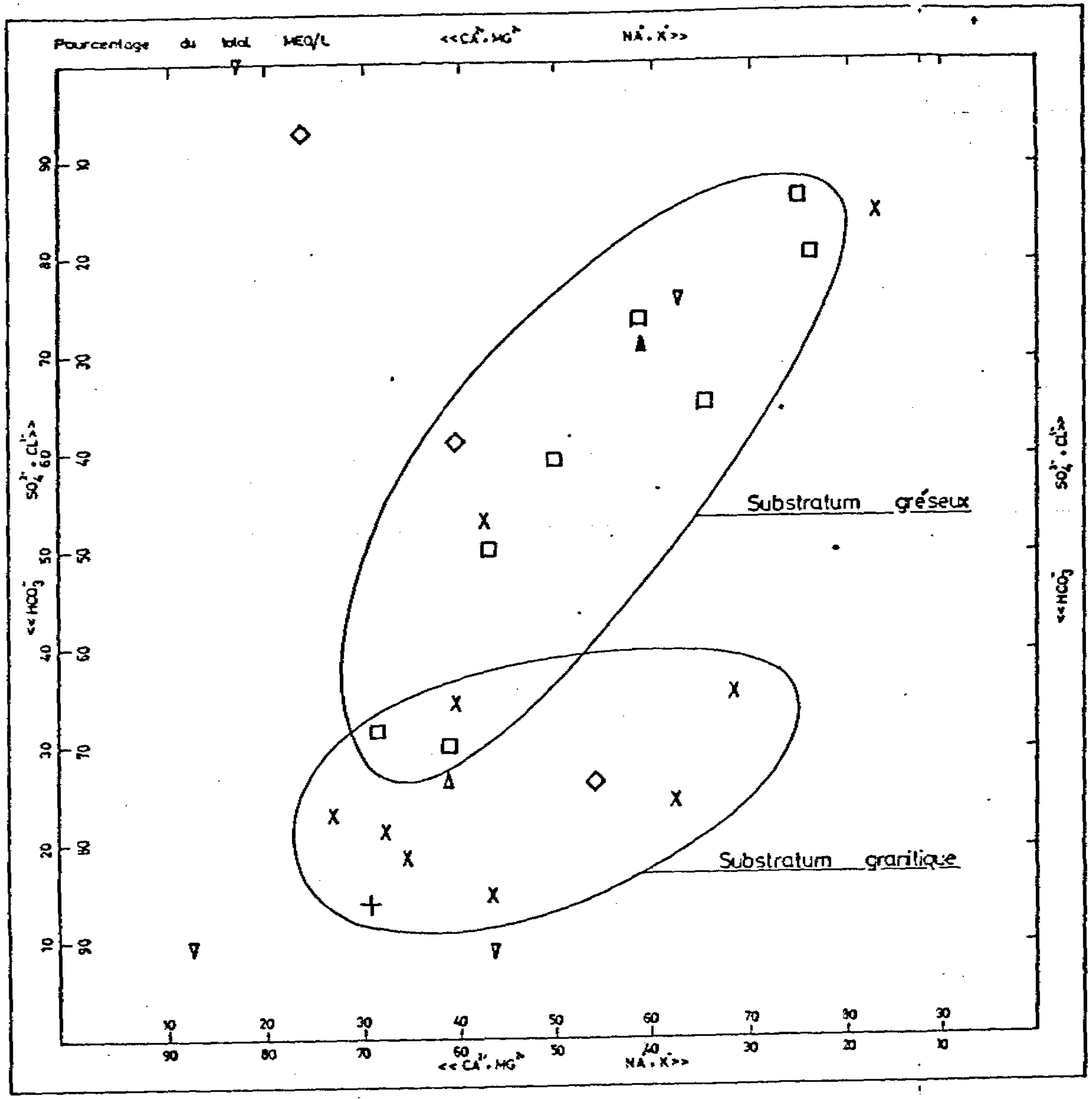


Diagramme de Piper

Δ ALL sans analyse de sulfate
+ GF " " " "
□ GRES " " " "
◇ GRES avec analyse de sulfate
X AAG / GA / GF
∇ AAS / SCH
▲ Robinet

The pH content in the sedimentary aquifers have high percentage (pH of 4-6). N° pH content was recorded for schist terrain and the alluvial aquifers.

In some of the open wells (machine dug wells) a pH of 11 was recorded in 1978 ; the reason is that the wells were not cleaned up after being dug.

The variations in chloride concentrations reflect the recharge rates at the point. In permanent groundwater discharge areas, where evaporation is strong enough to prevent water from appearing at the surface, elevated concentrations of chloride are possible.

6.5.1. Summary of Groundwater Investigation Assessment and Development in the Project Area

Ideally groundwater development should be proceeded by proper investigation and assessment. In many cases, groundwater development has been satisfactory in spite of the lack of data and lack of Scientific inquiry, as it happens in many rural water supply projects in west Africa. When a given area is first developed and when the groundwater extractions are small in comparison to the total resource, no harm is done.

As extractions become greater in comparison to the resources, and as the local economy becomes more dependent on assured groundwater supply, investigation and assessment become more important. When the water extractions equal or exceed the resources, the effect on the local economy may become serious if adequate precautions are not taken.

a) Different levels of Investigation

In arid or semi-arid areas like the project area, of the four provinces, even small amounts of groundwater may be of important socio-economic value and therefore warrant careful investigation and assessment.

Investigation and assessement can be undertaken at various levels of detail and/or intensity. Reconnaissance investigations usually are carried out in a short span of time with only limited use of more costly techniques, and may only provide a preliminary assessment of resources.

The relations between purpose of study and funding is an important to be taken to consideration. Funding is usually one of the constraints to the level of study and to the extent of development of groundwater. Groundwater development is usually carried out over extended periods of time but is normally phased or staged. Thus when funding for reconnaissance studies, some provisions may be made to include limited groundwater exploitation which later provides data for further refinement of resource estimates and for decisions on expanded exploitation.

In summary, the selection of methods of investigation and assessment of groundwater may not be under control of the technical staff if funds are limited. However, the selection of methods is important at the funding stage. Such is the emphasis of this section.

6.5.1.2. Evaluation and selection of methods

As discussed above, financing may place very strict limits on the choice of techniques. While experience and an open mind are required, it is obvious, that the least time and money consuming techniques should be used first.

Interpretation of geomorphic and geological features on available maps, aerial photographs, and Landsat imagery is the most reasonable first step. This should be followed by field reconnaissance and further map interpretation.

In deeply weathered areas, or areas covered by shallow surficial deposits, obviously favourable zones may be tested and perharps extended by geophysical methods. Normally results of geophysical methods are analysed using all available surface outcrop and subsurface data.

A common problem arises in the areas with no outcrops and where there are no wells against which to calibrate the interpretation of geophysical investigations. Where possible, the best way to approach this problem is to start a test drilling programme to obtain some subsurface data, then to carry out the geophysical sutdies to decide on the remaining drilling programme.

This project will benefit greatly, through the use of geophysical techniques and applying remotely sensed data (aerial photographs and satellite imagery).

The availiability of satellite images enables the geologist, to economise on survey time by selecting or rejecting areas in a first reconnaissance survey of large regions whith scanty information. In a second phase, more detailed study of selected areas by means of aerial photographs should be carried out, supplemented with field checks and observations.

In contrast to the sedimentary terrains of the sandstone formations in the north west and southern portions of the project area, where groundwater is to be found typically in the spoies of horizontal strata of rocks like sandstone or in the interstitial spaces of deposits like sand lenses, in crystalline rock (granites, gneiss) terrains groundwater occurs in fractures, fissures, crushed zones and joints.

The object of geophysical exploration is to locate such features. Generally, the overburden, which may consist of transported material or the products of in - situ weathering of the underlying rock, is of small thickness so that water - bearing systems of hard rock (crystalline rocks) areas commonly lie at shallow depth in contrast to the aquifers of sedimentary terrains. If the loose overburden is usually thick, geophysical methods may be needed for finding its thickness apart from locatin fractures faults and joints in the formations. The choice of type of geophysical . method depends on the information needed. However, electrical resistivity methods have proved very rewarding in groundwater investigations in the crystalline rocks of Burkina Faso (Réf. report on rural water supply programme IWACO 1978).

6.5.3. Groundwater Assessment and Development

6.5.3.1. General aspects

Steady increase in population in many developing countries has generated a strong demand for water in general and for groundwater in particular, especially in hard rocks. Current master plans for rural water supplies make provisions on the basis of a minimum of one well for 500 to 1000 inhabitants (United Nations, 1973). This is considered a critical minimum below which high rates of migration will be experienced. The water supply required under such critical conditions is approximately 10 litres per capita per day, supplied by wells. One or more wells would be required to produce 25 m^3/day for a village of 1000 inhabitants only. Adding village requirements for 500 head of livestock, a groundwater supply of 50 m^3/day becomes the critical minimum water supply for the village. Of course, supply requirements would increase linearly with population increase.

The state of water supply in the project area observation of water yield potential (IWACO. Report 1978, TAMS Report 1980) in the project area, even the critical minimum water supply to the rural population is hardly attainable.

Considering the potential yield in the hard rocks terrains, and the lack of adequate funds and technical expertise, a significant part of the solution to water supply requirements is the construction of dug wells with the construction of drilled wells as emergency support.

Dug wells, if sited on the basis of the best available geological techniques can meet requirements in areas of with apparent low groundwater potential (GWP.).

Although the increase in need has for outstripped the potential construction rate of dug wells, such wells are, and will remain in the foreseable future the most economically and socially practical source of water in crystalline rock terrains.

In hard rock areas, drilled wells, although relatively expensive at present, could serve two roles :

- the first is to meet emergency requirements since they can be drilled in a matter of day or two, as opposed to a month or more to construct a 30 meter deep dug well (ref. drillers log data time recording in the Bobo rural water supply project).
- the second role is to promote rapid development of an area to assist in producing cash crops and industrial products, which in turn increases the regions wealth.

It is apparent that both dug wells and drilled wells would do remarkably well in the crystalline rock formations of the project area, especially those areas with low groundwater potential (relative to sedimentary basins where groundwater potential is generally high).

6.5.3.2. <u>Traditional Hand - dug wells</u>

The traditional wells are generally dug by simple hand excavation techniques using a pulley or windlass with buckets and hand lines for removal of soil and rocks. Such wells have been dug to depths of 10-20 m. Many are unlined, except for a surface curbing and usually of diameters between 1-2 meters. They seldom penetrate more than a few meters below the water table and often go dry with the decline of the watertable in the dry season. The wells are subject to gross pollution and occasionally cave in endangering the lives of the local herds and farmers. Although there are still many of these wells, (in Dande there is a local well for each household) they are gradually being abandoned in favour of modern open wells.

6.5.3.3. <u>Modern dug wells</u>

These wells use the sinking shove method of construction. Considerable mechanical equipment including derricks, air compressors, jack hammers, explosives and sinking pumps is used as well as a large component of hand labour.

Virtually all modern dug wells require one or more deepening before a viable water supply can be assured through the dry season ; most of the machine dug open wells in the project have undergon once or twice deepening.

the prevailing rationale for the modern open dug wells or closed wells fitled with a hand pump is the provision of clean water for basic village use and a qell from which water can be with drawn with minimum maintenance requirement. The well yields in the sedimentary formations are very high, those on the crystalline formations are less productive. Also yields tend to fluctuate seasonally wells which produce about $5m^3/l$ during the rainy season may produce only $1m^3/l$ or even less at the dry season.

These modern dug wells provided with covers for sanitary protection, and equiped with hand pumps for water extraction have not been generally viable due poor maintenance. Except locally where regularly maintained by concerned volunteer, charitable or religious groups. In the absence of maintenance, the pumps fail, the covers are broken and water continues to be drawn by the villagers by hand line and bucket. Until the pump maintenance problem can be resolved it will be necessary to continue to rely on modern open wells for basic and livestock supply.

6.5.3.4. Mechanically - excavated wells

In addition to the prevailing open dug well, which requires a large component of hand labour, mechanical boring equipment is currently being used to construct large diameter (0.8 - 1.0 m) wells for village supply in the wealhered layers of the crystalline terrain. This method is useful for reconnaissance as well as production. The laterite duricrust of could be penetrated with no problem. Also because of the rapidity of construction, the fluid soupy clay layers can be controlled with working casing, where not thick.

The method does not lend itself to penetration vary far into depth. The effective depth limit of most wells contructed by this method is 25 m.

6.6.1 - CONCLUSION AND RECOMMENDATIONS

The investigation, assessement and development of rural water supply of the project area described in this report is incomplete due to limitations posed by time. Important topics worthy of consideration which would have been covered are those concerned with.

a) Water balance of the sedimentary basins
b) Water balance of the crystalline basin
c) Exploration techniques
d) Evaluation of pumping tests.

Those are few of the topics that could have contributed to the evaluation of groundwater potential for the four provinces. The conclusions that could be drawn however from the available data are as follows.

GROUNDWATER YIELD

The yield potential is high in the sedimentary terrains than the crystalline rock terrain.

- There is a general correlation of wells having higher yields with areas having high lineament density.

- There is a general correlation between well yield and rock type. The aquifer rating indicate high yield in the sedimentary than the crystalline formations.

There is a general correlation between highly weathered formations (degree of weathering) to potential water yield.

There is a general correlation between well depth and well production. Deeper wells seem to penetrate the highly fractured and weathered rocks where aquifer yields are possible.

- Evidence of aquifer continuity is prominent in the sedimentary basin. There is a general discontinuity within sedimentary formations, which are poorly fractured.

Hydrogeological boundaries in the formations are the result of dolerite intrusions, existence of faults or presence of impermeable non poorous layers.

Relationship between surface water hydrology and groundwater resources do not exist,generally, the intermittent flow of streams show that there are no groundwater aquifers draining into the stream channels.

The water quality appears to be satisfactory for domestic and municipal supply despite the general pollution infected by the users themself.

Both confined and unconfined aquifer conditions occur in all the geologic formations. Storativity and permeability in the rocks are a function of the rock type and the morphological and structural components.

Groundwater exploitation does indicate any threat to water deplection, in the areas which may lead to groundwater mining. What is need to be discouraged is the profuse local well exploitation.

The water requirement needs for the villages have not been sufficiently met. The number of modern dug wells do not reflect the population density.

The maintenance of handpumps are irregular and sometimes non existence.

The use of cost effective methodologies like geophysical prospecting and remotely sensed data, would contribute significantly to effective site selections.

Summarily, this project groundwater development for the rural population, have in a way contributed to the improvement of the socio-economic life of the people. Some areas have been adequately provided with good quality all year water supply.

.../...

6.6.2. RECOMMENDATIONS

Groundwater yields are sufficient in the sedimentary rocks but hardly adequate in crystalline rocks.

It is therefore necessary to develop a strategy for the exploration and development of groundwater in hard rocks areas including the determination of the most durable, efficient and economic means for siting, construction and exploitation of wells.

This strategy include :

- Defining and assessing the parameters which determine the storage capacity of aquifers ;

- Making proper use of groundwater exploration methods and using them in step like manner.

- Initiating as soon as possible a preliminary assessment of the potential groundwater resources of the area. When ever the amount of groundwater available is judged insufficient to furnish the required supply, consideration shoould be given to alternate sources of supply such as surface water. Expensive hydrogeological investigations should not be required in such cases.

Install well defined operation and maintenance programme.

Finding short-cuts in the process of determining favourable sites for wells.To that effect, it is necessary to use satellite imagery and air photographs.

Limiting costly field surveys to an acceptable minimum. In particular, by determination of site type categories on the basis of geomorphological and geological criteria and complementing by geophysical data.

Assessing the groundwater potential of aquifers in a realistic manner through pump test.

PLATE 1. Photograph showing the Bobo sandstone. With its characteristic stratification.

PLATE 2. Waterfall in the sedimentary formations near Koro village.

PLATE .3. On top of sedimentary plateau of Bobo sandston.

PLATE.4. Vegetation growth on sedimentary formation and indication of thick soil development.

ATE 5. River
alley controlled
lithology and
tructure.

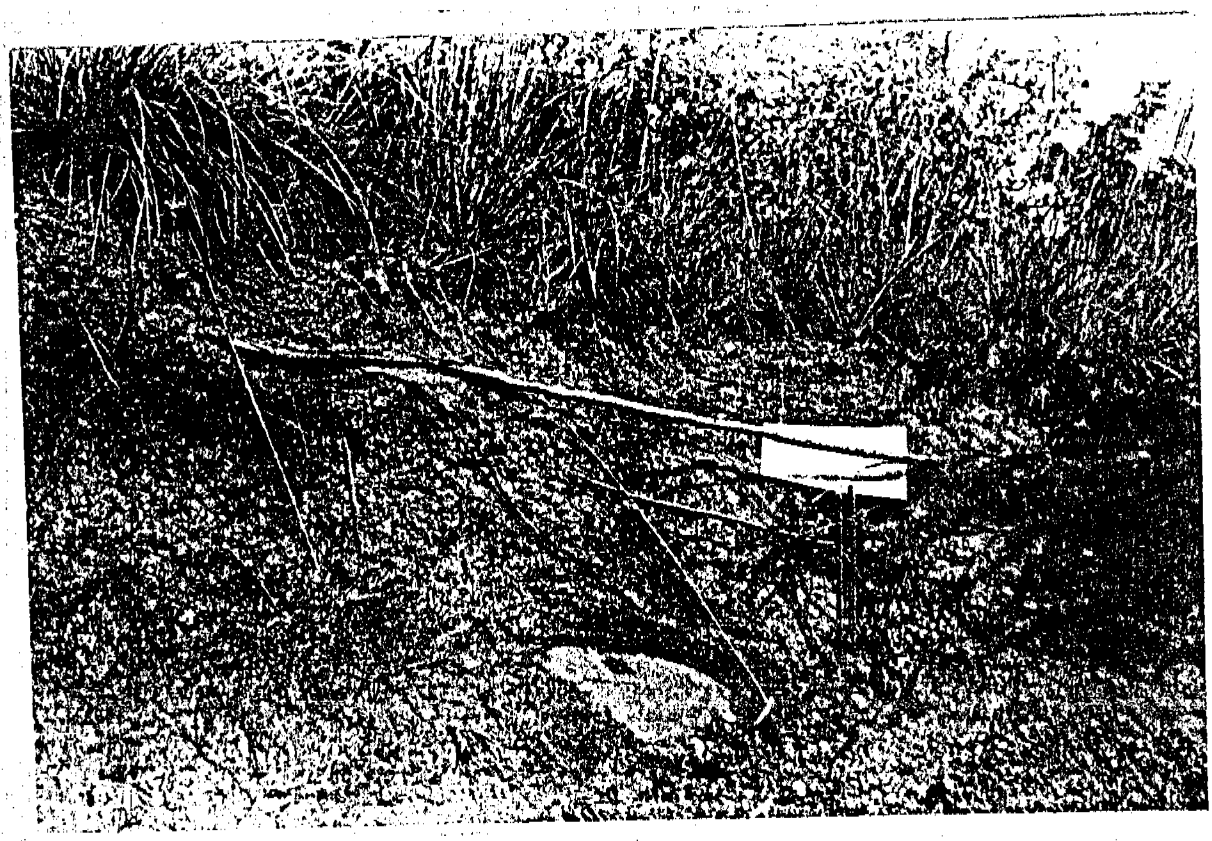


PLATE 6. Shick soil development an the granitic terrain. High potential recharge area. Kotedougou.

PLATE 7. Granitic outcrops in the GAOUA area.

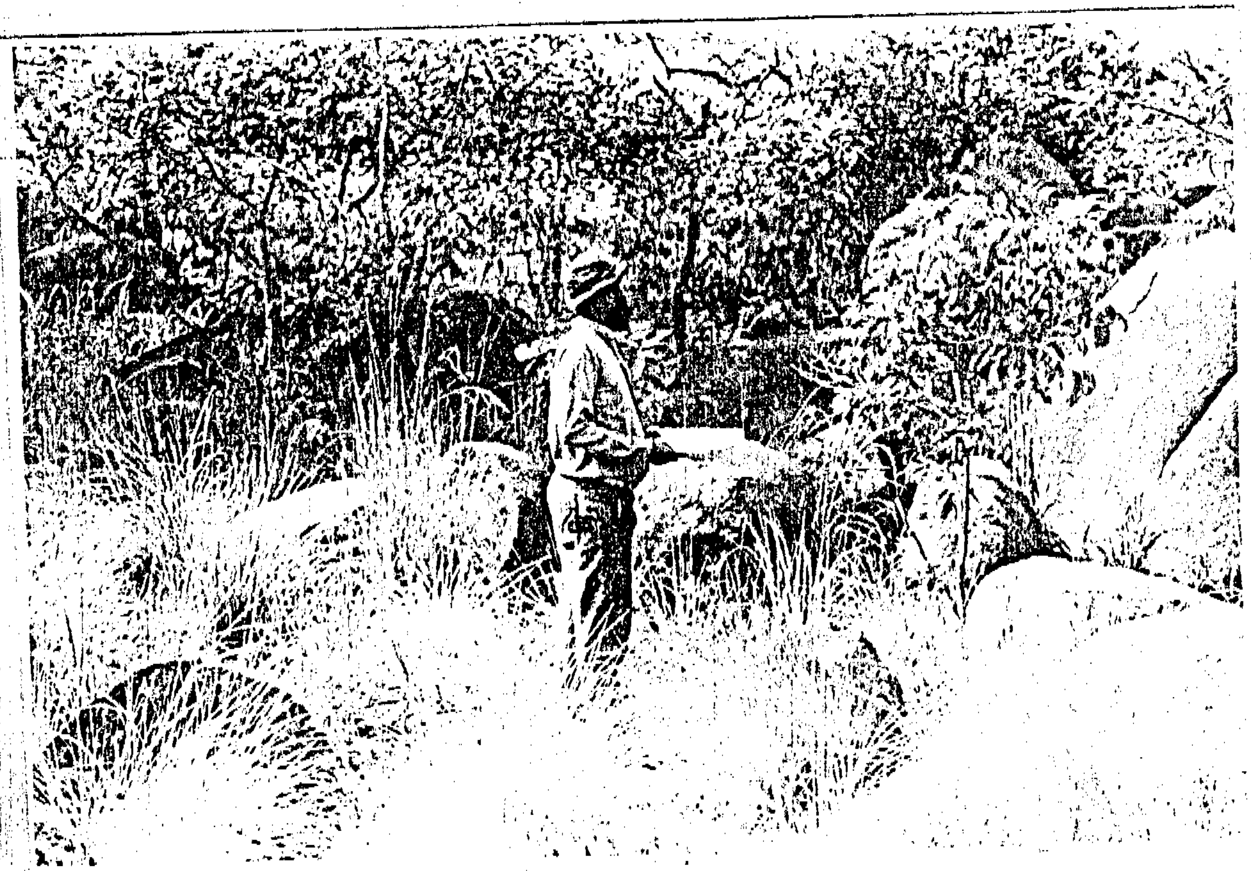


PLATE 8. Spring development near sedimentary/granit contact Bobo area

ATE 9.
Weathering pheno-
a (exfoliation)
ear Bodialindara.

PLATE 10. Butte formation with talus material accumulation of the foot hills Bodialindara area.

PLATE 11. Escarpment formation in the sedimentary terrain source of recharge for the depressions in the background.

PLATE 12. Thin soil development on the granitic terrain. Compare vegetation growth with plate 11.

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