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Overseas Geology Series

An Annotated Bibliography of the Geology and Hydrogeology of the Oju Area, Nigeria

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Dry season water source on Makurdi Sandstone

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PREFACE

The Department for International Development (DFID), latterly the Overseas Development Administration (ODA) , of the United Kingdom commissioned WaterAid to provide improved and sustainable village level water sources, primarily utilising the limited groundwater resources within the Oju LGA of south eastern Nigeria. As part of this project the British Geological Survey (BGS) investigated the nature of low permeability aquifers in and appropriate groundwater abstraction methods for Oju LGA. This is one of a series of reports that describe studies carried out by BGS in association with WaterAid.

This report is an up-to-date comprehensive compilation of annotated bibliographic material that describe the regional geology and hydrogeology of the southern Benue Trough of south east Nigeria within which the Oju LGA is located.

CONTENTS

INTRODUCTION

The following bibliography has been compiled as part of the ODA/WaterAid/BGS Oju Water and Sanitation Project. Oju Local Government Area is a remote part of south-eastern Nigeria that suffers from severe water shortage during the annual dry season. From November to April, unprotected ponds, seepages and hollows are the primary source of domestic water. Towards the end of the dry season, these sources become less reliable and many are contaminated. As a consequence, much of the population of Oju (300 000) is badly affected by a variety of water related illnesses, of which guinea worm and malaria are endemic; outbreaks of cholera, typhoid and dysentery are also common.

Oju is underlain by shaly, clay-rich rocks that offer only limited groundwater resources for development. Various attempts have been made - both by the local population and multi-national projects - to develop these resources but with limited success. Because of the complex hydrogeology, a detailed research programme is being undertaken by BGS to assess the groundwater potential of the area and develop a method for siting wells and boreholes. This bibliography forms part of the desk study carried out by BGS.

The bibliography covers a wide range of both published and unpublished literature. Material has been gathered in the UK using various sources: Water Resources Worldwide, Water Resources Abstracts, Geoarchive and Geobase. Literature has also been collected from Nigeria; in particular from the Geological Survey in Kaduna and Nsukka University near Enugu. The references cover three main subject areas: Geology, hydrogeology and geophysics. Material falls into two main categories: (1) relating specifically to Oju or Nigeria and (2) from similar environments elsewhere.

The bibliography has been ordered alphabetically by first author, regardless of subject matter. An index is included listing papers under several subject titles which should enable references to a particular topic to be found easily and quickly. The majority of the references include a short abstract. This is either a condensed and somewhat subjective version of the contents, or the entire abstract as appearing in the paper.

BIBLIOGRAPHY

Adams W M, Goudie A S and Orme A R (editors) 1996. The Physical Geography of Africa. Oxford University Press, Oxford, 429 pp.
Provides a relatively durable statement on the physical conditions of the continent of Africa. Discusses the main environmental factors: climate, tectonic history, soil types, vegetation, hydrology. Also discusses environmental history and evolution and linkages to human influence. A good source of basic information on a large variety of topics.

Adejuwon J O, Jeje L K, Ogunkoya O O 1983. Hydrological Response Patterns of Some Third Order Streams on the Basement Complex of Southwestern Nigeria. Hydrological Sciences Journal, vol 28, pp 377-389.
The hydrological response patterns of 15 third order rivers in southwestern Nigeria are described in terms of regime, discharge variability and recession of flow from peak discharge in the rainy season to the lowest discharge in the dry season. The maximum and minimum discharges of the rivers coincide with the rainy and dry seasons respectively. Most of the rivers exhibit erratic flow with quick responses to storms and storm water abating quickly, while some have a very low groundwater contribution to streamflow, a phenomenon which accounted for their drying up for considerable periods in the year. The variability indices of discharge of the rivers range from 0.25 to 2.12 while the recession constants range from 0.64 to 0.98. The variability indices are much higher than those of basins of similar size reported from other studies. Three types of rivers are recognizable on the basis of their hydrological response patterns: rivers characterized by perennial flow, low variability of discharge, and gentle recession of flow from peak discharge in the rainy season to minimum discharge in the dry season; rivers with high discharges during the rainy season but which dry up completely for between 100 and 150 days in the dry season; and seasonal rivers which dry up for between 190 and 270 days in the year. The nature of the superficial and solid geology has a greater influence on discharge characteristics than other factors such as depth of regolith and rainfall.

Adeleye D R 1975. Nigerian Late Cretaceous stratigraphy and palaeogeography. The American Association of Petroleum Geologists Bulletin, vol 59, pp 2302-2313.
Two principal Upper Cretaceous sedimentary successions in Nigeria show considerable hydrocarbon prospects, especially in parts of south-eastern Nigeria. The first succession, of Albian to Santonian age, is restricted to the eastern half of Nigeria and is comprised mainly of shale, limestone and sandstone. The basal sandy sediments possibly were deposited in a rift valley genetically related to opening of the South Atlantic. Advance denudation and subsequent thinning of the crust may have favoured the eastern part of Nigeria as the locus of rifting and early basin development. Marine Albian to Santonian sedimentary rocks are present in the southern parts of eastern Nigeria but the succession is less complete in the north. The pre-Santonian beds underwent a major tectonic deformation in Santonian-early Campanian time. The second succession, of Campanian-Maestichtian age, is present mainly in the western half of Nigeria. The basins are filled with a variety of sedimentary rocks: marine/non-marine shale and ironstone, sandstone, siltstone and lignite. The ancient "Guinea sea" and the Tethys sea probably merged twice across Nigeria in the Late Cretaceous, as indicated by faunal and lithologic evidence.

Adighije C I 1981. A gravity interpretation of the Benue Trough, Nigeria. Tectonophysics, vol 79, pp 109-128.
Reconnaissance gravity surveys carried out in the Benue Trough from 1975 to 1977 have revealed a broad positive regional anomaly over the whole of the trough attributable to Moho uplift. Superimposed on this regional gravity high in the Lower Benue Trough is an axial positive anomaly. This positive anomaly, with a maximum width of 100 km. and an amplitude of 20 mGal, seems to disappear around latitude 9 degs N, and is associated with a basic body of density 2.90 cm^3 that decreases in width and thickness from the south to the north. An axial negative anomaly observed in the Upper Benue is attributed to sedimentary fill, 6000 m. thick. In the Middle and Lower Benue, flanking negative anomalies are attributable to the accumulation in the marginal basins of post deformational sediments up to 5000 m. thick.

Adighije C I and Okeke P O 1988. Hydrogeological deductions from four geoelectrical profiles in Calabar, Nigeria. In Ofoegbu, C. O. (Ed) Groundwater and mineral resources of Nigeria: Vieweg-Verlag.
Geoelectric data and a stratigraphic cross section are presented for the Pleistocene Coastal Plains Sands of Calabar. Twelve VES using Schlumberger were interpreted

Agagu O K and Adighije C I 1983. Tectonic and sedimentation framework of the Lower Benue Trough, south-eastern Nigeria. Journal of African Earth Sciences, vol 1, pp 267-274.
The Aptian-Santonian lower Benue Trough was a relatively simple rift comprising a deep southern basinal area located south of Onitsha and a broad shallower platform to the north. Regional stratigraphy and sediment thickness patterns were thereafter strongly modified by the lower Santonian tectonism in the lower Benue Trough. The movement gave rise to a main axial Abakaliki High that was asymmetrically disposed in the trough to give a wider western complementary Anambra Syncline and a narrower eastern Afikpo Syncline. A transverse Nsukka High subdivides the Anambra Syncline into a northern Ankpa and a southern

Onitsha basins. These tectonic elements were active until the Miocene.

The Ankpa Basin now has a sediment thickness of about 5000 m comprising pre- and post-Santonian Cretaceous to Palaeocene sediments. The Onitsha Basin and the Afikpo Syncline are continuous into the modern Niger Delta where they each have sediment thickness of up to 12,000 m comprising pre- and post-Santonian as well as Tertiary sediments. The Tectonic highs received comparatively thinner sediments and were even non-depositional in places. They, however, constitute favourable regions for developing petroleum entrapment structures and stratigraphic pinch-outs.

Agagu O K, Fayose E A and Peters S W 1985. Stratigraphy and sedimentation in the Senonian Anambra Basin of Eastern Nigeria. Nigerian Journal of Mining and Geology, vol 22, pp. 25-36.

More than 2 000 metres thick sections of Santonian-Maestrichtian sediments have been penetrated in the Anambra Basin. In the area --------- the sediments are dominantly terrigenous comprising shales (approximately 60%), sandstones (approximately 40%), and only minor amounts of limestones. This highly resistive section was deposited at an anomalously high average rate of about 200 metres/million years. Hence the regressive nature of the sediments and the high rate of sedimentation contrast with those of coevil sediments in the South Atlantic and are indicative of local tectonism that activated source areas in the Benue Trough region.

Eight lithostratigraphic units were delineated in the Santonian-Maestrichtian section here namely: the Awgu, Agbani, Ogugu, Owelle, Nkporo, Mamu, Ajali and Nsukka formations. These units represent vertically stacked fluvial, deltaic, prodelta and shelf facies of repetitive delta building episodes viz: the Awgu/Agbani delta, Ogugu/Owelle delta, and the Nkporo/Mamu/Ajali delta. This depositional pattern is indicative of spasmodic quakes and quiescence in the Benue Trough region during this period. There was presumably rapid terrigenous sediment influx during the quakes (delta construction) and very slow deposition of shales and limestones during intervening quiescent periods. This depositional pattern has resulted in a generally consistent alternation of sandstone and shale units, an incidence that is propitious for petroleum generation and accumulation.

Awgu Formation: The Awgu Shales and Sandstones (Tattam, 1944) had been known to comprise both shales (Awgu Shales) and sandstones (Agbani Sandstone). These units were previously regarded as lateral equivalents with no definite stratigraphic relationship between them. The lithostratigraphic synthesis here, however, shows that there is a well defined shale unit well exposed in the Awgu area, east of Enugu and north-east of Oturkpo (Awgu Formation); and an upper sandstone well exposed around Agbani, Ogugu, Awgu and Oturkpo (Agbani Formation). This relationship is obscured in many parts of the basin mainly because of poor exposures especially in areas where the sandstone unit is relatively thin.

The Awgu Formation on the surface consists of grey to black well bedded fissile shales with commonly occurring thin (0.5 m) interbeds of shelly limestone and marl. There are also occasional interbeds of fine to medium moderately sorted sandstones which are massive and occasionally display some weak plannar cross-stratification in places. The ditch cuttings and cores show a monotonous dark grey, hard, brittle, silty and occasionally sandy shale. They are often pyritic, calcareous and micaceous and occasionally gypsiferous. Based on estimates made on surface exposures a thickness of approximately 900 metres was assigned to the formation by Simpson (1954) and Reyment (1965). Only two wells in the area studied penetrated the entire Awgu Formation and here the shale/limestone sequence is approximately 1100 metres thick. The Awgu Formation is characterised by a predominantly planktonic foraminiferal assemblage comprising *Heterohelix globulosa* (Ehrenberg), *Heterohelix reussi* (Cushman), *Hedbergella delrioensis* (Carsey), and *Hedbergella amabilis* (Leoblich and Tappan). Only a few benthonics such as *Ammobaculites sp., Haplophragmoides sp.* and *Gavelinella sp.* occur in the section. Ages ranging from Turinian to Santonian have been assigned to the formation. These include the Turonian (Simpson, 1954), late Turonian to Santonian (Geological Surveys of Nigeria, 1956), Coniacian (Reyment, 1965), Late Turonian to Lower Senonian (Murat, 1972) and Upper Turonian to Coniacian (Petters, 1978). Although no index plankton foraminifera were seen in the samples analysed, the association found here is similar to that occurring in the Coniacian of the Lower Benue Trough. The pollen data suggest an age that ranges from Late Turonian to Santonian.

The gross lithologic association in the Awgu Formation suggests a shelf environment of deposition. Petters (1978) has shown a gradual increase of foraminiferal diversity to a maximum diversity in Late Turonian to Coniacian times indicating that the maximum water depth in the Lower Benue Trough was probably attained during the deposition of the Awgu Formation. The interstratification with sandstones and occasional development of cross-stratification in some of the sandstone units however suggest that even at this maximum transgression, the shelf was still relatively shallow. It is noteworthy that in the subsurface shale intervals analysed, there were a preponderance of planktonic foraminifera in the Awgu Formation and almost a total exclusion of benthonics. The occurrence of abundant planktonic foraminifera here is indicative of open marine conditions. The marine conditions are further evidenced by the abundant ammonites and pelecypods which occur in the exposed parts of the formation (Reyment, 1965). The abundance of heterohelicids and hedbergelids here might be indicative of shallow water depth in line with Sliter (1972) who had pointed out that Cretaceous shallow-water habitats were dominated by heterohelicids and had a marked increase in hedbergelid. The generally low-diversity benthonic microfauna of the

limestone bands in the exposed sections of the Awgu Formation might also be indicative of shallow water nearshore marine conditions similar to the low diversity benthonic foraminiferal assemblage that have been found to prevail at shallow inner neritic depths off north-eastern United States (Buzas and Gibson, 1969). The exclusively planktonic foraminiferal assemblage that occur in the subsurface shale samples of the Awgu Formation might be suggestive of anaerobic bottom condition just as similar assemblages known from the Western Interior Cretaceous seaway of North America (Eicher and Worstell, 1970; Frush and Eicher, 1957) had been used to infer foul bottom conditions.

Agumanu A E 1989. The Abakaliki and the Ebonyi Formations: subdivisions of the Albian Asu River Group in Southern Benue Trough, Nigeria. Journal of African Earth Sciences, vol 9, pp.195-207.
The Asu River Group (middle-late Albian), exposed in the Nkalagu area of the southern Benue trough, consists of two formations, viz: the Abakaliki Formation at the base overlain by the Ebonyi Formation (new name). The Abakaliki Formation is composed mainly of illitic and kaolinitic black shales and mudstones interbedded with black micritic limestone, siltstone and minor feldspathic sandstones. The limestone is composed of grapestones, infralimeclasts and brown algal limestone remains. These together with the pyritic and fossiliferous shale, suggest oscillatory deposition of argillaceous sediment in a shallow but anoxic subsiding bottom and marine facies.

Rapid alternations of sandstone, siltstone, shales, mudstones, oolitic and serpulid grainstones and packstones-wackestone indicative of transitional environmental deposition characterise the Ebonyi Formation. The thick horizontal strata and interference ripple marks suggest lower flow regime of deposition while the thin evaporite laminite indicate locally short-term aridity during the Cretaceous in the southern Benue trough.

Agumanu A E 1990. Diagenetic processes in sandstones of the Cretaceous Southern Benue Trough, Nigeria. Journal of Mining and Geology, vol 26, pp 207-234.
Diagenetic processes in sandstones of the Cretaceous formations of the southern Benue trough including the Isinkpuma Sandstone, the Agbani Sandstone (Pre-Santonian) and the Owelli Sandstone (Post-Santonian) were studied. The pre-Santonian sandstones are arkosic and felspathic arenites with shell bands, carbonate nodules or glauconitic. The post-Santonian counterparts are fluviatile quartz arenites. The sandstones alternate with thick beds of pyritic shale.

Both geologic and geochemical (pore fluid) factors contributed to the diagenetic alterations - mechanical and chemical compaction, authigenesis, cementation and the development of secondary porosity. The Isinkpuma Sandstone in contact with the post-Turonian pyroclastics exhibits the highest degree of diagenetic features attributable to the chemical milieu and high thermal maturity consequent upon elevated temperatures during pyroclastic volcanism.

Poikilotopic calcite cement abundance in the pre-Santonian sandstone relates to the associated marine facies. Iron oxide cement results from smectite-Illite transformations, oxidation of pyrite, in situ alteration of glauconite by meteoric water and hydraulic communication with acid pore water as an accompaniment to the maturation of organic matter in the adjacent shales. Incompatible cementation exists between kaolinite and quartz due to the antipathetic relationship of quartz cement to detrital clay.

Secondary porosity results from the corrosion of quartz and feldspar by calcite, in situ partial solution of feldspar, grain deformation and mica degradation. The diagenetic stage is predominantly locomorphic with localized phylomorphic stage induced by volcanism.

Agumanu A E and Enu E I 1990. Late Cretaceous clay distribution in the Lower Benue Trough; its palaeoenvironmental and tectonic implication. Journal of African Earth Sciences, vol 10, pp 465-470.
The southern Benue Trough Late Cretaceous sediments were studied by X-ray diffraction for their clay mineral content. The clay distribution within the formations indicates that tectonics, relief, environment of deposition and burial diagenesis controlled the clay types and their distribution pattern. Two important tectonic episodes (Albian and Santonian), that brought about uplift of source areas, are discernible. From the overall clay distribution and burial diagenesis these played a significant role in the clay types within older sediments.

Ajakiaye D E, Hall D H, Ashiekaa J A and Udensi E E 1991. Magnetic anomalies in the Nigerian continental mass based on aeromagnetic surveys. Tectonophysics, vol 192, pp 211-230.
Analysis of aeromagnetic data from the Nigerian continental mass reveals magnetic lineations and regions of distinct magnetic character and field level which are interpreted as expression of tectonic features related to igneous intrusives of various ages. The total field magnetic intensity data derives from the crystalline shield area with its characteristic Jurassic granitic ring complexes and Neogene volcanics, and the Benue Trough which is considered to be a failed-rift arm. Classical analytical techniques were adopted for upward and downward continuation, frequency domain filtering of the data, and for the interpretation of surface and subsurface structures in the area. Major intrusives and fault zones were clearly delineated. The results of the analyses also revealed aspects of the regional tectonic framework of West Africa and its relationship with major structures in the adjacent Atlantic basins.

Ajayi O and Abegunrin O O 1994. Borehole failures in crystalline rocks of south-western Nigeria. Geojournal, vol 34, pp 397-405.
Boreholes drilled in the crystalline rocks of Nigeria have a reputation of failures and low yields. The performance of 256 boreholes drilled in different parts of the crystalline rocks of SW Nigeria were reviewed to determine their failure characteristics. 100% success was claimed for 105 boreholes constructed by one driller. Out of 111 other borehole records supplied by three other drillers 35 were abortive, representing a failure rate of 32%. In contrast, 24 owners of 40 boreholes reported 24 failures representing a failure rate of 60%. The common causes of borehole failure in the crystalline rocks of SW Nigeria are seasonal variations in water level, improper casing of the overburden, damage to pumps and other system failures such as blocked pipelines and malfunctioning tanks. Non-penetration into the water bearing horizon also features as a cause of borehole failure in this study. It is suggested that proper construction, operation and maintenance of boreholes will reduce the incidence of borehole failures in crystalline rocks of SW Nigeria.

Ajayi C O and Ajakaiye D E 1986. Structures deduced from gravity data in the Middle Benue, Nigeria. Journal of African Earth Sciences, vol 5, pp 359-369.
The Middle Benue is divided into five structural regions based on the results of a recent gravity survey. The locations and trends of most of the previously known structures in these regions are confirmed by the gravity data. However, the location and trend of the Giza syncline (graben) between Kadarko and Obi, as deduced from the gravity work, do not agree with those on the geological map. Among the prominent previously unrecognised structures revealed by the gravity data are a northeast-trending broad horst or ridge of basement material south of the Benue River, which is axially placed within the trough and a similar structure located north of the Benue River under the Keana anticline. Another previously unknown structure identified in this work is a south-east-trending gravity minimum located just to the east of the River Katsina Ala. This region is interpreted as a zone of subsidence possibly associated with block faulting.

Akande S O and Mucke A 1993. Depositional environment and diagenesis of carbonates at the Mamu/ Nkporo Formation, Anambra Basin, Southern Nigeria. Journal of African Earth Sciences, vol 17, pp 445-456.
At Leru-Okigwe, the Enugu-Port Harcourt expressway cuts through the Campanian Nkporo Shales which pass upwards into the cyclic, ripple laminated sandstones and shales of the Lower Maastrichtian Mamu Formation. The Mamu Formation at this locality consists of a 60 m thick shale-sandstone sequence with the basal and middle part of the section consisting of a total of 9 carbonate units. These carbonates vary from 10 to 70 cm in thickness, cyclically interbedded with shales and are overlain by coarsening upwards sandstone bodies. Detailed mapping and petrographic studies indicate that the carbonate units are divisible into a lower finely laminated mudstone which passes upwards into oolitic packstone/grainstone in the middle and is overlain by an upper set of laminated mudstones. The lowest mudstone unit (dark grey to greenish rock) is finely laminated, pelleted, oncolitic and sparsely fossiliferous. The oolitic packstone/grainstone consists of oolites cemented together by siderite microspar. Identifiable bioclasts include tests of small size benthic foraminifera, pelecypods and rare ostracod carapace. This unit attains a maximum thickness of about 70 cm. The upper mudstone units consists essentially of uniformly recrystallised siderite microspar. Intraclasts include micritised pelecypod fragments and small foraminifera tests. Ovoid, flat bottomed and biconvex vugs developed good geopetal structures in the mudstone.

Petrographic, Xray diffraction and microprobe analyses indicate that the carbonate constituent in these units consists of solid solutions of $FeCO_3$ - $MgCO_3$ - $CaCO_3$ and minor $MnCO_3$. Sideritization, the dominant replacement process has led to the recrystalisation of the micritic matrix and microcrystalline siderite is commonly associated with goethite, chamosite relics and quartz.

The carbonates with associated chamosite are thought to have formed in a shallow marine subtidal to intertidal environment developed during periods of rise and fall in sea level. Formation of chamosite-bearing oolites record periods of increasing wave energy corresponding to storm conditions between quite shallow marine sedimentation. At least five diagenetic stages involving micritization, dissolution of the primary chamosite, replacements of chamosite by siderite cement, growth of blocky calcite and a continuing replacement of the pre-existing minerals by goethite were established from textural and compositional evidence.

The recognition of shallow marine subtidal environments for carbonates at the Mamu/Nkporo Formation transition supports continuous marine influences with periodic subaerial exposure of sediments in the Mamu deltas after deposition of the prodeltaic Nkporo Shales.

Akpokodje E G and Hudec P P 1994. The influence of petrology and fabric on the engineering properties of concretionary laterite gravel aggregates. Quarterly Journal of Engineering Geology, vol 27, pp 39-50.
The probable field performance of concretionary gravel aggregates is difficult to predict in the tropics, mainly due to the lack of understanding of the factors that control their engineering properties. The mineralogy and fabric of commonly used laterite gravel aggregates in Nigeria were studied to assess their influence on the engineering properties. Thin-section studies revealed two characteristic features which greatly influence the physic-mechanical properties:

(a) abundant voids and fissures of different sizes, and
(b) varying degrees of iron oxide impregnation.

The variations in these characteristics are due to differences in the degree of lateritization. Strong and well developed gravels and pisolites are composed of 65-95% goethite/haematite and are dominated by small voids. Weak and immature laterite gravels contain much larger pores and greater amounts of quartz and kaolinite. The quartz grains show extensive cracking which further reduces the mechanical strength of these laterite gravels. The void/fracture dominated fabric of laterite gravel aggregates is mainly responsible for their unusually high absorption/porosity and relatively low strength. In some laterite gravels, the strength loss on wetting is mainly due to weak cementation and the presence of interstitial clays.

Allen J R L 1965. Late Quaternary Niger Delta, and adjacent areas: sedimentary environments and lithofacies. Bulletin of the American Association of Petroleum Geologists, vol 49, pp 547-600.
The Late Quaternary Niger delta in the Gulf of Guinea is a large, arcuate "classical" delta associated with marginal estuary and barrier island-lagoon complexes. The Late Quaternary deltaic lens (minimum volume 900 km^3) is the latest accretion within the Nigerian Coastal Plain geosyncline. Sediment originating in a vast and geologically complex hinterland is dispersed through the delta by river, tidal, wave and ocean currents.

Delta growth began during the Late Wisconsin lowstand of the sea when the rivers entrenched the continental shelf to reach mouths above submarine canyons at the shelf edge. The oldest stratigraphic unit of the Late Quaternary deltaic pile is a strand plain sand (Older Sands) representing a marine transgression into the hinterland. Later, in the Holocene, when sea-level became relatively stable, regressive advance across the sands of concentrically arranged delta environments gave rise to the Younger Suite, the uppermost stratigraphical formation in the deltaic lens. Lithofacies of this suite grade upward from open shelf clays, through pro-delta slope layered clays, silts and sands, to well bedded sands formed on the delta-front platform, river-mouth bars, and beaches. Behind each ridge barrier islands fringing the visible part of the delta occur tidal mangrove swamps in which organic -rich sands and silts are being deposited. Cross-stratified river bar sands are accumulating in association with top-stratum silts and clays in the delta floodplain environment.

The sedimentary framework of the Late Quaternary Niger Delta is based on essentially facies elements, as in many other "classical" deltas, rather than on radial elements as in the Mississippi birdfoot delta.

Alo E B, Akosim C and Arifalo E I 1994. Observations on the effects of land-use practices on water resources in upper Benue Basin of Nigeria. Environmental conservation, vol 21, pp 70-72.
Short paper describing some of the effects of land use changes on water resources. Agriculture: contamination and increased runoff. Livestock: increased runoff and gullying due to overgrazing. Bush burning: increased runoff.

Amajor L C 1985. The Cenomanian hiatus in the Southern Benue Trough, Nigeria. Geological Magazine, vol 122, pp 39-50.
Basal Turonian Eze-Aku Sandstone ridges along the Cenomanian hiatus in the Afikpo area contain sandstone pebbles, cobbles and boulders randomly distributed in nearly all the coarsening upwards subfacies of the host units. Contacts with the host sandbody are sharp and in places, lined with solution grooves. Generally, the angular to subrounded clasts have their 2 mm rims ferruginized, are fine to coarse grained and very strongly bioturbated. They are compositionally and texturally more similar to the adjacent Albian Asu River Group sand units. These characteristics suggest an extra-basinal origin for these marine sandstone clasts. Albian Asu River Group sediments uplifted by the Cenomanian deformation are the most likely source. The general absence of similar clasts towards the eastern palaeostrandline where the primary Cretaceous source rocks lay is consistent with the interpretation. The remarkable parallelism between the trend of the clast outcrops and the axis of the Santonian anticlinorium (NE-SW) suggests the same direction for both tectonic phases.

Amajor L C 1985. Sedimentary facies analysis of the Ajali Sandstone (Upper Cretaceous), Southern Benue Trough. Nigerian Journal of Mining and Geology, vol 21, pp 171-176.
The Campano-Maastrichtian Ajali Sandstone in Okigwe is sub-divisible into two upward fining sequences, each with three sub-facies.

The basal sequence 'A' begins with lower cross-stratified sandstone facies characterised by fairly well sorted, medium to coarse-grained sand with planner, herringbone and trough cross-strata which display a bimodal bipolar palaeocurrent pattern. Lenticular, flaser and ripple-stratified fine to medium-grained sand, mudstone and clay with abundant leaf impressions and occasional bioturbation typify the middle facies. A strongly burrowed (Ophiomorpha) silty mudstone facies with locally developed erosive top constitutes the upper unit and terminates the lower sequence. The facies are correspondingly interpreted to reflect sediments of low, mixed and high intertidal flat depositional environments.

The upper sequence 'B' begins with a poorly sorted intraformational conglomerate followed by a middle trough and planar stratified, fine to medium-grained, poorly sorted sandstone with carbonaceous drapes and low relief erosional surfaces. A red mudstone facies, homogenised by laterisation terminates the sequence with an erosive base. These localised

channel deposits were likely deposited by a meandering stream on a tidal flat.

The Ajali Sandstone, formerly regarded as strictly continental, contains marginal marine deposits at the base in places.

Amajor L C 1987. The Eze-Aku Sandstone (Turonian) ridges of South-eastern Nigeria: a re-interpretation of their depositional origin. Nigerian Journal of Mining and Geology, vol 23, pp 17-26.
Sedimentary facies analysis of the Turonian Eze-Aku sandstones of the south-eastern Benue trough was undertaken to establish the dominant depositional mechanism. The sandbodies, about 30 m thick on average, are fairly parallel linear northeast-south-west trending ridges characterised by a coarsening upward textural gradient.

Six sedimentary facies were recognised (bioturbated mudstone = facies 1, heterolithic unit = 2, cross-stratified unit = facies 3, bioturbated sandstone = facies 4, channel sandstone = facies 5, and matrix support conglomerate = facies 6). Facies 1 consists of mudstone that is intensely reworked by organisms. The heterolithic unit (facies 2) comprises and interlaminated assemblage of shale, mudstone, siltstone and sandstone that are moderately bioturbated. Facies 3 is made up of low angle, medium scale, planar cross stratified sandstones with rare bioturbation. Facies 4 is a structureless coarse to very coarse sand that is slightly bioturbated whereas facies 5 comprises and erosively based coarse to fine channel sand (fining upwards) with small scale trough cross-stratiphication at the base. Both units are restricted atop facies 3, in places. Very strongly bioturbated pebble to cobble size sandstone and limestone clasts set in a matrix of sand, mudstone and limestone and of random occurrence characterise facies 6. The inter-ridge swales are dominated by marine shales with localised development of bioclastic limestone lenses.

It is argued that the facies attributes of these deposits suggest deposition in a storm-dominated, not tide-dominated, shallow shelf environment during the early transgressive phase of the Turonian sea.

Amajor L C 1987. Major and trace element geochemistry of Albian and Turonian shales from the Southern Benue trough, Nigeria. Journal of African Earth Sciences, vol 6, pp 633-641.
A geochemical study on the Albian and Turonian shales from the southern Benue trough of Nigeria was carried out to establish their geochemical fingerprints. The results show that these shale units are geochemically dissimilar both in major element oxides, trace and some rare earth elements. The element pairs which differentiate them best are MgO/Fe_2O_3, MgO/MnO, CaO/P_2O_5, CaO/Sr, K_2O/Rb, Zr/P_2O_5, Pb/Th, Sr/Rb and Zr/Y.

The Albian shales are chemically fairly similar to the North American Albian Mowry shales (sediments of shallow restricted inland seas) whereas the Turonian shales compare favourably well with the average normal shales.

Changes in source rock characteristics, palaeo-depositional environments and diagenesis are collectively thought to have caused the variation in geochemistry of these shales. The palaeogeographic significance of the chemical variation is discussed.

Amajor L C 1992. Storm induced turbidite like deposit: An example from the Turonian Eze-Aku Formation at Nkalagu, south-eastern Nigeria. (Nigerian) Journal of Mining and Geology, vol 28, pp 7-17.
Four quarry faces at Nakalagu Southern Benue Trough, Nigeria, each about 30 m thick and 2.5 km wide on the average reveal a cyclic succession of shales and fining upwards limestone beds within the Turonian-Coniacian interval. The shale units vary from 1.2 to 5.7 m in thickness whereas the limestone beds range from 0.8 to 6.1 m in thickness.

On the basis of lithology, fauna, sedimentary structure and textures three sub-facies were distinguished from each of the limestone units. From base to top these are a basal shell lag, middle massive micrite and the top interlaminated shale and limestone sub-facies. The basal shell lag unit is normally graded and comprises unabraded and unsorted broken and whole fossils as well as angular shale intraclasts. These are set in a dark grey micrite matrix. The base is erosional with pot and gutter casts. The middle micrite sub-facies is massive and structureless with a few whole fossil and limestone clasts randomly distributed within the unit. The top interlaminated limestone and shale subfaces is characterised by diffuse lamination resembling flaser bedding. Micrite clasts are common and bioturbation is moderate.

The Nkalagu limestone beds are though to have been deposited by turbidity currents generated by catastrophic storms in a shallow shelf environment during the Upper Cenomanian-Coniacian rise in sea level.

Amajor L C and Ofoegbu C O 1988. Determination of polluted aquifers by stratigraphically controlled bio-chemical mapping: example from eastern Niger delta, Nigeria. In: Ofoegbu, C.O., editor. Groundwater and mineral resources of Nigeria, Vieweg, pp 85-100.
The study area is around Port Harcourt within the Benin formation - fine to course sand and gravel with minor clay. States that not enough consideration is given to geology within groundwater studies. They advocate the use of geophysics and aerial photographs.

Andrews J N, Fontes J-C, Aranyossy J-F, Dodo A, Edmunds W M, Joseph A and Travi Y 1994. The

evolution of alkaline groundwaters in the continental intercalaire aquifer of the Irhazer Plain, Niger. Water Resources Research, vol 30, pp 45-61.
This paper discusses the hydrochemical evolution of groundwaters in the multilayer artesian aquifer of the Continental Intercalaire (the mainly Jurassic Agadez-Dabla sandstones) aquifer of northern Niger. Isotopic and chemical changes in relation to the geological setting suggest that the increasing HCO_3- alkalinity of the groundwaters is caused by interaction of deep CO_2 with the aquifer matrix. Alteration of feldspars by CO_2 with a ^{13}C value of -3.0‰ accounts for the observed alkalinity and isotopic trends. Carbon 14 ages have been estimated for recent and Holocene groundwaters which have a distinct stable isotopic (^2H and ^{18}O) signature compared with ^{14}C dead groundwaters from further west on the Irhazer Plain. Recharge temperatures, estimated by analysis of noble gas contents, show that the ^{14}C dead waters were recharged under conditions cooler than present averages in the region, possibly at the beginning of deglaciation (16ka B.P.) or during the period 23-30 ka B.P. Trends in the hydrochemistry of U are related to the deep CO_2 alteration process. Radiogenic He contents increase along the flow direction and extremely high values occur in the proximity of U ores. Denitrification in the palaeowaters of the Irhazer was assessed by measurements of nitrogen/argon ratios.

Anyadike R N C 1993. Seasonal and Annual Rainfall Variations over Nigeria. International Journal of Climatology, vol 13, pp 567-580.
Variations of monthly and annual rainfall over the southern, middle belt and northern regions of Nigeria, as well as the country as a whole, were examined for a 72-yr period (1916-1987). In this way, the zonal distribution of the country's rainfall was evaluated. The extent and nature of non-random changes, such as fluctuations, trend, and persistence, were investigated. The fluctuations were filtered by a Gaussian low-pass filter to generate curves. Trend analysis showed a tendency toward decreasing annual rainfall totals in all regions, with rates of decrease being greatest after 1961 in the southern region. All regions experienced the reverse of the trend during the 1931-1960 period. Overall, no significant persistence was evident in all the series. Power spectrum analysis revealed the existence of significant oscillations in the rainfall totals. These have time periods of 2.0-2.82 yrs in the middle belt and northern regions; 3.0-4.8 yrs in the middle belt; and, 8.0-9.6 yrs in all the regions.

Armstrong R G 1955. Peoples of the Niger-Benue Confluence; The Idoma Speaking Peoples. In: FORDE, D. editor. Ethnographic Survey of Africa, Western Africa, Part X. International African Institute, London, pp91-158 and map.

Arua I 1988. Episodic sedimentation: an example from the Nkporo shale (Campano-Maastrichtian), Nigeria. Journal of African Earth Sciences, vol 7, pp 759-762.
The predominantly shaly Campano-Maastrichtian sediments in south-eastern Nigeria contain thin beds of oolitic ironstone and coquina. Three facies are distinguished: Facies 1 - Beds (5-30 cm thick) of coquina within laminated black shale; Facies 2 - Beds (10-60 cm thick) of oolitic ironstone within grey shale; and Facies 3 - Beds (35-80 cm thick) of fossiliferous, oolitic ironstone within black, finely laminated shale. These facies are evidence of recurring catastrophic events. They might have been deposited by small scale storm-generated debris flows carrying the shoal (swell) sediments into the euxinic basin.

Asohika M B 1986. Resistivity studies for aquifer depths in Gboko, Benue State, Nigeria. Nigeria Water Supply and Sanitation Association, first annual symposium and exhibition - Groundwater Resources in Nigeria. Paper 3, pp 55-67.

Awwiller D N 1993. Illite/smectite formation and potassium mass transfer during burial diagenesis of mudrocks: A study from the Texas Gulf coast Palaeocene - Eocene. Journal of Sedimentary Petrology, vol 63, pp 501-512.
Mudrock samples from a well penetrating Eocene and Palaeocene strata (1235-4455 m) of the Texas Gulf Coast have been studied to assess geochemical distribution in mudrocks during burial diagenesis, and the mechanism by which detrital smectitic illite/smectite (I/S) is transformed into diagenetic illitic I/S.

Idealised smectite and illite end-member compositions for interstratified I/S are estimated to be $[K_{0.00}X^{+1}{}_{0.56}Mg_{0.39}Fe_{0.57}Al_{1.13}Si_{3.90}O_{10}(OH)_2]$ and $[K_{0.53}X^{+1}{}_{0.18}Mg_{0.17}Fe_{0.16}Al2.28Si_{3.40}O_{10}(OH)_2]$, respectively. There is no obvious difference in the amount of K addition to I/S in random- and ordered-interstratified I/S. Aluminium substitution into both tetrahedral and octahedral sites suggests that the smectite-to-illite reaction is a complete dissolution-precipitation reaction rather than a solid-state $[K^{+1} + Al^{+3}]$ for Si^{+4} substitution reaction. Depth-related mineral trends and mass-balance calculations suggest that illitic I/S may form from kaolinite, and possibly illite or mica, as well as from smectitic I/S.

Although most whole rock element abundances are invariant over the sampled interval, K_2O content increases from ca. 2.0 weight percent at 1500 m of burial to ca. 3.8 weight percent at 4000 m. Some of this increase is probably caused by import of K into the shale via fluids derived from interbedded sandstones, implying that Gulf Coast mudrocks behave as open chemical systems during burial diagenesis. If this is the case, a minimum of 10^3 pore volumes of fluid must have passed through the most K-enriched shales to have introduced the added potassium, provided that the K content

of present-day formation water is representative of that of ancient formation water.

Barker J A and Herbert R 1989. Nomograms for the analysis of recovery tests on large-diameter wells. Quarterly Journal of Engineering Geology, London. Vol 22, pp 151-158.
A set of nomograms has been constructed to facilitate the application of the solution of Papadopulos and Cooper to recovery tests on fully-penetrating large-diameter wells in confined aquifers. The data required are: the well geometry, the abstraction rate and period, the drawdown at the end of pumping and the time taken for 25, 50 or 75% recovery to occur.

Barker J F, Barbash J E and Labonte M 1988. Groundwater contamination at a landfill sited on fractured carbonate and shale. Journal of Contaminant Hydrology, vol 3, pp 1-25.
Landfill is sited in shaly dolomite with chert layers which is in turn underlain by shale. The fractures in the cherty dolomite are extensive and well connected ($K = 10^{-4} - 10^{-5}$ m/s). There is little groundwater flow through the underlying shale ($K = 10^{-8} - 10^{-11}$ m/s). The bulk of the paper discusses groundwater chemistry.

Barker R D, White C C and Houston J F T 1992. Borehole siting in an African accelerated drought relief project. In Wright, E. P. and Burgess, W. G. (editors) The Hydrogeology of Crystalline Basement Aquifers in Africa, Geological Society Special Publication No 66, pp 183-201.
A combined method using EM and resistivity (Offset Wenner) was used to site the boreholes. They used a 40 m spacing horizontal dipole. They claim that the depth of investigation is much less than that claimed by McNeill (1980). Depth of 3.8. 7.6 and 15.2 m for vertical coils and 8.7, 17.4 and 34.8 m for horizontal coils. These were calculated assuming that the depth of investigation is defined as the depth at which above or below 50 % of the signal originates. The EM was used to roughly estimate the depth of weathering and also to identify dykes etc.

Barker R D 1981. The offset system of resistivity sounding and its use with a multicore cable. Geophysical Prospecting, vol 29, pp 128-143.
Describes the theory and methodology of the Offset Wenner Technique of vertical electric sounding.

Barker R D 1979. Signal contributions and their use in resistivity studies. Geophysical Journal of the Royal Astronomical Society, vol 59, pp 123-129.
Shows the signal contributions from Dipole-dipole, Wenner and Schlumberger arrays. Diploe-dipole is most suited to profiling, while Wenner and Schlumberger to sounding. Schlumberger has a slightly lower vertical resolution for horizontal layered media than Wenner.

Bath A H 1993. Clays as chemical and hydraulic barriers in waste disposal: evidence from pore waters. In: D A C Manning, P L and C R Hughs (editors) Geochemistry of Clay-Pore Fluid Interactions. Chapman and Hall, London.
Overview paper of the role of clays in waste disposal. They found that diffusion was the dominant process when mudrocks are unfractured. Permeability parallel to clay layers was much greater than permeability perpendicular to layers.

Beeson S and Jones C R C 1988. The combined EMT/VES geophysical method for siting boreholes. Groundwater vol 26, pp 54-63.
Example from Kano. EM with two depths of penetration; then use the VES to assess any anomalies. Crystalline basement - success (10l/min) in 75 % boreholes. They mention negative readings - these can be caused by the presence of highly conductive material. The equipment responds to this non-linearly. Can be indicative of vertical dykes or highly conductive surface layers.

EM cannot be used near manmade conductors such as power lines or metal roofs. They tended to use vertical dipole; horizontal was used in areas of potential. They searched for adequate conductance at depth (ie vertical dipole being greater than the horizontal dipole). Then at an anomaly they did a short orthogonal traverse and then Schlumberger VES

Benkhelil J 1989. The origin and evolution of the Cretaceous Benue Trough. Journal of African Earth Sciences, vol 8, pp 251-282.
The intracontinental Benue Trough was initiated during the Lower Cretaceous in relation with the Atlantic Ocean opening. The first stage of its evolution started in the Aptian, forming isolated basins with continental sedimentation. In the Albian times, a great delta developed in the Upper Benue Trough, while the first marine transgression coming from the opening Gulf of Guinea occurred in the south and reached the Middle Benue. The widespread Turonian transgression made the Atlantic and Tethys waters communicate through the Sahara, Niger Basins and the Benue Trough. The tectonic evolution of the Benue Trough was closely controlled by transcurrent faulting through an axial fault system, developing local compressional and tensional regimes and resulting in basins and basement horsts along releasing and restraining bends of the faults. Two major compressional

phases occurred: in the Abakaliki area (southern Benue) during the Santonian; and at the end of the Cretaceous in the Upper Benue Trough. In Abakaliki, the sedimentary infilling was severely deformed through folding and flattening, and moderate folding and fracturing occurred in the north-east. The Cretaceous magmatism was restricted to main fault zones in most of the trough but was particularly active in the Abakaliki Trough, where it has alkaline affinities. From Albian to Santonian, the magmatism was accompanied in part of the Abakaliki Trough by low grade metamorphism. Geophysical data indicate a crustal thinning beneath the Benue Trough and, at a superficial level, an axial basement high flanked by two elongated deep basins including sub-basins. The model of the tectonic evolution of the trough is based upon a general sinistral wrenching along the trough responsible for the structural arrangement and the geometry of the sub basins. During the early stages of the Gulf of Guinea opening the Benue Trough was probably the expression on land of the Equatorial Fracture Zones.

Benkhlil J, Guiraud M, Ponsard J F and Saugy L 1989. The Bornu-Benue Trough, the Niger Delta and its Offshore: Tectono-sedimentary reconstruction during the Cretaceous and Tertiary from geophysical data and geology. In: Kogbe, C.A. (ed) Geology of Nigeria, Rock View (Nigeria) Ltd, 2nd revised edition 1989, pp 277-310.

Bennett R H, Bryant W R and Hulbert M H 1990 (editors). Microstructure of Fine-grained Sediments: From Mud to Shale. Springer-Verlag.

Bidin K, Douglas I and Greer T 1993. Dynamic response of sub surface water levels in a zero-order tropical rainforest basin, Sabah, Malaysia. Hydrology of Warm Humid regions (Proceedings of the Yokohoma Symposium, July 1993). IAHS Publications No 216, Wallingford.
Water level recorders were established in a shallow well (2 m) in the stream head hollow of an incised zero order channel. Piezometers were set up along the channel. Soil saturated hydraulic conductivity was measured from Talsma ring permeameter tests. If the water table was shallow, the channel reacted very rapidly (5 - 45 minutes). Diurnal variations in water level of a few centimetres were recorded. Precipitation in the forest was estimated as 78% precipitation in the open.

Biella G, Locej A and Tabacco I 1983. Experimental study of some hydrogeophysical properties of unconsolidated porous media. Ground Water, vol 21, pp 741-751.
Laboratory investigations were carried out on artificial sand samples to estimate relations between formation factor, porosity and permeability. Log relation between porosity and formation factor (Archies law). There is also direct relation between permeability and formation factor.

Binks R M and Fairhead J D 1992. A plate tectonic setting for Mesozoic rifts of West and Central Africa. Tectonophysics, vol 213, pp 141-151.
Africa by virtue of its central position within Gondwana, has recorded much of the complex history of plate interactions which have progressively fragmented this subcontinent since the early Mesozoic. Continental reconstructions reveal both a temporal and spatial relationship between the development of the continental margins of Africa and the formation of rifted sedimentary basins deep within the African continent. The multi-stage opening of the Atlantic Ocean and associated rifting in West and Central Africa provide one of the most impressive examples of ocean-continent tectonic interactions. During the Early Cretaceous the onset of rifting along the future margins of the South Atlantic is contemporaneous with intra-continental rifting generating both strike-slip and extensional basins within West and Central Africa. The syn-rift phase of intra-continental basin development continued until the Santonian, by which time Africa and South America had been physically separated for approximately 10 Ma. Except for minor rifting during the Senonian and Tertiary, the short-lived phase of deformation at about 80 Ma marks the transition into the post-rift or "sag" phase of basin development. This deformational event can be correlated with a period of plate motion changes, recognised from fracture zone geometries, seen in both the Central and South Atlantic Oceans. Using present day stress analogies, Cretaceous rifting in Africa can provide a means of indicating the regional palaeostress directions within Africa at this time.

Birch F S 1984. Bedrock depth estimates from ground magnetometer profiles. Groundwater, vol 22,pp 427-432.
Bedrock depths can be calculated using Fouries spectral analysis. Six filed examples are given from crystalline basement.

Bohannan L and Bohannan P 1953. The Tiv of Central Nigeria. In: Forde, D. editor. Ethnographic Survey of Africa, Western Africa, Part VIII. International African Institute, London.

Bolton P, Imevbore A M A and Fraval P 1990. Field evaluation in Northern Nigeria of a rapid assessment procedure for identifying environmental and health hazards in irrigation schemes. Hydraulics Research Report No. OD/P 103.

Bolton P, Imevbore A M A and Fraval P 1990. A rapid assessment procedure for identifying environmental and

health hazards in irrigation schemes: initial evaluation in Northern Nigeria. Hydraulics Research Report No. OD 120.

Bosscher P J, Bruxvoort G P and Kelley T E 1988. Influence of discontinuous joints on permeability. Journal of Geotechnical Engineering, American Society of Civil Engineers, vol 144, pp 1318-1331.
Extensive jointing is a feature common to many fined grained soils with a high clay content. Field tests show K 2-3 orders of magnitude higher than lab tests. This study looked at the influence of joints that are not necessarily connected. The used remoulded fine grained till. Permeability parallel to the joint was significantly larger than permeability perpendicular to the joint. Conclusions:

(1) Joint orientation is crucial when the orientation is within 30% of the flow direction
(2) jointed soil K = 100 x K nonjointed soil
(3) potential flow models offer little understanding (though worthwhile?!).

Bouma J, Jongmans A G, Stein A and Peek G 1989 Characterizing spatially variable hydraulic properties of Boulder Clay deposits in the Netherlands. Geoderma, vol 45, pp 19-29.
Cylinders were pushed over excavated undisturbed cylindrical columns of soil. They stressed the importance of gaining a REV. Groundmass 0.3 m/d; sandy material around fractures 6.9 m/d.

Bredehoft J D and Papadopulos 1980. A method for determining the hydraulic properties of tight Formations. Water Resources Research, vol 16, pp 233-238.
This paper describes the adaption of the slug test for low K environments. Use a standpipe with a very small radius and if transmissivity is very low use a pressurised slug test. It could take over a year for a slug test to become completed while a pressurized test could be over in days

Bredehoeft J D, Neuzil C E and Milly P C D 1983. Regional Flow in the Dakota Aquifer: A Study of the Role of Confining Layers. U.S. Geological Survey Water-supply Paper 2237.
In situ and lab hydraulic conductivity tests have been undertaken on the confining layers of the Dakota Sandstone (Cretaceous shales). They carried out slug tests in packers measuring the change in head with pressure transducers. Successively smaller sections of the hole were tested. Some leakage occurred across the packers . All the hydraulic conductivity measured from lab and slug tests was low - $<10^{-10}$ m/s and decreased with depth. Numerical modelling showed that K was 2 - 3 orders of magnitude greater than this - probably from fractures.

The Dakota Sandstone in South Dakota is one of the classic artesian aquifers; it was first studied by N.H. Darton at the turn of the century. Since then, hydrogeologists have debated the source of the large quantities of water which have been discharged by artesian flow from the Dakota. Among suggestions for the source of this water are (1) recharge of the aquifer at outcrops in the Black Hills, (2) compaction and compression storage within the aquifer, (3) leakage through confining layers, and (4) upward flow from the underlying Madison Grouo limestones.

A series of increasingly refines models of the aquifer system in South Dakota have been developed and used for numerical simulations of the groundwater flow. The simulations have provided estimates of leakage through the confining layers. The results indicate that, before development, most of the flow into and out of the Dakota Sandstone occurred as leakage through confining layers and, sice development, most of the water released from storage has come from the confining layers.

In situ and laboratory hydraulic conductivity measurements have been made for the Cretaceous shale confining layer which overlies the Dakota. These data indicate hydraulic conductivities which are one to three orders of magnitude lower than the conductivities indicated by the numerical analyses; this suggests that the leakage through the confining layer is largely through fractures. The fractures apparently did not influence the laboratory and in situ measurements.

To test the conception of flow in the aquifer-confining layer system derived from our analyses, the transport of sulphate in the system was simulated. Simulations using a numerical ground-water transport model were reasonably successful in explaining the present distribution of sulphate in the system. This result increases confidence in the flow system implied by the flow simulations in which leakage through confining layers is dominant.

Breiner S 1973. Application manual for portable magnetometers. Geometrics, Sunnyvale, California.
Useful practical manual on the use of proton processor magnetometers. The earth's magnetism is discussed along with filed procedures and data reduction. Further chapters deal with data surveys and interpretation and the magnetic susceptibility of various materials.

Bromley J, Mannstrom B, Nisca D and Jamtlid A 1994. Airborne Geophysics: Application to a groundwater study in Botswana. Ground Water, vol 32, pp 79-90.
The main aquifer in the area is confined between mudstones (below) and basalts (above). Airborne geophysics and VLF were flown to try and penetrate this cover. The results then helped to guide the drilling. Highest yields were associated with fractures identified by the VLF. They had the gridded data so could analyse it in detail. They produced a grey tone image of aeromag residuals which picked up the dolerite

dykes and grabens. The dykes had a positive anomaly to the north and a negative anomaly to the south. The measured the magnetic susceptibility of the dolerite (0.009-0.034 SI) and basalt (0.002-0.02). The magnetic survey gave the most information about dykes. Dykes from 10 - 40 m thick. In this area the dykes are considered as barriers.

Bronders J 1994. Hydraulic conductivity of a tropical residual soil prone to landslides. Quarterly Journal of Engineering Geology, vol 27, pp 375-382.

Saturated hydraulic conductivity or the coefficient of permeability (k) of a residual soil prone to landslides was determined for a study area in Fiji. The techniques used were not new but the approach and the resulting k-values may be useful for other studies (e.g. landslides). Inverse auger-hole tests are used to estimate k-values. Tests conducted in sandy silty soils indicate values in the order of 10^{-6} ms^{-1}. No significant difference was found between calculated values at the surface and at 3 m depth. Infiltration tests showed saturated infiltration rates of $10^{-5}ms^{-1}$.

Brown K M and Ransom B 1996. Porosity corrections for smectite-rich sediments: Impact on studies of compaction, fluid generation, and tectonic history. Geology, vol 24, pp 843-846.

Porosity is a fundamental parameter that must be correctly determined in order to relate physical property, hydrologic, and chemical flux studies to natural systems. Traditional porosity determinations generated from physical property or seismic data can greatly overestimate the true porosity of sediments in which hydrated minerals such as smectite are abundant. To produce a true porosity distribution such data must be corrected to account for the H_2O residing in smectite interlayers which can make up to 25% of the total hydrated mineral mass. Such H_2O is easily removed from the mineral by oven drying and/or exposure to low humidities. Standard physical property measurements can be corrected, provided the weight percent smectite in the sediment is known and the interlayer H_2O content of the mineral can be estimated. We illustrate the significant consequences of this correction by comparing profiles of reported and corrected porosities for smectite-rich Barbados abyssal plain and accretionary wedge sediments from Ocean Drilling Programme Leg 110, Sites 671 and 672.

Bruijnzeel L A 1993. Land-use and hydrology in warm humid regions: where do we stand? Hydrology of Warm Humid regions (Proceedings of the Yokohoma Symposium, July 1993). IAHS Publications no 216, Wallingford.

Reviews the role of land use types in regard to hydrology, sedimentation and soil fertility. The removal of vegetation cover can lead to increase in soil moisture content which in turn leads to a vigorous runoff response. If less than 20% of the forest is affected there is little effect on water yield. Greater than 20%: increase in yield for the first 3 years, thereafter dependent on crop. Afforestation of grasslands can lead to decreasing streamflow. Since clearing increases the soil moisture content both the runoff and recharge can increase.

Burke K C, Dessauvagie T F J and Whiteman A J 1972. Geological history of the Benue valley and adjacent areas. In: T. F. J. Dessauvagie and A. J. Whiteman (eds) African Geology, pp 187-205.

The Cretaceous of the Gulf of Guinea a opened about RRR triple junctions north of the Takatu Rift, Guyana and under the present position of the Niger Delta. Opening followed existing lines of weakness close to the edges of the West African and Congo cratons. Gravimetric and magnetic data under the Niger Delta are consistent with the hypothesis that a spreading ridge underlay this area and extended a short distance up the Benue trough during part of the Cretaceous. Sediments deposited in the trough were folded in Late Santonian times as a result of misfit motion within the African plate due to faster spreading opposite the bulge of Africa than in the South Atlantic.

A marked gravity high in the Abakaliki area overlies volcanics of intermediate and basic composition. It is possible that to accommodate the misfit motion an episode of consumption took place in this area in Santonian times. The occurrence of andesite at Abakaliki indicates that a subduction zone existed thereabouts.

A compilation gravity map of the Benue Valley - Niger Delta indicates the continuation of the Benue Rift system into the Chad Basin. A positive anomaly marks the axis of the Benue rift which is flanked by a series of negative anomalies (-40 milligals maximum). These overlie miogeoclinal wedges formed during the spreading phase.

Late Cretaceous delta systems advanced down the Benue trough and were interrupted by minor B2 Bima (Albian) and major Pindiga (Turonian) marine incursions.

The Santonian closing episode produced long linear folds subparallel to the trough margins resulting in the formation of some anticlines more than 60 km long. In contrast to the unfolded gently dipping Cretaceous sediments of the Bida Basin those of the Yola Basin are folded subparallel to the local trough axis.

In Tertiary time delta systems advanced southwards eventually burying the continental margin and extending over oceanic crust into the Gulf of Guinea.

In Miocene times the new Cameroon rift-ridge feature began to develop. Regional uplift was locally in excess of 1,000 m. and was accompanied by alkaline volcanicity. Erosion, consequent upon this uplift, resulted in a more rapid advance of the delta system. Development of the Quaternary delta system was modified by ice-controlled sea level changes.

Capuano R M and Jan R Z 1996. In situ hydraulic conductivity of clay and silty-clay fluvial-deltaic sediments, Texas Gulf Coast. Groundwater, vol 34, pp 545-551.

Two aquifer pumping tests (13 and 24 hours) and a tracer injection test were performed on shallow (7.5 m) clay and silt-clay sediments of the fluvial-deltaic Beaumont Formation from the U.S. Gulf Coast. The insitu horizontal hydraulic conductivity determined from these test is found to be approximately 10^{-5} m/sec (1 m/d). This value is one to three orders of magnitude larger than that of typical silts and clays, and two to four orders of magnitude larger than the vertical hydraulic conductivity measured on core in laboratory permeameter experiments. A uniformity of the drawdown curves from different observation wells strongly suggests that hydraulic conductivity is relatively homogeneous and isotopic in the horizontal plane at the scale of the test. This relatively large in situ horizontal hydraulic conductivity for these clay-rich sediments is attributed to macroporosity rather than matrix porosity

No water entered the boreholes until they encountered a silty-clay layer which comprised the aquifer. They encountered a lot of collapse. They gained a lot of drawdown data. Core samples for lab tests were collected using a Shelby tube. The more permeable horizons had 42-83% silt and clay and 17-58% fine sand.

Carruthers R M and Smith I F 1992. The use of ground electrical methods for siting water supply boreholes in Shallow crystalline basement terrains. In Wright, E. P. and Burgess, W. G. (Editors) The Hydrogeology of Crystalline Basement Aquifers in Africa, Geological Society Special Publication No 66, pp 203-220.

Discusses the use of resistivity and EM in siting boreholes in crystalline basement. EM methods are useful for profiling and finding lineations more precisely. Data need to be analysed sufficiently to provide useful hydrogeological data. In shallow bedrock areas the emphasis should be on profiling to identify the fracture systems. Horizontal coil information should be collected in sufficient detail.

Chamley H 1989. Clay sedimentology, Springer-Verlag, Berlin.

More advanced book on clays. Have a copy of Chapter 1, Clay minerals on file. Also a copy of Chapter 2, Clay Formation through weathering. No abstract - see literature review for more details.

Charlesworth D L, Howard K W F and Nadon R 1992. An innovative use of groundwater sampling equipment to determine aquifer characteristics in Precambrian basement rocks in Uganda. Quarterly Journal of Engineering Geology, Vol 25, pp 165-168.

In many hydrogeological investigations, particularly those involving crystalline basement aquifers in Third world countries, it has not been possible to obtain good data on the aquifer characteristics. This short-coming arises from a variety of reasons, including the lack of funds to carry out large-scale pumping tests, the lack of suitable boreholes for test pumping and the local lack of appropriate testing equipment.

In a recent study carried out in southwestern Uganda, the Waterra inertial pump, originally designed as alow-cost dedicated sampling device for ground-water monitoring holes, was effectively used in conjunction with pneumatic packers to obtain hydraulic conductivity profiles in both new and existing boreholes. The work was carried out as part of a research project funded by the International Development Research Centre (IDRC) of Canada and primarily utilized boreholes drilled as part of a UNICEF/Government of Uganda rural water supply project.

Chorover J and Sposito G 1995. Dissolution behaviour of kaolinitic tropical soils. Geochimica et Cosmochimica Acta, vol 59, pp 3109-3121.

Batch experiments at controlled pH and ionic strength were conducted with representative kaolinitic soils from Brazil to investigate their short-term dissolution behaviour. The release of Al and Fe from the soils showed similar pH dependence, exhibiting a minimum value (p.m.d.) just above the point of zero net charge for soils. Both Al and Fe release rates below the p.m.d. were correlated positively with soluble organic C, proton concentration, and net proton surface charge, the last two relationships being power-law functions similar to those observed for the dissolution rates of specimen metal oxides and aluminosilicates. Below the p.m.d., release of Si from the soils exhibited a pH dependence very much like that observed for specimen kaolinites and the molar ratios, Si/Al and Fe/Al released, were smaller than 1.0, probably because of the rapid solublization of organic Al forms. Above the p.m.d., colloidal dispersion occurred and Al, Si and Fe were released in both dissolved and microparticulate forms.

Christensen N B and Sorensen K I 1994. Integrated use of electromagnetic methods for hydrogeological investigations. Proc 7th Symp SAGEEP, published by SEMG, pp 163-176.

Using TEM and geoelectric soundings the vulnerability of an aquifer can be assessed, the depth to the lower boundary, type of sediments and the water quality. Examples from Quaternary Geology. Data has to be collected on a high density.

Clarke E and Clark T D G 1994. Errors in using the BGGM as a Navigation reference due to short term magnetic disturbance. British Geological Survey Technical Report WM/94/27C.

Confidential report to shell by Geomag group in Edinburgh. Two or three pages about the equatorial electrojet. The EEJ results from an increase in the horizontal activity of the ionosphere perpendicular to the magnetic field. It occurs where the field is approximately horizontal (ie in equatorial regions). Electrons and ions collide causing a current which induces a magnetic field. The EEJ is therefore a result of a current flowing at about 100-110 km altitude. It is confined to a small region either side of the dip equator where the geomag filed is nearly horizontal (Oju falls within this area). The EEJ has a dominant daily period due to solar heating. A much greater range in H is observed than would be predicted from the rest of the earth - up to twice that expected (200 nT). Another phenomenon known as the Counter Equatorial Electrojet (CEEJ) can be observed where the current flows from east to west in the morning or afternoon. This can enhance the daily range in D, I and F.

Clarke E, Riddick J C and Ogunade S O (compilers) 1995. Magnetic results 1994: Ile-Ife Observatory, Nigeria. British Geological Survey Technical Report WM/95/14.

Daily geomagnetic data from an observatory in western Nigeria. Data were frequently lost due to power cuts. A lot of noise up to 10 nT. Large amount of interference for working hours from July 1994 onwards; this resulted in the data being removed. In general the diurnal variations show an amplitude of 50-100 nT and peak in the middle of the day. In the first half of the year many magnetic storms were observed on a monthly basis. The smallest harmonic within the diurnal variation is about 3 hours. It may be possible to gain data from the observatory to post analyse the data

Clarke W S, Graziani W M, Bulla P S and Magditsch A E 1989. Permeability of fractured rocks in a quarry proposed to be a sanitary landfill. Proceedings Focus conference on eastern regional ground water issues: October 17-19, 1989, Valhalla Inn, Kitchener, Ontario, Canada ; National Water Well Association Dublin, OH, US; 1989, pp 435-448.

It has been proposed that the northern part of the Acton Quarry (approximately 105 ha), which will be mined out in 2-3 years, be developed into a municipal solid waste landfill. The quarry is located at the edge of the Niagara Escarpment, approximately 33 km west of Toronto. On-site investigations were conducted to determine hydrogeological conditions; assess design concepts; assess potential impacts on groundwater resources; and identify and recommend a groundwater monitoring program. Determination of in situ permeabilities in the various lithological units had high priority. Characterization of the hydrogeological properties of the 18 m thick Cabot Head shales, lying immediately under the landfill, was emphasized. Thirty five well nests (101 individual wells) were installed at the site; 89 wells were constructed in bedrock to obtain water levels, water quality, vertical hydraulic gradients and in situ permeabilities in the various rock units. The in-situ permeability tests, including mechanical and pressure packer tests, recovery tests, pumping tests and constant head tests, are described. These methods were used to calculate the hydraulic conductivity values for each of the main hydro stratigraphic units. The hydraulic conductivity values measure the permeability of the rock formations in the horizontal direction. The upper Cabot Head shale has a low permeability which decreases by approximately two orders of magnitude with depth. Values are also presented for the Amabel, Reynales, Manitoulin, Whirpool and upper Queenston formations. Further studies will be undertaken to determine the in situ permeability values in the vertical direction.

Cochran H A 1937. The Technique of Well Sinking in Nigeria. Geological Survey of Nigeria, Bulletin No. 16.

Colin F, Brimhall G H, Nahon D, Lewis C J, Baronnet A and Danti K 1992. Equatorial rain forest lateritic mantles: a geomembrane filter. Geology, vol 20, pp 523-526.

The superimposed weathered layers in equatorial rain forest lateritic mantles from Gabon, Africa, function as interactive compartments forming a dynamic semipermeable geomembrane filter. Selectivity of the filter is controlled by a progressive downward disappearance of connected macropore pathways created by bioturbation and dissolution. The natural balance of root activity, translocation, dissolution, deformation, and pore evolution leads to the development of porous and permeable, mature, open geochemical weathering systems at the expense of the lithosphere. These conclusions can be useful in modelling the fate of lateritic soils, which cover one-third of the emerged area of the world and which are economically important both as metal deposits and agricultural soils.

Cotecchia F and Chandler R J 1995. Geotechnical properties of the Pleistocene clays of the Pappadai Valley, Taranto, Italy. Quarterly Journal of Engineering Geology, vol 28, pp 5-22.

This paper presents a set of experimental data that characterizes the Lower Pleistocene Pappadai Blue Clay in the Pappadai Valley, Taranto, southern Italy.

Basic geotechnical classification data are given, along with the results of chemical and mineralogical analyses which describe the variations of the properties of the clay for various vertical profiles through the deposit. The results reflect the near complete history of a sedimentary basin, add to the data base for the blue clays of the Apulian Region, and provide a full description of the distribution of properties of a blue clay deposit. The variations of the properties of the clay can be related to the depositional history, to micropalaeontological studies, and to weathering process subsequent to deposition. The microstructure of the clay is studied using a scanning electron microscope.

Of particular interest are the relationships between the geological history of sedimentation, which is known with reasonable accuracy, and aspects of the mechanical behaviour of the clay.

Courville P et Thierry J 1993. Nouvelles donnees biostratigraphiques sur les depots cenomano-turoniens du Nord-Est du fosse de la Benoue (Nigeria). Cretaceous Research, vol 14, pp 385-396.
The Upper Cretaceous deposits of the Upper Benue(North-East Nigeria) record regional and local events (sea-level changes, biological successions and tectonic movements) which throw light on the Upper Cenomanian transgression. Evidence of discontinuities and sedimentary assemblages well dated by micropalaeontological data, allows the sedimentary sequence to be interpreted in the context of sequence stratigraphy. The discovery of new ammonite faunas has enabled a more precise definition of the local biostratigraphy and a correlation of this with the standard zonal scheme. In the near future, when they are better known, the ammonite successions recognised in the Upper Benue could enable a more precise delineation of Cenomanian - Turonian time than that proposed here; this would both complement and help to clarify existing schemes recently proposed for other African areas.

Cooper H H, Bredehoeft J D and Papadopulos I S 1967. Response of a finite diameter well to an instantaneous change in water. Water Resources Research vol 3, pp 263-269.
A solution is presented for the change in water level in a well of finite diameter after a known volume of water is either injected or withdrawn. A set of type curves is presented.

Cragg D J and Ingman J 1995. Rock weathering descriptions: current Difficulties. Quarterly Journal of Engineering Geology, vol 28, pp 277-286.
The guidance given in BS5930: 1981 for rock weathering descriptions at the material scale is considered to be inappropriate for UK practice, and is seldom applied to rock core logging. Practitioners turn to alternative weathering schemes for logging rock cores, some of which are inappropriate at the material scale; others are intended for specific, uniform lithologies and may also prove to be unsuitable when geological conditions vary from the presumed uniformity. The authors present examples from various geological situations, to demonstrate the difficulties arising when existing published weathering schemes are applied. The difficulties associated with derived mass zonations from material scale descriptions are considered. The description of cores at the material scale is considered to require quantified detail, independent of the prescribed schemes currently existing.

Cratchley C R and Jones G P 1965. An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria. Overseas Geological Surveys, Geophysical Division, Geophysical Paper No. 1.
On the available geological evidence these is little to choose between the two apparently contradictory hypotheses that the Benue 'trough' is a buried Cretaceous rift valley produced by tension, or a minor geosynclinal furrow formed by compression. The gravity survey was undertaken in an attempt to resolve this problem.

Stratigraphical evidence indicates that sinking along a linear depression must have commenced by mid-Albian time and continued until perhaps late Senonian, interrupted by some uplift and possibly folding in the late Albian. Compressional folding of the Cretaceous rocks began in the Senonian and resulted in the formation of a series of long, narrow folds whose axes are generally parallel to the boundaries of the linear basin. Minor intrusions and lead-zinc mineralisation probably follow immediately afterwards along the centre of the basin. A limited amount of volcanic activity took place in the Tertiary and Recent times.

The Bouguer isogals are, in general, parallel or sub-parallel to the Cretaceous-crystalline basement boundaries. Over the Cretaceous basin a medial zone of high gravity is flanked to the north and south by narrow elongated negative anomalies. Over the bounding areas of crystalline granites and gneisses, the Bouguer values decrease away from the basin. This pattern is interpreted as being due to (a) thinner crust beneath the basin than beneath the flanking basement, (b) a central zone of intruded rocks where basement may be at shallow depth, and (c) narrow troughs filled with lighter Cretaceous rocks at either side. The belt of lead-zinc mineralisation shows a striking coincidence with the central zone of positive anomaly. The depth of sedimentary rocks in the northern trough may be 18,000 ft. while in the southern trough it probably does not exceed 13,000 ft. The contacts at both edges of the main Benue trough are probably faulted beneath Cretaceous cover. The gravitational interpretation leads to the conclusion that the Benue Valley originated as a rift under tension which continued while the sediments were being laid down. Intrusion and uplift occurred at a later stage.

The stratigraphic and structural evidence enables an approximate sequence of events to be worked out. The combined interpretation leads to a tentative structural history of the Benue Valley which supports the hypotheses of Bucher (1957) that the geosynclinal 'welts' are formed under tension, the later folding being due to compression. The tensional origin of the Benue trough in Albian time is consistent with L. King's hypothesis on the separation of South America from Africa.

Crouch G A 1993. Benue State Agricultural Support Project. Working paper III - rural infrastructure: water. IFAD for the Federal Republic of Nigeria.

Dakin R A, Farvolden R N, Cherry J A and Fritz P 1983. Origin of dissolved solids in groundwaters of Mayne Island British Colombia, Canada. Journal of Hydrology, vol 63, pp 233-270.
Interbedded shales and sandstones. The high TDS in the aquifer is due to slow release of salt from the shale into the silt and sandstones. The salty water originated probably from post depositional compaction and emersion in the sea. Fresh meteoric water has flushed out the more permeable parts of the aquifer.

Daniel D E 1989. In situ hydraulic conductivity tests for compacted clay. Journal of Geotechnical Engineering, vol 115, pp 1205-1227.
Summarises the various in situ tests for compacted clays; the Boutwell permeameter; constant-head borehole permeameters; porous probes; single ring infiltrometers; sealed double ring infiltrometers, air entry permeameters, lysimeter pans. Most of the methods are for conductivity values less than we would be dealing with.

Davies J 1994. Water supply and sanitation project, Oju and Katsina Ala LGA's, HYDROGEOLOGICAL INPUT. BGS Technical Report WD/94/38R.
A review of all relevant geological and hydrogeological information available from the south-central part of the Benue Trough, covering the Oju and Katsina Ala Local Government Areas of Benue State, Nigeria as defined by the TOR has been undertaken. Associated environmental, health and socio-economic factors have been addressed.

The Igedde and Tiv peoples populating the Oju and Katsina Ala areas respectively form two distinct tribal groups with dissimilar settlement patterns. However both have similar water supply and health problems, that are inter-related. Water related illnesses such as Guinea Worm infestation, diarrhoeal diseases, malaria, typhoid and yellow fever are endemic in both areas. Long distances are walked by women and children to collect water for domestic purposes, carried back to the village in various containers balanced on their heads commonly causing malformation of spinal columns. Water is drawn from unprotected sources such as perennial streams and seepages during the dry season. During the wet season water can be obtained from nearer seasonal springs and streams, as well as hand dug wells and rain water collection systems. The rural population groups consulted were all well aware of the health and economic benefits they would accrue from supply of a local clean water supply, sustainable throughout the year. Numerous attempts have been made by villagers to excavate hand dug wells that have usually resulted in failure due to the collapsing nature of the near surface weathered formation.

In the short term there is a need to upgrade existing dry as well as wet season water sources, to protect the population from disease infection. This could be achieved using community based systems of construction based upon the Nigeria Guinea Worm Eradication Programme (NIGEP) village education system. At the same time there is a need to establish systems to monitor water table movements in response to rainfall events and abstraction during the year. The hydraulic parameters of the upper weathered zone and lower country rock aquifers need to be assessed through the drilling and testing of a series of exploration boreholes. Information from these exercises will permit a better understanding of aquifer conditions, to permit construction of hand dug wells and boreholes designed to supply water throughout the year. Such groundwater abstraction systems should be used in conjunction with rainfall harvesting and storage systems to ensure sustainable supplies throughout the year in the mid term. In the long term the construction of piped water supply systems utilising perennial rivers as sources may have to be considered should the aquifer systems prove to be of too small a capacity to supply future water requirements.

Dennehy K F and Davis P A 1981. Hydrologic testing of tight zones in southeastern New Mexico. Ground Water, vol 18, pp 482-489.
Investigating tight zones for storing hazardous waste. They used slug tests and pressurised slug tests. They found pressure transducers invaluable for measuring the head changes in the slug tests. They found slug tests and shut in tests to be best for $T < 1$ m2/d. The slug tests gave better results than the shut in tests because (1) problems of discharge from the shut in test and the non-uniqueness of curve fitting. Pressurized slug tests were useful for $T < 10^{-4}$.

Dorn M 1985. A special aspect of interpretation of geoelectric sounding curves and its application for groundwater exploration. Geoexploration, vol 23,pp 455-469.
Two layers of data are available from a sounding curve: (1) the general structure which gives information on the general arrangement of the strata and the top and bottom layer (2) fine structure giving information on the number of layers, the thickness and resistivity. (1) can be gained from sounding curve alone, (2) a geological concept is needed. Problems from the principle of equivalence are reduced by fixing the resistivity of the aquifer and using that as the model. Then hydrogeological decisions are unaffected by ambitious fine structure. The number of layers is unimportant for the hydrogeologist.

Du Preez J W and Barber D F M 1965. The distribution and chemical quality of groundwater in Northern Nigeria. Geological Survey of Nigeria Bulletin No 36.

Dumbleton M J 1967. Origin and mineralogy of African red clays and Keuper Marl. Quarterly Journal of Engineering Geology, vol 1, pp 39-45.
African red clays and the Keuper Marl are materials of contrasting origin and mineralological composition. The red

clays are residual soils produced by weathering of rocks at the land surface under relatively high temperature, leaving the soil rich in iron and aluminium. In Kenya the clay minerals and iron oxide occur respectively as metahalloysite and hematite under relatively dry conditions, and as hydrated halloysite and goethite under moister conditions. The plasticity of the clay minerals is modified by the iron oxide. Black montmorillonitic clays, rich in bases and silica, occur in association with the red clays but on lower ground.

The Keuper Marl is the product of weathering of higher land, which accumulated to a great thickness in a wide basin. Conditions of internal drainage led to enrichment of bases and silica. Calcium and magnesium are present as calcite and dolomite, and silica is present as quartz. All the clay minerals found were rich in magnesium and silica, Illite and chlorite were universal, and much of the chlorite was of the swelling type. In addition, sepiolite and palygorskite commonly occurred. Quantitative x-ray analyses showed up to 90 per cent of clay minerals, but particle-size analyses showed a much smaller proportion of clay-sized minerals, due to particle aggregation or to the occurrence of unusually large clay mineral particles.

Edet A E, Teme S C, Okereke C S and Esu E O 1994. Lineament analysis for groundwater exploration in Precambrian Oban Massif and Obudu Plateau, SE Nigeria. Journal of Mining and Geology, vol 30, pp 87-95.

Lineament mapping and analysis of lineament density using radar imageries and aerial photographs have been used to delineate groundwater productive zones in Obudu plateau and Oba massif of SE Nigeria. With the aid of lineament length and intersection density for both areas a regional groundwater potential map has been produced.

Results show that the lineament density is higher in the Obudu plateau than in the Oban massif areas. Secondly, the overburden is thicker around most parts of the Oban massif that Obudu plateau. In addition overburden ratio, defined as the ratio of the overburden thickness to lineament density and/or frequency, decreases with increasing lineament density giving a negative slope on a bi-log plot.

Shallow boreholes/hand dug wells and deep boreholes fitted with submersible pumps are recommended for the Obudu plateau (high lineament density zones) and Oban massif (low lineament density zones) respectively.

Edmunds W M and Gaye C B 1994. Estimating the spatial variability of groundwater recharge in the Sahel using chloride. Journal of Hydrology, vol 156, pp 47-59.

Interstitial water chloride profiles were obtained from the unsaturated zone in a Quaternary aquifer in Senegal. Also a regional survey of hand dug wells. Rainfall input chemistry was also obtained. Using simple theory the recharge can then be calculated.

Egboka B C E and Okpoko E I 1984. Gully erosion in the Agulu-Nanka region of Anamabra State, Nigeria. In: Walling, D. E., Foster, S. S. D. and Wurzel, P. (editors), Challenges in African Hydrology and Water Resources (Proceedings of the Harare Symposium, July 1984). IAHS Publ. No. 144. pp 335-347.

In the Agulu-Nanka area gully erosion covers an area of about 1100 km^2. The gullying started around 1850 and the rate of gully growth is estimated at 20-50 m $year^{-1}$. The British Colonial Office and the local inhabitants attempted to control the gullying by constructing small dams and planting trees, but the measures failed. The area lies within the humid tropical rain-forest belt of Nigeria. The landscape is a cuesta within the Awka-Orlu uplands formed by the Nanka Formation (early Eocene) and the Imo shale Formation (Palaeocene). Both the geological, hydrogeological, geotechnical and hydrogeochemical characteristics of the area and human activity have contributed to gully development and growth. Major aquifers and aquitards form multi aquifer systems and heavy rainfall causes a rise in the water table. The increase in hydraulic head produces rapid flow rates that enhance the gullying process. Expansion and contraction of the clays and shales in the rainy and dry seasons respectively lead to slumping and landslides. Slightly acidic waters produced by radox reactions decompose cementing materials, thereby desegregating the sand grains and facilitating gullying. An integrated approach is suggested for controlling erosion and gullying. It includes detailed mapping of the affected areas and other areas of potential gullying, and evaluating the adverse effects of rainfall, groundwater flows and seepage, water geochemistry, and anthropogenic activities such as agriculture.

Egboka B C E and Nwankwor G I 1985. The hydrogeological and geotechnical parameters as agents for gully-type erosion in the Rain-Forest Belt of Nigeria. Journal of African Earth Sciences, vol 3, pp 417-425.

The Agulu-Nanka gully complex is located in Anambra State, Nigeria. The gullies formed by erosion have damaged the environment extensively and driven people from homes and farm lands. The rate of growth of the gully system is estimated to be about 30 m per year. Earlier studies attributed the genesis and growth of the gullies to human activities and geomorphological processes. This study shows that the root causes of the gully genesis and growth strongly lie in the hydrogeological and geotechnical properties of a complex aquifer system. These properties are related to the high hydrostatic pressures in aquifers that reduce the effective stress of unconsolidated coarse sands, thereby leading to erosion. On the basis of the hydrogeological and geotechnical data available, it is suggested that a major dewatering scheme would check the growth of the gullies and also better water supply to the rural communities.

Egboka B C E and Uma K O 1986. Comparative analysis of transmissivity and hydraulic conductivity values from

the Ajali aquifer system of Nigeria. Journal of Hydrology, vol 83, pp 185-196.

The lack of data on aquifer parameters such as hydraulic conductivity (*K*), transmissivity (*T*) and storativity (*S*) is a major problem bedevilling groundwater resource planners and managers in many developing countries like Nigeria. In these countries pumping-test analysis is rarely carried out during aquifer evaluation. Where done, the available data commonly are incomplete or unreliable. An attempt is made here to find alternative methods of aquifer analysis that are simpler and cheaper, and can yield usable *K* and *T* values in situations where pumping-test analysis has not been or cannot be done. Three grain-size statistical methods and Logan's (1964) approximation method were used to calculate *K* and *T* for aquifers of the Ajali Formation of Nigeria. The resulting data were compared with those of pumping-test methods where available. It was found that the Masch and Denny (1966) statistical method gave values that were as reliable and useful as Logan's and other pumping-test methods. The Hazen (1893) and Harleman et al. (1963) statistical methods gave unreasonably high K and T values.

Ekpechi O L 1967. Pathogenesis of endemic goitre in Eastern Nigeria. British Journal of Nutrition, vol 21, pp 537-545.

1. A survey in Eastern Nigeria revealed an area of endemic goitre with a marked variation in incidence from village to village not accounted for by iodine deficiency alone.
2. As dried unfermented cassava was consumed in large quantities in the highly goitrous areas, experiments with rats were undertaken to assess the significance of this factor.
3. Groups of rats were fed (a) cassava, (b) equal parts cassava and standard diet, (c) cassava with added iodine, and (d) standard diet, and each rat received an intraperitoneal injection of 20 μc iodine 24 hr before being killed.
4. The iodine content and hardness of the water in the various areas were estimated and the chemical and bacteriological indices of pollution determined.
5. The following effects were observed: thyroid weight, iodine uptake and plasma-protein-bound iodine were all increased in the cassava-fed animals, the last markedly so. The thyroid's precursor and hormone iodine stores were severely depleted in these animals, which also showed an impaired transfer of iodine from monoiodotyrosine to diiodotyrosine and a high proportion of the iodine present as iodothyronine. The giving of iodine with the cassava did not prevent these changes taking place.
6. Many of the observed effects suggest that cassava was acting like the thionamide group of an antithyroid drug.
7. These findings are discussed.

Ekwueme B N 1992. Petrology of intermediate igneous rocks in the Oyioba-Uganga area, Southern Benue Trough, Nigeria. Journal of Mining and Geology, vol 28, pp141-147.

Syenites, diorites and microdiorites have been recognised in the Oyioba-Uganga area of southern Benue Trough, Nigeria. These rocks are rich in plagioclase feldspar of oligoclase composition. Other minerals in the rocks are opaque oxide (believed to be iron oxides), pyroxene, epidote, biotite and hornblende. Quartz is rare in these rocks whilst K-feldspar has been extensively altered to kaolinite in some samples.

The rocks are enriched in Al_2O_3 and Na2O but impoverished in SiO_2 and Fe_2O_3 (total). They show alkaline affinity.

Ekwueme B N 1994. Basaltic magmatism related to the early stages of rifting along the Benue Trough: the Obudu dolerites of south-east Nigeria. Geological Journal, vol 29, pp 269-276.

Dolerites of the Obudu Plateau of south-eastern Nigeria occur prominently as dykes cutting Precambrian Basement gneisses. Minor dolerite sills have also been mapped. The dolerites are dominantly olivine thokeiites and are geochemically of ocean basalt type. They were emplaced in a within-plate tectonic setting and yield a $^{40}Ar/^{39}Ar$ plateau age of 140.5±0.7 Ma, which is interpreted as the age of their emplacement. This age indicates that the Obudu dolerites are the products of basic magmatism related to the early stages of rifting along the Benue Trough of Nigeria. The Obudu dolerites are comparable with Mesozoic tholeiitic dykes of the northern Amazon craton, whose intrusion preceded the break-up of Africa and South America.

Etu-Efeotor J O and Akpokodje F G 1990. Aquifer systems of the Niger Delta. Journal of Mining and Geology, vol 26, pp 279-284.

A detailed stratigraphic analysis of the various geological/geomorphological units was carried out in an attempt to delineate the various aquifer horizons within the multi-layered aquifer system of the Niger Delta. One major aquifer was detected in the dry plains and freshwater swamps/meander belts. This aquifer contain lenses of clay aquitards. More than two sub aquifer units were identified in the saltwater mangrove swamps and the coastal beach islands/ridges. These sub-units may have partial hydraulic connections because the intervening aquitards are not laterally continuous. A perched water aquifer (2.5 m thick) occurs above the regional aquifer in the coastal beaches.

Fan C H, Allison R J and Jones M E 1996. Weathering effects on the geotechnical properties of argillaceous sediments in tropical environments and their geomorphological implications. Earth Surface Processes and Landforms, vol 21, pp 49-66.

Outcrops of young, sedimentary, argillaceous rocks with well developed fabric display rapid changes in their properties when subject to tropical weathering. The change in the materials is often accompanied by mass movement activity

and the geomorphological consequence in terms of landforms is usually the development of badlands topography. Detailed field and laboratory studies have been undertaken on the Joe's River Formation, Barbados, and the Lichi Melange, Taiwan. Both are sedimentary mudrocks with well developed, scaly fabrics. Physical and geotechnical laboratory tests have been conducted on samples collected from type site locations to elucidate associations between mineral properties, earth surface processes and landform development. While the inherent physical properties show little or no difference in the transition from weathered to highly weathered minerals, by applying the critical state model, the mudrock geotechnical properties can be shown to change significantly. As weathering commences, material strength surprisingly increases. Only after a period of more extensive weathering do mechanical properties confirm increasingly incompetent materials. The initial strength increase appears to be due to weathering-induced modification of the fabric. The subsequent strength drop is a product of weathering-induced modification of both the fabric and the *in situ*, intact sediment. It is suggested that by applying the critical state model, a greater consideration can be gained of the geotechnical response of the sediments to weathering.

Farrington J L 1952. A preliminary description of the Nigerian lead-zinc field. Economic Geology, vol 47, pp 583-608.
Deposits of lead and zinc in the Cretaceous rocks of Nigeria have been known for a long time but have only been mined in the past on a very small scale owing to difficult communications and low metal prices. This large field, over 30,000 square miles in extent, containing several score occurrences of lead and zinc minerals has not yet been mapped in detail or comprehensively described. This paper gives a short account of the history and preliminary description of the physical features, the geology, and the mineralization of the field. The lead-zinc veins are regarded as occurring in structurally controlled fractures and the mineralization to have been of hydrothermal origin deposited under mesothermal conditions. The mineralization is thought to have taken place before the end of the Turonian stage of the Cretaceous and to be related to small but widely distributed dioritic intrusions.

Firman J B 1994. Palaeosols in laterite and silcrete profiles: Evidence from the south east margin of the Australian Precambrian shield. Earth-Science Reviews, vol 36, pp 149-179.
Laterite and silcrete profiles are common in arid and semi-arid areas of the Australian Precambrian Shield - a vast planar surface masked by the regolith. Much of the geological history of the shield subsequent to its early development is recorded in ancient cover rocks and younger basin sediments which occur in important stratigraphic sequences, particularly on the margins of the shield. Within these sequences, stratigraphically associated or as companion materials, weathering zones and palaeosols were developed which individually and as assemblages of layers and horizons record the history of weathering and soil formation since the Proterozoic. Laterite and silcrete profiles are seen to be assemblages of palaeosols, stratigraphically associated deposits and companion materials which were formed in response to changes in groundwater conditions at particular times in the past. The palaeosols record the evolution of regolith: Older weathering zones and bleached rocks were features of successive landscapes after the early Palaeozoic; ferruginous mottling, ferricrete and silcrete pans were formed after the early Cainozoic; ferricretes and mottled clay palaeosols - some of which have been described as "laterite" - were formed during and after the Pliocene. Materials in laterite and silcrete profiles are overlain in places by calcretes formed after the early Pleistocene and by younger soils. The assemblages are distinctive and are characteristic of particular morphological provinces.

Fitterman D V, Meekes J A C and Ritsema I L 1988. Equivalence Behaviour of three electrical sounding methods as applied to hydrogeological problems. Presented at the 50th annual meeting of the European Association of exploration geophysicists, June 6-10. 1988. The Hague, The Netherlands.
Sclumberger (VES), Time Domain EM (TDEM) and frequency-domain EM (EM). They apply the techniques to 4 different environments: H (middle conductive); K (middle resistive); Q (more conductive with depth) and A (more resistive with depth). VES: equivalence problems for both H and K scenarios and suppression of 2nd layer in Q and A. TDEM is better able to resolve the equivalence problems. All methods have problems with Q and A.

Fitton J G 1980. The Benue trough and Cameroon line. A migrating rift system in Central Africa. Earth and Planetary Science Letters, vol 51, pp 132-138.

Fix R E and Burt T P 1995. Global positioning system: An effective way to map a small area or catchment. Earth Surface Processes and Landforms, vol 20, pp 817-827.
The Global Positioning System (GPS) is an established method for establishing high accuracy horizontal and vertical control points over large areas. Recent improvements in receiver technology, differential surveying and software have made the use of GPS technology more practical for smaller projects. This paper compares different GPS methods with occupation times of 2 s, 2 min and 12 min using an existing control network, and the gathering of topographic data from a difficult field site. Two examples are given, one in East Texas, demonstrating the speed and accuracy of different techniques, and the other in the Quantock Hills in Somerset.

Fookes P G, Gourley C S and Ohikere C 1988. Rock weathering in engineering time. Quarterly Journal of Engineering Geology, vol 21, pp 33-57.
The paper attempts a comprehensive review of *in situ* weathering of rock used in civil engineering construction. It also presents some new data on weathered rock from Britain which have been used to develop a proposed Rock Durability Indicator scheme. This is based on simple engineering tests to help assess the potential performance of the rock in service.

It is concluded that weathering in geological time can have significant influence, under certain circumstances, on the durability of aggregate or stone in-service. Durability is defined as the rock material's ability to resist degradation during its working life and is considered to be dependent on a number of parameters; viz. the original state of weathering of the rock mass; the degree of imposed stressing during winning, production, placing and service; the climatic, topographical and hydrological environments in-service.

The production and construction procedures can have an important influence on the mechanical strength of the material. Physical weathering processes and imposed loading generally have the most significant effect on deterioration but chemical weathering could be significant in-service, especially in hot, wet climates.

No one engineering test can be used as an absolute predictor of performance. Combinations of common mechanical and physical tests such as water absorption, specific gravity, point load strength, modified AIV and magnesium sulphate soundness can be used in various combinations to help assess potential durability. For a more complete evaluation, environmental factors such as the climate, topography and hydrological regimes need to be taken into account.

Fortin G, Van Der Kamp G and Cherry J A 1991. Hydrogeology and hydrogeochemistry of an aquifer-aquitard system within glacial deposits, Saskatchewan, Canada. Journal of Hydrology, vol 126, pp 126-292.
The hydrology and hydrochemistry of an aquifer-aquitard system within glacial drift has been studied. The paper majors on the chemistry. Most of the flow data and interpretation has been given in other papers.

Foster S S D 1993. Groundwater conditions and problems characteristic of the humid tropics. Hydrology of Warm Humid regions (Proceedings of the Yokohoma Symposium, July 1993). IAHS Publications No 216, Wallingford.
Classifies groundwater systems into five groups: crystalline, major alluvial, recent volcanics, intermontain valley fills and karstic limestones. Groundwater very important in the ecosystem since it is so shallow. Aquifer generally have low transmissivity (1-5 m^2/d). Wetting has lead to the clayey materials being transported to the depressions. Recharge often given by steams. In the wet season aquifers fill up rapidly and may reach the ground surface. Good review paper.

Fraval P 1990. Health and environmental hazards in small irrigation projects in Northern Nigeria. Hydraulics Research Report No OD/P 99.

Frederica J 1990. Saturated hydraulic conductivity of clayey tills and the role of fractures, Nordic Hydrology, vol 21, pp 119-132.
They found a difference of between 1 and 2 orders of magnitude, in hydraulic conductivity, between lab and field samples.

Frohlich R K and Kelly W E 1985. The relation between hydraulic transmissivity and transverse resistance in a complicated aquifer of glacial outwash deposits. Journal of Hydrology, vol 79, pp 215-219.
Rhode Island USA. Schlumberger Sounding curves were undertaken and interpreted. They have a plot of transmissivity against transverse resistance. Quite a convincing direct relation with 5 points. They explain the use of the Dar Zarrouk parameters.

Gautschi A, Ross C and Scholtis A 1993. Pore water-groundwater relationships in Jurassic shales and limestones of northern Switzerland. In: D A C Manning, P L and C R Hughs (editors) Geochemistry of Clay-Pore Fluid Interactions. Chapman and Hall, London.
Interesting results from a motorway tunnel. Groundwater circulation in the clay (70-80% clay, 15% quartz, 5-10% Ca) is limited despite a very high head differential. The groundwater was also highly saline due to the little flushing that occurred.

Geological Society Engineering Group 1995. The description and classification of weathered rocks for engineering purposes. Working Party Report. Quarterly Journal of Engineering Geology, vol 28, pp 207-242.

Geological Society Engineering Group 1990. Tropical residual soils. Quarterly Journal of Engineering Geology.

Good review of the origin of tropical residual soils. Also describes the soils and suggests a system of classification. Various definitions:

duricrust	hardened horizons resulting from an accumulation of iron or aluminium or precipitation of calcite, dolomite or gypsum.

Laterite	soft clay rich horizons showing segregation - loose gravelly material comprising concretions or pisoliths.
Ferricrete	when the duricrust is rich in iron.
Bauxite	when the duricrust is rich in aluminium.
Calcrete	redistribution of calcite to form duricrust
dolocrete	redistribution of dolomite to form duricrust
gypcrete	redistribution of gypsum to form duricrust

Laterite and bauxite are the most common forms of duricrust found in the tropical regions. A classification system based on weathering, loss of silica and dominance of new clays has been suggested.

Fersiallitic	13-20 C 500 - 1000 mmpa with a dry season. Weathering of the primary materials during the wet season; elements retained in the profile due to capillary action in the dry season. The main new clay is smectite especially if drainage is impeded.
Ferruginous	20-25 C 1000 - 1500 mmpa sometimes a dry season. Kaolinite is dominant in these areas
Ferrallitic	>25 C, >1500 mmpa, little or no dry season. All minerals apart from quartz are weathered by hydrolysis. Ferrites if iron oxide dominant, allites if aluminium oxides dominant. Kaolinite development is enhanced by poor drainage

Can get extensive plateaux capped by summit laterite. The laterite protects the lower horizons

Gillot J E 1987. Clay in Engineering Geology, Developments in Geotechnical Engineering 41. Elsevier, Amsterdam.

Little of direct relevance to groundwater. Describes an equation that relates k to physical properties. States that permeability is often enhanced by clay or silt. Clays with elongate fibrous shapes are often more permeable than platy clays. Difficult to extrapolate lab measurements to the field because of inhomogeneities, multiphase flow and the problems of gaining a representative sample. It is also difficult to devise tests that will represent field conditions because of fractures, the orientation of clays, water content and overconsolidation. Permeability can be measured using a constant head permeameter for permeable soils and a variable head permeameter for less permeable soils.

Grabow W O K 196. Waterborne diseases: Update on water quality assessment and control. Water S. A., vol 22, pp 193-202.

Water-borne diseases are the most important concern about the quality of water. The pathogens involved include a wide variety of viruses, bacteria and protozoan parasites. Due to differences in size, structure, composition and excretion by humans and animals, their incidence and behaviour in water environments differ. This constitutes difficult challenges for testing the safety of water and the efficiency of treatment processes. Further complications are that many water-borne pathogens, notably the great majority of viruses as well as protozoan cysts and oocysts, are not readily detectable. In addition, the prevalence of various water-borne pathogens changes as selective pressure change. In view of the diverse and variable goalposts, new epidemiological data, and progress in technology and expertise, the methods and strategies for quality monitoring and control of water-borne diseases are continually being revised and updated. This paper reviews the latest approaches to water quality monitoring using indicators of human and animal faecal pollution, and new methods for the detection of viruses. The importance of simple, economic and rapid methods for high frequency basic monitoring of water quality and the efficiency of treatment systems is emphasised. Reference is made to the fundamental need for microbiological quality data in the management of national and regional water resources and supplies.

Grant N K 1971. South Atlantic, Benue Trough, and Gulf of Guinea Cretaceous triple junction. Geological Society of America Bulletin, vol 82, pp 2295-2298.

During the early separation of Africa from South America, the South Atlantic and the transform faults of the Gulf of Guinea were joined by a short-lived line of lithosphere spreading running north-east from the Niger delta, under the Benue trough. The separation of the continents was established by Aptian times, and the spreading under the Benue Trough lasted from the Albian to the Santonian. The early separation of West Africa from northern Brazil was characterised by lateral movements of the two continents against each other along the St Paul's and the Romanche oceanic transform faults. Some 20 m.y. of transform fault motion may have elapsed before West Africa was completely separated by oceanic crust from northern Brazil.

The southern Atlantic, Benue trough, and the Gulf of Guinea formed an unstable RRR triple junction, which may have caused internal strain in the African plate. It may also have resulted in the possible dilation of the Gulf of Guinea transform faults which, together with the short intervening ridge segments, served to localise the Cretaceous volcanicity thought to be responsible for the recently discovered north Brazilian Ridge.

Greef G J 1994. Ground-water contribution to stream salinity in a shale catchment, R.S.A.. Ground Water, vol 32, pp 63-70.
The salinity in the Breede River in the Robertson area (S.W. Cape, South Africa) has increased at an alarming rate over the past two decades. Water analyses have shown that a few tributary streams which drain Bokkveld Shale catchments are responsible for the high salinity in this agriculturally important river. Research carried out to investigate the sources of salinity in one such catchment, the Poesjesnels River Valley, found that heavy salt loads were contributed by return flow seepages after irrigation of deeply ripped, thin soils which overlie decomposed shale. A smaller contribution was coming from groundwater which had leached out some salt from these shales while moving through the bedrock fractures under pressure from the head in the encircling mountains, and eventually seeped into the river; evidence for this was provided by comparison of the oxygen isotope ratios of the various water bodies in the valley with that of the river water. A salt balance model drawn up to differentiate between the sources of salinity gave an indication of the systems which need management in future hydrological and agricultural development in this and similar valleys.

Guiraud M and Plaziat J-C 1993. Seismites in the fluviatile Bima sandstones: identification of palaeoseisms and discussion of their magnitudes in a Cretaceous synsedimentary strike-slip basin (Upper Benue, Nigeria). Tectonophysics, vol 225, pp 493-522.
The Upper Benue Basin (northeastern Nigeria) is interpreted as a complex strike-slip basin which consists of a set of sub-basins controlled by synsedimentary N60 E-trending, strike-slip faults which were active during Early Cretaceous times.

The oblique planar cross-beds made of the medium- to fine-grained sandstones of the upper member of the Bima Sandstone Formation are affected by various soft-sediment i.e., early diagenetic but soft-sediment deformational structures. These are present not only close to the synsedimentary faults but also on a larger regional scale. Three main types of structures (undulated and recumbent-folded cross-bedded lamination, dislocated convolutions and concordant microbreccias, discordant fluidised intrusions) are described. These are related to processes of sediment deformation favoured by sand hydroplasticity, liquefaction and fluidisation.

The local organization of these soft-sediment intrastratal deformational structures, their spatial distribution with respect to synsedimentary faults, and their independence with respect to marginal palaeolopes, suggest that they cannot be explained by slumping or current drag. All the deformations are related to pore water expulsion and it is proposed that the required sand reorganization was triggered by seismic waves. The spatial and chronologic distribution and intensity of the various types of deformation structures suggest that they were produced around different epicenters repeated by earthquakes of varying magnitudes associated with the synsedimentary strike-slip tectonics.

Griffiths D H and Barker R D 1993. Two-Dimensional resistivity imaging and modelling in areas of complex geology. Journal of Applied Geophysics, vol 29, pp 211-226.
Describes the electrical imaging (electrical tomography) method devised at Birmingham. An automated method of generating electrical resistivity pseudo sections. The method is then applied to Zimbabwe and England.

Gunn H D 1953. Peoples of the Plateau Area of Northern Nigeria. In: Forde, D. editor. Ethnographic Survey of Africa, Western Africa, Part VII. International African Institute, London.

Habila O N and Daagu J 1992. A step-by-step approach for the evaluation of the aquifer potential of the Lower Benue sedimentary lithologies for rural water supply to communities in Oju area, Benue State. Paper presented at the 5th annual national conference of the Nigerian Association of Hydrogeologists (NAH) held at Shiroro Hotel, Minna, Niger State, 25-28 October 1992.
Important paper on the hydrogeology of the Oju area. The used resistivity to try and site boreholes. If the later data suggested high resistivity then it became a target. Found good yields in a dyke. They concluded that the intrusions were the best targets but that the sandstones and siltstones were also feasible.

Hallam J R, Brightmam M A, Jackson P D and Den M A 1992. Summary and conclusions of the faults-in-clay project. British Geological Survey Technical Report WE/91/26.
Faults were detected using geophysics. Schlumberger traversing was used in conjunction with seismic refraction. Modelling was used to create typical responses. The resistivity of the clays was found to be anisotropic by 2-3 times. Localised reorientation of the anisotropy lead to a zone of markedly higher apparent resistivity.

Hanneman D L, Wideman C J and Halvorson J W 1994. Calcitic palaeosols: Their use in subsurface stratigraphy. American Association of Petroleum Geologists Bulletin, vol 78, pp 1360-1371.
Analysis of well log data from Cenozoic basin fill of the Deer Lodge Valley, southwestern Montana, provides evidence for identifying palaeosols and palaeosol stacks in the subsurface. The palaeosol stacks are continental sequence boundary markers and appear as several relatively thin, high-velocity/high-density zones within basin fill. Zone thickness ranges from 1 to 1.5 m; zones are stacked to thicknesses of up to 15 m. Density varies within the zones by as much as 0.6

g/cm^3, and differs by as much as 0.9 g/cm^3 from material immediately above these zones. Velocity differs by as much as 10 ft/ms from the overlying material and causes bright reflections on seismic sections. Synthetic seismograms are used to tie well log and seismic data.

Basing our interpretation upon well log data and well cutting analyses, we determined the high-velocity/high-density zones to be limestone. The pedogenic origin of the limestone is shown by (1) well cutting chips from the high-velocity/high-density zones that exhibit pedogenic features associated with calcitic palaeosols, (2) palaeosol horizonation interpreted from well log analysis, (3) the absence of minerals normally associated with lacustrine deposits, and (4) comparison with surface palaeosol exposures.

Hayward D and Oguntoyinbo J 1987. Climatology of West Africa, Hutchinson, London. 271 pp.
The book is divided into three sections: (1) description of the climate of West Africa (2) explanation and (3) application. A good regional guide.

Hazell J R T and Barker M 1995. Evaluation of alluvial aquifers for small-scale irrigation in parts of the southern Sahel, West Africa. Quarterly Journal of Engineering Geology, 28, S75-S90.
Discusses the fadamas of northern Nigeria. Coarse alluvium carried from the Jos and Air Massifs deposited along the rivers several kilometres wide and generally 10 m thick. Good review of the fadama systems with three case studies.

Hazell J R T, Cratchley C R and Jones C R C 1992. The hydrogeology of crystalline aquifers in northern Nigeria and geophysical techniques used in their exploration. In Wright, E. P. and Burgess, W. G. The hydrogeology of crystalline basement aquifers in Africa, Geological Society Special Publication No 66, pp155-182.
Describes the work carried out in Kano and Sokoto States. Borehole siting methodology starts with desk studies - records and aerial photographs. Then field reconnaissance of lithology and existing water points. EM and resistivity followed in targeted areas. They used the response ratio (horizontal/vertical dipole) A smaller response ratio indicated deeper weathering. In particular, deep weathering was given by high vertical dipole readings at 40 m spacings.

In northern Nigeria, steeply dipping fracture zones are considered targets. These can be readily found using EM34. Steeply dipping fractures give a characteristic negative anomaly in vertical dipole mode. Lots of examples are given. Along with a method for determining the dip of boreholes.

Hazell J R T, Cratchley C R and Preston A M 1988. The location of aquifers in crystalline rocks and alluvium in Northern Nigeria using combined electromagnetic and resistivity techniques. The Quarterly Journal of Engineering Geology, vol 21, pp 159-176.
The tenfold increase in borehole siting in Northern Nigeria during the last few years has resulted in an increase in the use of electromagnetic (EM) methods and a corresponding decrease in the more traditional but less cost effective resistivity methods. The role of geophysics in exploration is optimally in combination with direct geological observation. Two types of aquifer which are amenable to geophysical investigation in the Nigerian environment are weathered, jointed crystalline rocks and alluvium.

Location of joints and associated narrow zones of deep weathering in crystalline terrain is best achieved by EM techniques with resistivity backup where needed. Resistivity alone does not always reveal such features. Location of shallow aquifers in alluvium is amenable to a combination of EM and resistivity techniques. However, the complexities of alluvial and underlying Quaternary sedimentation necessitate extensive computer modelling of both sets of data in order to optimise the field techniques and interpretation methods. In particular the use of selected combinations of intercoil spacings to estimate maximum thicknesses of aquifers shows some promise.

On high ground, deeply weathered zones and vertical fractures are conductive in comparison to the host rock. These can be located using geophysics in conjunction with aerial photographs, soil and well surveys. In general higher conductivities produce high anomalies. Dykes however give negative anomalies. In large villages, they undertook a small grid in an area and looked for troughs of weathered material. They regard bands of conductive rock going to depth as suspicious - clay.

Heigold P C, Gilkeson R H, Cartwright K and Reed, P C 1979. Aquifer transmissivity from surficial electrical methods, Groundwater, vol 17, pp 338-345.
VES and pump test data were analysed in a glacial outwash aquifer in Illinois. An indirect relation was indicated between aquifer resistivity and hydraulic conductivity. Very few data (only three points).

Herzog B L and Morse W J 1984. A comparison of laboratory and field determined values of hydraulic conductivity at a hazardous waste disposal. In 7th Annual Madison Waste Conference - Municipal and Industrial Waste (University of Wisconsin, Madison, USA 1984) pp 30 - 52.
The hydraulic conductivity of fine grained deposits from a waste disposal site in Southern Illinois was determined from both field and lab tests. Lab tests used both undisturbed and recompacted samples and a Harvard-type miniature permeameter. Field methods included both slug tests and recovery tests. Most of the lab tests gave results at least one order of magnitude lower than the others. Slug tests were also carried out in angle holes to try and get vertical fractures. K was greater in the angle holes. The piezometers were constructed using a Shelby tube to core out the bottom.

Hill I D 1979 (editor). Land Resources of Central Nigeria: Agricultural Development Possibilities, volume 4B The Benue Valley. Land Resource Study 29, Land Resources Development Centre.

Hunter J M 1996. An introduction to guinea worm on the eve of its departure: *Dacunculiasis* transmission, health effects, ecology and control. Social Science and Medicene. Vol 43, pp 1399-1425.
A broad ranging discussion of the basic nature of guinea worm disease, fused with personal field observations in Ghana, shows its long overlooked serious clinical aspects and the many environmental and social influences that explain its persistence in the face of control efforts. It is a disease of neglect *par excellence* in remote rural areas. The global eradication campaign (which is not reviewed here) may be expected to come to closure over the next half decade. This account offers an overview, synthesis, and interpretation of a fascinating example of disease ecology at the time of its global vanishing.

Hospers J 1970. The Geology of the Niger Delta Area. In: ICSU/SCOR (editors) The Geology of the East Coast Atlantic Continental Margin, No. 4, Africa. ICSU/SCOR Working Party 31 Symposium, Cambridge 1970. Institute of Geological Sciences report No. 70/16, NERC.
The geology of the Niger delta and its frame are briefly described. It is suggested that the structure of the continental geological framework directed the Niger and Benue Rivers towards the present site of the delta.

The available data on the thickness of the delta sediments (which are of Eocene - Recent age) are evaluated. They comprise well data, bathymetric, aeromagnetic and gravity data. The latter show the delta to be in near-isostatic equilibrium.

It is suggested that the delta has a clay/shale base of considerable thickness, that the maximum thickness of its sediments is about 8 km, and that the total volume of its sediments is about 500 000 km^3. The delta is thought to be underlain by oceanic crust. The detailed subsurface structure of the delta is characterised by typical growth faults with associated rollover structures, which are interpreted as being caused by gravity.

Idowu J O and Ekweozor C M 1993. Petroleum potential of Cretaceous shales in the Upper Benue trough, Nigeria. Journal of Petroleum Geology, vol 16, pp 249-264. A geochemical study of the argillaceous sequences of Turonian - early Santonian age penetrated by ten shallow boreholes in the Upper Benue Trough was carried out. The average total organic carbon contents of the sampled sections of the Bima, Yolde, Pindiga, Sukuliye and Jessu Formations were 0.30, 1.40, 0.85, 0.60 and 0.54% respectively. Apart from the Bima Formation, all exceed the minimum value (0.5% TOC) normally required for a petroleum source rock. In spite of the moderate TOC, however, the content of soluble organic matter (SOM) and saturated hydrocarbons (SHC) was generally low.

In terms of organic matter type, a predominant marine facies with some terrigenous input is inferred for the Sukuliye and Pindiga Formations. This indicates that open marine conditions might not have been established during the Turonian marine transgression, which deposited these units.

Within the updip sector of the basin, the organic matter is thermally immature. The most promising zones seem to be located south of the study area, where source rocks that have attained optimum levels of maturity for hydrocarbons occur.

Iiyioriobhe S E and Ako B D 1986. The hydrogeology of the Gombe subcatchment, Benue Valley, Nigeria. Journal of African Earth Sciences, vol 5, pp 509-518.
The area of study, which is about 90 km2, is underlain by five major stratigraphic units of Palaeocene to Cretaceous age except for the Precambrian Basement Complex inlier which forms about 2.7% of the rocks present. Results of our investigation show that the Kerri-Kerri Formation is of aquifer type material but dry in the surveyed area. The Gombe Formation with its high percentages of silts is slightly permeable, whilst the Pindiga and Yolde Formations are essentially aquicludes, although the latter has scattered water bearing horizons. Chemical analyses of borehole water indicate good quality water despite the differences in depth of sampling. Two groups of water emerged - sodium bicarbonate rich and sodium bicarbonate deficient types. Results of isotope hydrology suggest that the sodium deficient type water has similar characteristics to the waters from the middle zone aquifer of the Chad basin and deep aquifer of the Sokoto basin. The highest computed transmissivity value (T) of 432 m^2/d and storage coefficient (S) of 2.3 x 10^{-3} in the subcatchment were for the Bima Formation. The Bima Formation is thus the best aquifer in the subcatchment. Since the available data show that the aquifer of the Bima Formation is gradually being over-developed, and the observed characteristics of a few boreholes in the Pindiga and Yolde Formations are encouraging, a detailed hydrogeological assessment of the other Formations in the Gombe subcatchment is recommended.

Iloeje N P 1981. A new geography of Nigeria. Longman Nigeria Ltd, Ikeja.
School text book about the physical and social geography of Nigeria.

Isiorho S A and Nkereuwem T O 1996. Reconnaissance study of the relationship between lineaments and fractures in the southwest portion of the Lake Chad

Basin. Journal of Environmental and Engineering Geophysics, vol 1, pp 47-54.
One of the problems facing drought-stricken parts of the world is the location of potable sources of water. The delineation, verification, and study of the effect of fractures on groundwater resources and movement are essential parts of the hydrologic data set in drought-prone regions. In this reconnaissance study prominent lineaments were mapped from Landsat images of the Lake Chad region. A Wenner array profile 14 kilometres in length was made perpendicular to a lineament identified on Landsat images. The profile shows a segment with significantly lower resistivity values at the position of the lineament. Low total dissolved solids (TDS) values were also recorded for shallow groundwater samples near the lineament, suggesting it is a recharge zone. Prominent Landsat lineaments in this area are thus probably fractures, as suggested by the resistivity profile and TDS values, and should be investigated through more detailed geophysical and hydrogeological surveys.

Jiao J J and Rushton K R 1995. Sensitivity of drawdown to parameters and its influence on parameter estimation for pumping tests in large-diameter wells. Groundwater, vol 33, pp 794-800.
The sensitivity features of drawdown to aquifer parameters and their influence on parameter estimation and pumping-test design ire investigated in terms of pumping tests conducted in a large-diameter well. It is concluded that the well storage reduces the sensitivities of drawdown to transmissivity and storativity, and increases the correlation between them. This leads to uncertainties in estimating the aquifer parameters, especially storativity. The most informative drawdowns in terms of parameter estimation change with time and space. This is instructive for pumping-test design in a large-diameter well. Both hypothetical and real examples are used to demonstrate key ideas.

Johnsson M J 1990. Overlooked sedimentary particles from tropical weathering environments. Geology, vol 18, pp 107-110.
Two varieties of sedimentary particles that are common in tropical weathering environments have remained largely overlooked by sedimentary petrologists. Alterites are grains that have been so thoroughly altered by chemical weathering processes that identification of the precursor grain is impossible. They consist of secondary weathering products such as clays, zeolites, and iron sesquioxides, as well as completely weathered remains of relatively stable mineral phases. Alterites that consist of clay-sand composites allow the transport and deposition of hydraulically dissimilar constituents under a single hydraulic regime and may be important in the production of some graywackes. A second class, the pedogenic ferruginous particles, takes on a variety of forms, including laterite fragments, soil pisolites, and oxidised burrow rinds. Although these particles are common in modern fluvial sands in the tropics wholesale dissolution of amorphous or poorly crystalline iron sesquioxides during burial diagenesis may help to explain the rarity of such particles in ancient sediments. Although their potential for preservation is low, dissolution of ferruginous particles may be an important source of diagenetic iron, which may be redeposited to form ferruginous cements or diagenetic redbeds.

Kalinski R J, Kelly W E and Bogardi I 1993. Combined use of geoelectric sounding and profiling to quantify aquifer protection properties. Ground Water, vol 31, pp 538-544.
Evolving environmental regulations have increased the need for defining the protective properties of geologic layers. Of particular significance is the need for defining vertical times-of-travel (TOT) through aquitards located above municipal water supply wellfields. Surface geoelectrics provide an inexpensive field measurement method that can be used to quantitatively define protective properties. Protective layer longitudinal unit conductance squared (S^2) can be theoretically related to ROT using material relationships between resistivity and hydraulic conductivity divided by porosity (K/n).

In an example presented for a municipal wellfield, it is possible to utilize a limited number of geoelectrical soundings to establish relationships between S of a conductive protective layer and apparent resistivities measured at individual electrode spacings, providing a method to estimate S with profiling. In this case, longitudinal unit conductance (S) was the geoelectrically equivalent parameter of the protective layer. The use of combined sounding and profiling data in the wellfield area resulted in an overall reduction in the kriging estimation error of S for the protective clay layer and a larger area of coverage over what was obtained with soundings alone.

Karabin S, Smit B, Heidug W, Urai J and Van Oort E 1996. The swelling of clays: Molecular simulations of the hydration of montmorillonite. Science, vol 271, pp1102-1104.
The swelling of clay minerals on contact with an aqueous solution can produce strong adverse effects in the exploration and production of gas and oil. Molecular dynamics and Monte Carlo simulations were used to study the mechanism of swelling of sodium-montmorillonite. The simulations showed that the abundant clay mineral has four stable states at basal spacings of 9.7, 12.0, 15.5, and 18.3 angstroms, respectively. The amount of swelling and the locations of the stable states of sodium-montmorillonite are in good quantitative agreement with the experimental data.

Kehinde M O and Loehnert E P 1989. Review of African groundwater resources. Journal of African Earth Sciences, Vol 9, pp 179-185.
Africa is bedevilled by recurrent water supply problems to its teeming millions most of them scattered in far-flung rural

units without infrastructural facilities. In this paper we have attempted to elaborate on the problems facing water resources development, devoting efforts mainly to groundwater resources. Based on research results of various workers and groups on the continent, we were able to show that despite unfavourable hydrologic situation where almost 80% of incident precipitation is lost through evapotranspiration processes, there is enough of this resource to cater for the present and future needs of the continent.

This paper further identifies areas suitable for groundwater development mentioning where problems may likely be encountered and cautious care against over-development especially in arid and semi-arid regions and in coastal areas. Extensive regional aquifers which are present throughout the continent offer the best possibilities for large scale groundwater development and need to be studied in more detail. Finally, based on our work in Africa, suggestions are made to improve on problems such as man-power deficiencies, planning and management strategies, data generation and retrieval, quality control and monitoring, legislation and above all, introduction of adaptable technology.

Keller G V 1992. Electrical and electromagnetic methods in areas of complex geology. Journal of applied Geophysics, vol 29, pp181-192.
Tests three methods with a model. He concludes that to identify three dimensional objects multiple measurements are needed for each source position (ie em at different spacings etc). DC mapping, magneto telluric and TDEM.

Keller C K, Van Der Kamp G and Cherry J A 1988. Hydrogeology of two Saskatchewan tills, 1. Fractures, bulk permeability and spatial variability of downward flow. Journal of Hydrology, vol 101, pp 97-121.
Paper discusses recharge throughout the till. K was determined on unremoulded samples of till cut from 76 mm sample tubes using falling head tests. They found a substantial difference between lab and field tests of K. This is because the lab tests are point measurements while the piezometers are spatially averaged. The shorter the screen length the more variable was the measured K; therefore it is important for the screen length to be sufficient to give the REV. Local scale topography caused recharge to be focussed.

Keller C E, Van Der Kamp G and Cherry J A 1989. A multiscale study of the permeability of a thick clayey till. Water Resources Research, vol 25, pp 2299-2317.
We describe and evaluate two previously undocumented methods of bulk permeability (K) determination and compare results obtained with results of conventional smaller-scale tests on the same clayey till deposits. Analysis of the downward propagation of seasonal watertable fluctuations yielded a bulk K of approximately 10^{-10} ms^{-1}, inclose agreement with results of laboratory consolidation and permeameter tests, slug tests, and distribution of vertical hydraulic gradient with depth in the deposit. This agreement suggests that for such materials, high-gradient tests conducted at small scales of distance and time can provide reasonable estimates of bulk K. The results also imply groundwater residence times in the till of thousands of years. The flow pattern observed near a large excavation in the till was consistent with the initial recoveries of piezometers installed in much smaller boreholes, assuming perturbation of hydraulic head in the formation due to borehole excavation. Time scales of these perturbations, which prevent interpretation of measured hydraulic head using conventional methods, varied from months to tens of years.

Keller W D and Matlack K 1990. The pH of clay suspensions in the field and laboratory, and methods of measurement of their pH. Applied Clay Science, vol 5, pp 123-133.

Kelly W E and Frohlich R K 1985. Relations between aquifer electrical and hydraulic properties. Groundwater, vol 23, pp 182-189.
For this example (Rhode Island) the primary factor controlling material level relations between aquifer electrical and hydraulic properties is an inverse relation between grain size and porosity. Relation between a Dar Zarrouk parameter and transmissivity are influenced by aquifer layering and the position of the aquifer layer relative to the non-producing layers. Transverse resistance was found to be the most useful Dar Zarrouk parameter in this example. TR is most useful when the aquifer lies on less permeable material rather than directly on the bedrock.

Kelly W E and Reiter P F 1984. Influence of anisotropy on relations between electrical and hydraulic properties of aquifers. Journal of Hydrology, vol 74, pp 311-321.
Relations between formation factor and the hydraulic conductivity are strongly dependent on the material level relations between porosity and permeability. Best correlations are found when the Dar Zarrouk parameter, Transverse resistance is used. Where aquifers are clay free - direct correlations between res and K are common, where clay id present it may control the relationship and inverse correlations should be allowed for. The paper discusses a direct correlation from Rhode Island USA. The illustrate a fairly poor relation between longitudinal resistivity and hydraulic conductivity.

Klinck B A, Hopson P M, Sen M A and Shephard-Thorn E R 1993. A review of the hydrogeology of superficial clays with special reference to the Boulder Clay and Clay-with-Flints. British Geological Survey Technical Report WE/93/21.

The lithology and structure of superficial clays is described with particular reference to East Anglian tills and the Clay-with-Flints. Measurements of hydrogeological properties of clays pose particular problems: (1) piezometer installation can cause smearing (2) conventional tests my take months (3) fracturing can increase K by two orders of magnitude. They used pressurized slug tests. K for the matrix was 0.3 m/d and for fractured areas 6.9 m/d.

Klinck B A and Wealthall G P 1996. Hydrogeology and hydrochemical studies of the Lowestoff Till, East Anglia. British Geological Survey Technical Report WE/95/37.
This report discusses the field investigations in East Anglia for the superficial clays project. Boreholes were cored and slug/pulse tests carried out in them. Boreholes were augured at 100 or 150 mm and cleaned with sodium hexametaphosphate to deflocculate and remove the smear. The piezometers were sand packed and sealed with bentonite.

The following report is an account of field investigations conducted in East Anglia in support of the Hydrogeological Characterisation of Superficial Clays programme, a co-funded research initiative by the British Geological Survey (BGS) and the National Rivers Authority.

Two sites in Norfolk, Hall Farm and Uphall Farm, and one in Essex, Hob's Aerie, were investigated. The sites selected were all underlain by the Lowestoft Till, and additionally the Hall Farm site is overlain by cover sand. Fieldwork consisted of drilling a cored borehole at each of the sites to obtain samples for laboratory study and pore water analysis. Further more a number of piezometers were installed to obtain estimates of hydraulic conductivity.

The drilling confirmed that the upper part of the Lowestoft Till is oxidised to a depth of between two and eight metres and that an oxidised base is also present at the sites studied. The oxidation of the till correlated well with the occurrence of fractures; fracture density was lower in the unoxidised till compared to the oxidised till. The differentiation between oxidised and unoxidised tills and hence the incidence of fracturing is also evident in the results of the hydraulic testing programme.

Hydraulic testing of the piezometers was accomplished with a combination of slog tests and pulse tests. Oxidised tills have a hydraulic conductivity in the range of 10^{-6} to 10^{-8} ms^{-1} while unoxidised tills have a hydraulic conductivity in the range of 10^{-8} to 10^{-11} ms^{-1}.

The cover sand, which is widely distributed in the neighbourhood of Hall Farm, is capable of supporting a perched water table above the till. In the vicinity of point source contamination e.g. due to manure stockpiling, it is possible to maintain pore water concentrations of NO_3 in fractured till in excess of 100 mgl^{-1}, which can be detected to depths of eight metres from the surface.

Below pasture land situations, such as at Uphall Farm and Hob's Aerie, nitrate concentrations in the pore water profile rapidly decline to low concentration within a depth of three to six metres. This decline is thought to be due to denitrification and there is still some evidence to suggest that most of this takes place within the oxidised till. The unoxidised till is an effective barrier to the migration of nitrate through the profile, but it may be bypassed through the more permeable layers or persistent fractures connected through to the upper oxidised till.

Kogbe C A, Tokarski A, Osijuk D and Wozny, D E 1978. Geology of the Makurdi Sheet 251 in the Middle Benue Valley, Nigeria. Occasional Publication 5/1978, Department of Geology, Ahmadu Bello University, Zaria, Nigeria.
The Makurdi area lies within the Middle Benue Valley and consists of Cretaceous sediments of marine to fluvio-deltaic origin. The continental sediments are mostly sandstones which are often feldspathic and coarse-grained. There are also fine-grained and micaceous varieties. The marine deposits are predominantly shales, limestones and well-bedded sandstones.

Sedimentation in the Benue Valley is closely related to the origin of the South Atlantic and the breaking up of South America from Africa creating the way for a northward transgression of marine waters from the Atlantic.

Palaeontologic studies reveal that the sediments are of late Cenomanian to Turonian age but probable Coniacian sediments may be represented in the Western as well as parts of the northern sector.

In the absence of any detailed previous work on the Makurdi sheet 251, (with the exception of the geological mapping of some localised portions by Shell-BP, 1957), the present work is aimed at providing important information on the geology of the area with special emphasis on the stratigraphy, sedimentology and structure.

The formations present include Makurdi and Eze-Aku Formations and, probably Awgu Formation. More detailed work would be requires (including the drilling of boreholes) in order to confirm the presence of the Awgu Formation. This is due to total absence of good exposures of the Awgu Formation in the area mapped.

The Makurdi Formation is composed of massive, medium to coarse-grained, cross-bedded and feldspathic sandstone. It is the dominant formation in the area and is most probably the lateral equivalent of the Keana Formation on the Lafia Sheet (Offodile, 1976). It is overlain by the Eze-Aku Formation and is likely to have been formed during the Cenomanian regression.

The Eze-Aku Formation, which occurs in localised portions of the sheet, consists of clay, shale and limestone members.

It is likely to have been deposited during the late Cenomanian to early Turonian transgression. The formation was probably deposited in a shallow, marine coastal environment.

The extreme north-western portion of the map consists of dark alluvium and clay which may belong to the Awgu formation which continues into the Lafia sheet, although more detailed work is recommended to clarify this problem using borehole data.

The deposits are affected by Santonian folding, and the folding trend is in the northeast - southwest direction which conforms with the proposal established by Cratchley and Jones (1965). Major structures include the Keana anticline and Makurdi syncline. Both extend into the Lafia-Awe area (Offodile, 1976) and are possibly related to the major northeast - southwest fold recorded in the Upper Benue (Carter et al, 1963). Minor structures include the Guma anticline and the Norkor syncline.

Parts of the Makurdi sheet are affected by the Cenozoic magmatic activity resulting in the extrusion of extensive sheet of basalt particularly in the northwestern portion of the area investigated.

Hydrogeological Studies of a synclinal structure in the Makurdi S.W. sheet around the Apir airport base established the following results:

i. The sandstone body could serve as an important aquifer.
ii. The Api Airbase syncline could be considered as a significant hydrogeological basin.
iii. From about 35 wells, distributed all over the area, it has been possible to confirm that the flow of groundwater is in the direction of dip of the structure.
iv. There appears to be strong subsurface flow which may be quite considerable.
v. Finally, a basis on which future rural water supply could be carried out should be similar to that of the Api-Airbase area.

Kogbe C A 1983. Geological interpretation of Landsat imageries across Central Nigeria. Journal of African Earth Sciences, vol 1, pp 213-220.

Investigation of Landsat imageries across Central Nigeria was carried out on a scale of 1:500,000. The multispectral imagery as well as bands 7 and 4 imageries were combined to provide the basis for meaningful geological interpretation. Results obtained from the analysis include the following: (1) identification of major rock boundaries; (2) identification of regional structural trends; (3) identification of different landform patterns; (4) identification of different landcover, and (5) identification of major drainage patterns. Supplementary remotely sensed data used in conjunction with Landsat imagery to aid geological interpretation include low altitude aerial photos and topographic maps on a scale of 1:50,000. Recommendations for effective landuse of the areas investigated were provided. Some results of this study have regional geodynamic implications. These include the observation of linear faults on both sides of the Niger and Benue Valleys. The NW-SE trending faults bordering the Niger valley suggest a rift origin similar to that of the Benue Trough. Curvelinear structures representing ring intrusions have been identified in areas where they were not known to exist. The geographical extent of the Younger Granite Ring Complex Province around the Jos Plateau may be greater than normally envisaged. Three major lineament trends predominate on all the imageries studied. These are NE-SW, NW-SE and N-S. The NE-SW and NW-SE lineaments truncate the N-S trending ones and are therefore younger in age. This tends to suggest that the NE-SW and NW-SE trending lineaments are related to the Kibarian and Pan-African orogenies (younger than 800 Ma). The N-S trending lineaments, on the other hand, are much older and are probably or possibly related to the Liberian orogeny (over 2500 Ma) and Eburnian orogeny (over 1800 Ma). The effects of structures within the basement are evident in the overlying sedimentary cover.

Kogbe C A 1989. Palaeogeographic history of Nigeria from Albian times. In: Kogbe, C.A. (ed) Geology of Nigeria, Rock View (Nigeria) Ltd, 2nd edition, pp 257-276.

In Pre-Cretaceous times, Nigeria consisted of an uplifted continental landmass, made up of Pre-Cambrian basement rocks which are unconformably overlain by Lower Cretaceous Continental sediments. The earliest dated marine transgression occurred during the Albian with the opening up of the Gulf of Guinea. The Anambra basin of south-eastern Nigeria and the Lower-Middle Benue Valley were invaded by marine waters. The end of the Albian, witnessed the beginning of a regressive Cenomanian phase which was characterised by extensive deltaic developments in the Upper Benue (Bima Sandstone) and also in the Sokoto Basin (Gundumi and Illo formation). During the Turonian, a very widespread transgression linked the Atlantic and Tethys waters. The sedimentary deposits of the Benue Valley range in age from Aptian-Albian to Maastrichtian. The extensive Maastrichtian transgression began during the Campanian and uppermost Cretaceous deposits also outcrop in south-eastern and north-western parts of the country. This important transgression continued into the Palaeocene after which there was a return to continental conditions in most parts of the country. Tertiary sediments are restricted to the Niger Delta, the Sokoto Basin, the Upper Benue Valley (Kerri Kerri Formation) and the Southern Nigeria Coastal basin.

The generalised folding which affected the Cretaceous sediments in the Benue Valley resulted from a compressional phase during the Santonian. The intensity of the folding varies greatly from SW to NE and locally from the axis towards the edges of the basin.

After the Palaeocene - Eocene transgression there was a generalised regression throughout the Benue Valley and the

Coastal basin. This regression coincided with the building-up of the modern Niger Delta.

Kogbe C A 1989. The Cretaceous and Palaeogene sediments of southern Nigeria. In: Kogbe, C.A. (ed) Geology of Nigeria, Rock View (Nigeria) Ltd, second edition, pp 325-334.
The stratigraphy of the Cretaceous and Palaeogene sediments in the southern Nigeria basin is described and sediments in the western and eastern portions of the basins are correlated. The controversy over the age of the Ewekoro Formation is discussed and an accurate delineation of two stratigraphic units (Oshoshun and Ilaro Formations) within the Eocene of south-western Nigeria is proposed from the study of borehole lithologic logs and cuttings as well as outcrop samples. A type section is described for the Ilaro Formation and a supplementary section is described for the Oshoshun Formation. The Palaeocene Imo Formation of south-eastern Nigeria is lateral equivalent of the Ewekoro and Akinbo Formations may be correlated with the Oshosgun and Ilaro Formations in south-western Nigeria

Kosinski W K and Kelly W E 1981. Geolectric Soundings for predicting aquifer properties. Groundwater, vol 19, pp 163-171.
Field work carried out in two bedrock valleys filled with glacial outwash material. Res was calculated at 16 sites where pumping tests had previously been run. Relationships were then derived between Res, T and K. Electricity follows the path of least resistance - as does water. They found a direct relation between permeability and apparent formation factor. The findings cant be used elsewhere but the methodology can.

Langsholt E 1992. Water Balance Study in Lateritic Terrain. Hydrological Processes, vol 6, pp 11-27.
The water balance of a 600 sq m field site on a lateritic hillslope in Kerala, southwest India, has been studied during two southwest monsoon seasons. Surface runoff was of minor importance while infiltration and evapotranspiration were the major components amounting to approximately 2/3 and 1/3 of the rainfall, respectively. Groundwater response was rapid, involving fluctuations of several metres. Recharge mechanisms hypothesized are water movement via preferred pathways from the ground surface to the capillary fringe where rapid rise in groundwater level is brought about by a transmitted pressure pulse. Groundwater recharge was found normally to take place during the southwest monsoon season only. After a period of initial soil moisture recharge, groundwater fluctuations of up to 6-7 m were observed throughout the southwest monsoon season. The clay layer did not impede these variations. Typical response time for the fluctuations relative to the rainfall event was roughly 10 hours. The field study demonstrates that seasonal shallow groundwater recharge representing the major portion of the rainfall may be observed in this lateritic terrain in the humid tropics. It indicates a good potential for further groundwater development. Moreover, conditions are conducive to a considerable contribution to possible recharge to deeper aquifers.

The site at which the studies took place has 2000 - 4000 mmpa rainfall and is distributed over 125 days. T = 20 - 32 C. A well developed 10 m thick lateritic profile overlaid a charnockite bedrock (a coarse granular rock).

Lawal O 1991. Palynological age and correlation of a black shale section in the Eze-Aku Formation, Lower Benue Trough. Journal of African Earth Sciences, vol 12, pp 473-482.

Lin J T 1989. Water permeability of clay sediment - theory of seepage consolidation. Applied Clay Science, vol 4, pp 247-262.
A theory of seepage consolidation is described which uses the (non-seepage) sedimentation data to predict the water permeability of the sediment when seepage through a pervious bottom takes place. Theoretically, the inflation resistance of sediment under seepage consolidation is a function of time, weight of solid per unit area, initial solid consolidation, dynamic pressure drop across the system, and the characteristics of the sediment including the correlation between the permeability and the solid fraction, the correlation between the compressive stress of solid and solid fraction, and tortuosity or axial ratio of the particles. In this article, the correlations mentioned above were obtained from batch sedimentation experiments. The dynamic pressure drop, the weight of solid per area, and the initial solid concentration in independent variables. When the axial ratio is 25, the theory predicts from numerical analysis an infiltration resistance - time curve and a seepage flow rate-time curve which match the experimental curves of a kaolinite system fairly well within the first 5 min. After that, deviations occur which are believed to be due to the wash-in mechanism in the real system.

Loehnert E P 1988. Major chemical and isotope variations in surface and subsurface waters of West Africa. Journal of African Earth Sciences, Vol 7, pp 579-588.
Conclusions are drawn as to the origin of natural waters in West Africa based on a combined interpretation of hydrochemical and environmental isotope data. The former include major cations, the latter tritium, deuterium, oxygen-18 and - to a lesser extent - carbon-13 and carbon-14.

In a case study Southwest Nigerian surface and subsurface waters were assessed with respect to their position within the hydrological cycle. Influences of Precambrian Basement rocks on chemical and isotopic composition of base-flow and

inter-flow have been recognized in headwater areas of streams. Fossil groundwaters of sedimentary basins (Nigerian Coastal Basin, Sokoto Basin, Chad Basin, Senegal Basin) are presented as examples displaying a complicated history of the genesis of the respective waters and practical implications are briefly touched upon.

Lomenick T F and Kasprowicz J D 1990. Disposal of radioactive and hazardous wastes into clay rich rocks,. In: Bennett, R H, Bryant W R and Hulbert MH (editors). Microstructure of Fine-grained Sediments: From Mud to Shale. Springer-Verlag.
Shale is considered a good host for radioactive waste due to (1) the small matrix/pore size; and (2) the self healing of fractures at shallow depths. Most of the paper refers to mined cavities in shales.

Loughnan F C 1962. Some considerations in the weathering of the silicate minerals. Journal of Sedimentary Petrology, vol 32, pp 284-290.
The weathering of silicate minerals is considered a function of two variables; (1) the mobilities of the essential cations; and (2) the mineral structure. It would appear that in the normal pH range of 4 to 10, the leaching potential is the most important factor influencing the mobilities of the cations though the redox potential considerably affects the solubility of iron. Parent mineral structures are instrumental in controlling the accessibility of the percolating waters to the bonded cations.

Mack G H, James W C and Monger H C 1993. Classification of palaeosols. Geological Society of America Bulletin, vol 105, pp 129-136.
Despite increased interest in palaeosols during the past decade, no satisfactory classification is in current use. Presented here is a largely descriptive classification system that utilises those pedogenic features that have the highest preservation potential in the rock record. Emphasised in the classification are morphological and mineralogical features that are easily recognisable in the field and through the petrographic microscope.

The classification is based upon elevation of the relative prominence in a palaeosol of six pedogenic features or processes: organic matter content, horizonation, redox conditions, *in situ* mineral alteration, illuviation of insoluble minerals/compounds, and accumulation of soluble minerals. The most prominent of these six features/processes provides the key to classifying a palaeosol into one of nine orders. Four of the order names are borrowed from Soil Taxonomy (Histosol, Spodosol, Oxisol and Vertisol), whereas the other five names are presented here for the first time (Calcisol, Gypsisol, Gleysol, Argillsol, Protosol). The orders may be proceeded by one or more subordinate modifiers that describe other important features of the palaeosol. The classification is relatively easy to apply to the rock record and should enhance communication and aid in the standardisation of terminology.

Madsen F T and Muller-Vonmoss M 1989. The swelling behaviour of clays. Applied Clay Science, vol 4, pp 143-156.
In swelling clays two categories of swelling are observed. The first category - the innercrystalline swelling - is caused by the hydration of the exchangeable cations of the dry clay. The second category - the osmotic swelling - results from the large difference in the ion concentrations close to the clay surfaces and in the pore water. The stepwise nature of the innercrystalline selling can also be seen in the water vapour adsorption isotherm. The swelling stress can be calculated from the isotherm. The measurement of osmotic swelling in the laboratory is discussed. The swelling behaviour of clay rocks depends on the type and quantity of clay minerals encountered, their surface charge and the valence of the cations in the double layer. The swelling properties of the rock can be estimated from its characteristic values. An example for such a calculation is given.

Maluski H, Coulon C, Popoff M and Baudin P 1995. 40Ar/39Ar chronology, petrology and geodynamic setting of Mesozoic to early Cenozoic magmatism from the Benue Trough, Nigeria. Journal of the Geological Society, London. vol 152, pp 311-326.
The Benue Trough is a continental-scale intraplate tectonic megastructure which is part of the Mid-African Rift System. This rift, initiated in the latest Jurassic, was related to the opening of the Central and South Atlantic oceans. Mesozoic to early Cenozoic magmatism accompanied this evolution. Two principal magmatic domains are evident, the Northern and Southern Benue. In the northern domain, magmatism is characterised by transitional alkaline basalts and transitional tholeiitic basalts. Acidic magmatism of peralkaline nature is also present. In the Southern Benue several magmatic districts exhibit alkaline or tholeiitic affinities. A detailed chronology of emplacement of this volcanism has been established using the $^{40}Ar/^{39}Ar$ radiometric method which lead to recognition of three periods of magmatic activity: (1) 147-106 Ma, well expressed in Northern Benue represented by transitional basaltic types; (2) 97-81 Ma, occurring only in the Southern Benue, represented by exclusively alkaline intrusive rocks; (3) 68-49 Ma, restricted also to the Southern benue, with alkaline intrusions followed by tholeiitic subvolcanic rocks. In the light of the general geodynamic evolution, a scenario is proposed, supported by the three chronological periods. The late Jurassic to Albian magmatism occurred when the Equatorial Atlantic was still closed, contemporaneous with the NE Brazilian magmatism. Both magmatism could represent the forerunners of opening of the Equatorial Atlantic. This activity occurred under a general extensional regime during which crustal strike-slipe faults gave rise to the emplacement of transitional alkaline basalts. Transitional tholeiitic basalts erupted along normal faults. The second period of activity, Cenomanian to Santonian, restricted to the Southern benue, occurred after

the opening of the Atlantic ocean during a period of decreasing extension. The period ended with a Santonian compressional episode. The last period of activity, from late Maastrichtian to Eodene, is characterised by subsidence, generated as an isostatic response to the early Cretaceous crustal thinning and post-rift relaxation of the lithosphere, expressed by Tertiary E-W extension.

Marui A, Yasuhara M, Kuroda K and Takayama S 1993. Subsurface water movement and transmission of rainwater pressure through a clay layer. Hydrology of Warm Humid regions (Proceedings of the Yokohoma Symposium, July 1993). IAHS Publications No 216, Wallingford.
Transmission of rainfall pressure through entrapped air can play an important part in how deep groundwater responds to storm events. Wetting front moved according to Darcy's law; pressure transmitted through compressed air at about 25 cm/minute.

Mathieu R and Bariac T 1996. An isotopic study (^{2}H and ^{18}O) of water movements in clayey soils under a semiarid climate. Water Resources Research, vol 32, pp 779-789.
We applied the natural variations of stable isotopes in water to the study of infiltration in clayey soils and to the study of groundwater recharge in the small drainage basin of Barogo in West Africa. The comparison between the variations in isotopic contents of soil water and rainwater in 1988 and 1989 led us to characterise two infiltration processes: (1) an infiltration through the soil matrix of rainwater that mixed with mobile water which was held in the superficial part of the soil and was enriched in heavy isotopes by evaporation and (2) a fast and deeper infiltration by preferential flow along macropores that bypassed the superficial part of the soil. The study of the variations in groundwater isotopic content led us again to separate the recharge process into two components: (1) a slow infiltration through the soil matrix and the weathered basement (distributed recharge) and (2) a fast and direct recharge through conducting fissured zones (localised recharge). A schematic and local representation of groundwater recharge in the Barogo basin allowed us to estimate that direct recharge represented around 70% of the total recharge in 1989.

Mazac O, Cislerova M, Kelly W E, Landa I and Venhodova D 1990. Determination of hydraulic conductivities by surface geolectric methods. In: S.H.Ward (editor) Investigations in geophysics No 5 (Geotechnical and Environmental Geophysics: Vol II: Environmental Geophysics and Groundwater. SEG Volume) pp 125-132.
In saturated zone they found that both direct and inverse relations exist between K and resistivity - depending on the rock and permeability types. They state that the relationship is directly proportional to the grain size; is curvilinear.

Mazac O, Kelly W E and Landa I 1985. A hydrogeophysical model for relations between electrical and hydraulic properties of aquifers. Journal of Hydrology, vol 79, pp 1019.
The paper discusses the factors influencing the relations between electrical and hydraulic properties. They mention that where transverse resistivity and thickness can be estimated from sounding curves - good correlations are possible with transmissivity and hydraulic conductivity. The reliability of relations between electrical and hydraulic aquifer parameters depends on two factors: (1) the material-level relation (eg between porosity and permeability) and (2) mutual relations between direction of groundwater flow , layering and the hydrogeophysical conditions within the aquifer. Both direct and indirect relations can exist.

Mbonu P D C, Ebeniro J O, Ofoegbu C O and Ekine A S 1990. Geoelectric sounding for the determination of aquifer characteristics in parts of the Umahia area of Nigeria. Geophysics, vol 56, pp 284-291.
Imo State, within the Coastal Plains Sands. Seventeen Schlumberger VES were undertaken and interpreted; pumping tests were also carried out and analysed. Three geoelectric layers overlying basement. Used the Dar Zarrouk parameters to estimate transmissivity. The had problems however with changing pore water resistivity.

McFarlane M J 1976. Laterite and Landscape. Academic Press, London.
Early, comprehensive review of laterite, based mainly from work in East Africa. Chapter headings are: Historical review, What is laterite? Laterite and Geology, Laterite and Topography, Laterite and Climate, Laterite and Vegetation, Laterite and the profile, Laterite structures, Chemical constituents of laterites, laterite genesis, laterite and denudation chronology of Uganda.

McFarlane M J 1983. A low level laterite profile from Uganda and its relevance to the question of parent material influence on the chemical composition of laterites. In: Wilson, R. C. L., Residual deposits, Geol. Soc. Land. Spec. Blackwell, Oxford.
Gives mineral progressions in the weathered profile. She concludes that the absence of bauxite is due to unfavourable leaching conditions rather than geology.

McFarlane M J 1983. Laterites. In: Goudie, A. S and Pye, K., (editors). Chemical Sediments and Geomorphology: precipitates and residua in the near-surface environment, Academic Press, pp 7-58
Very useful review into the origin of laterite. Discusses the geochemistry. She describes laterization as a process breaking down the parent rock, leaching them of some of their minerals and then the formation of secondary minerals from the residue. Later stages of mineralization are found

further up the profile. The paper also discusses the various laterite structures, e.g. banded and unbanded pisoliths and vermiform and the various forms of accumulation, e.g. pedogenetic and groundwater laterite.

McKay L D, Cherry J A and Gillham R W 1993. Field experiments in a fractured Clay till. 1. Hydraulic conductivity and fracture aperture. Water Resources Research, vol 29, pp 1149-1162.

Field values of horizontal conductivity measured in the upper 1.5-5.5 m of a weathered and fractured clay-rich till were strongly influenced by smearing around piezometer intakes and the size of the measuring device. K in normal piezometers was 1-2 orders of magnitude lower than those designed to reduce smearing. An over cored Shelby tube was used to minimise smearing and a sandpack placed around the piezometer tip. The rest of the borehole was sealed with bentonite. Measurements of K in piezometers (intersect about 10 fractures) 10^{-10} - 10^{-6} m/s. In trenches (which intersect thousands of fractures) K ranged from 10^{-7} to 3 x 10^{-7}. Hydraulic fracture aperture of 1-43 um was calculated from the cubic law; as was fracture porosity, 3 x 10^{-5} to 2 x 10^{-3}. The trenches were used to give a constant head test conducted over 700 days; water was pumped into one trench and pumped out of the other.

McMahon P B, Vroblesky D A, Bradley P M, Chapelle F H and Gullet C D 1995. Evidence for enhanced mineral dissolution in organic acid-rich shallow ground water. Ground Water, vol 33, pp 207-216.

Total concentrations of formate, acetate, and isobutyrate varied from less than 5 to greater than 9,000 µmol/l over distances of <3 m in ground water from a shallow hydrocarbon contaminated aquifer. Laboratory incubations of aquifer material indicate that organic acid concentrations were dependent on the amount of hydrocarbon loading in the sediment and the relative rates of microbial organic acid production and consumption. In heavily contaminated sediments, production greatly exceeded consumption and organic acid concentrations increased. In lightly contaminated sediments rates were essentially equal and organic acid concentrations remained low. Concentrations of dissolved calcium, magnesium and iron generally were one or two orders of magnitude higher in organic acid-rich groundwater than in groundwater having low organic acid concentrations. Carbonate and Fe(III)-oxyhydroxide minerals are the likely sources of these elements. Similarly, concentrations of dissolved silica, derived from quartz and k-feldspar, were higher in organic acid-rich groundwater than in other waters. The positive relation ($r=0.60, p<0.05, n=16$) between concentrations of silica and organic acids suggests that the microbially mediated buildup of organic acids in groundwater enhanced quartz/k-feldspar dissolution in the aquifer, although it was not the only factor influencing their dissolution. A model that included organic acid microequivalents normalised by cation microequivalents significantly strengthened the correlation ($r=0.79, p<0.001, n=16$) between dissolved silica and organic acid concentrations, indicating that competition between silica and cations for complexation sites on organic acids also influenced quartz/k-feldspar dissolution. Physical evidence for enhanced mineral dissolution in organic acid-rich waters included scanning electron microscopy images of highly corroded qhartz and k-feldspar grains from portions of the aquifer containing organic acid-rich groundwater. Microporosity generated in hydrocarbon contaminated sediments may adversely affect remediation efforts that depend upon the efficient injection of electron acceptors into an aquifer or on recovery of solutes from an aquifer.

McNeill J D 1980. Electrical conductivity of soils and rocks. Technical Note TN-5, Geonics Ltd, Mississauga, Canada.

Discusses resistivity and conductivity and the factors that affect terrain conductivity: e.g., porosity, moisture content, dissolved electrolytes, temperature, composition and concentration of colloids. The note then discusses the electrical conductivity of soils and rocks in more detail and finishes with examples from around the world.

McNeill J D 1980. Electromagnetic terrain conductivity measurement at low induction numbers. Technical Note TN-6, Geonics Ltd, Mississauga, Canada.

Discusses the principle of operation of EM equipment and the instrumentation. The survey techniques are then discussed along with the pros and cons of using Inductive Terrain Conductivity measurements. Some case histories are given.

McNeill J D 1983. EM34-3 survey interpretation techniques (revised). Technical Note TN-8, Geonics Ltd, Mississauga, Canada.

Discusses in more detail the operation of the EM34-3. Also illustrates the response with depth. Using a vertical dipole the penetration of the instrument is deeper since surface conductivity is not measured. Horizontal dipoles, however, have a shallower depth of penetration and give most information about the surface and soil layers.

McNeill J D 1989. Advances in electromagnetic methods for groundwater studies. Proceedings Exploration '87, Ontario Geological Survey Special Volume No 3 (ed G Garland), pp 678-702.

Factors affecting terrain conductivity: porosity, conductivity of soil moisture, shape of soil/rock pores, temperature, presence of clays with moderate to high CEC. In most groundwater studies the rock matrix does not conduce electricity. Clays are often thought just to add an additional component to the electrical component which is a function of content and type. And is independent of Archie's law. The significance of clay is therefore greatest when the ionic component is low. The paper describe VLF, EM and

TDEM. The paper has some good diagrams of responses over dykes. Horizontal dipole is often affected by conductive overburden and therefore might not be sensitive to dykes at depth. The vertical dipole is insensitive to the near surface and therefore can pick up the dykes more easily. The paper then gives examples similar to the 1991 paper - non directly applicable to Oju.

McNiell J D 1991. Advances in electromagnetic methods for groundwater studies. Geoexploration, vol 27, pp 65-80.
EM survey techniques have been particularly successful over the past decade at locating potable water and identifying contamination. Advantages: fast, cheap. Effective at looking for conductors - relatively ineffective at finding resistive material; also quite shallow penetration. The case studies taken are from basement in Africa.

Milsom J 1996. Field Geophysics, Second Edition. The Geological Field Guide Series, John Wiley & Sons, Chichister.
Basic and practical introduction to field geophysics techniques. Chapters include: gravity methods, magnetic methods, radiometric surveys, DC and IP methods, Electromagnetic methods, VLF, Ground penetrating radar, seismic and resistivity.

Mirabella A and Carnicelli S 1992. Iron oxide mineralogy in red and brown soils developed on calcareous rocks in central Italy. Geoderma, vol 55, pp 95-109.
Samples of 9 red and brown closely associated soils developed from highly calcareous materials in central Tuscany, Italy, were analysed to determine: the mineralogical properties of the iron oxides, the relationship between redness and heamatite content, and the relationship between parent material and iron oxide mineralogy.

Goethite and heamatite were the only crystalline iron oxides detected in the A, E and B horizons studied. X-ray data indicated that they were either poorly crystalline or of small particle size. A high proportion (67 to 95%) of the total iron was extracted by dithionite, and oxalate-extractable Fe was less than 10% of Fe_d in most of the samples. The extent of Al substitution in goethite was positively correlated (R^2=0.68) to crystal dimension along the 110 direction. This finding is consistent with those for aluminous goethite synthesized at 25 C but at odds with some published data for natural goethites.

Redness rating of dry crushed samples, as determined with Munsell colour charts, was positively correlated (R^2=0.79) with haematite content. Redness rating, however, would provide only a crude estimate of haematite content.

The soils with the lowest content of total iron had by far the lowest haematite content; nearly all of the crystalline iron oxide was goethite. This lends support to the hypothesis that parent material influences the development of iron oxides in soils.

Mirzajanzade A H and Mamed-Zade A M 1990. Effect of clay minerals on fluid filtration in a porous medium. Lithos, vol 24, pp 251-260.
The development of oilfields in rocks containing clay minerals involves a series of complications. For this reason, some effects of clay on fluid filtration in porous media were studied under laboratory conditions: (1) The effect of clay on the displacement efficiency of fluid hydrocarbons by water, (2) The effect of a magnetic field on the velocity of single phase water infiltration, (3) The effect of a magnetic field on the swelling capacity of clay minerals, (4) The effect of magnetised water on the displacement efficiency.

Mitchell-Thome R C 1963. Average annual natural recharge estimates of groundwater in Eastern Nigeria, with comments on consumption. Paper presented at the Science Association of Nigeria, Annual Conference, Zaria, 21st December 1963.
Lacking necessary observational and statistical data, it is not possible to arrive at accurate figures regarding the annual groundwater recharge in Eastern Nigeria. Using what information is available, and applying what are believed to be reasonable figures for various coefficients, an estimate is made that some 780,000 million gallons are annually exploitable in the Region

While these is no immediate cause for alarm as regards consumption needs, when consideration is taken of the alarming population increase, expansion of industrial and agricultural development projects, it is imperative that careful water planning begin now.

Mohamed A N 1991. Spectral analysis of aeromagnetic data over the middle Benue trough, Nigeria. MSc thesis, Department of Geology, Nsukka University, Nigeria.
2D spectral analysis showed two sources of anomalies (1) deep 1600 - 5000 m and (2) shallow 66-1200 m. These correspond to basement and intrusions respectively.

Monkhouse R A 1963. Groundwater in the Eastern Region of Nigeria: A compilation of present knowledge. Geological Survey of Nigeria, Enugu, unnumbered report.

Morgan J 1996. WaterAid Nigeria/Oju LGA Support Programme: Public Health Consultants Report. Internal WaterAid report.
Discusses the findings of the Public Health Consultant's during a 5 week visit to Oju. Gives some background to the

Igedde tribe, and their health and hygiene behaviour. Then proposes a strategy for WaterAid work within Oju. This will involve empowering the communities and in particular to enable women's decisions to gain influence within communities.

Morgan W B and Solarz J A 1994. Agricultural crisis in Sub-Saharan Africa: Development constraints and policy problems. The Geographical Journal, vol 160, pp 57-73.
The agricultural production 'crisis' in Sub-Saharan Africa is manifested by mainly in a fall in export crop and commercial food production, apart from food supply problems in individual countries as a result of drought, war or civil unrest. Major constraints include limited used of modern agricultural inputs, land tenure problems, seasonal production bottlenecks, poverty and lack of capital, the risks of depending on the market, lack of government financial support, government indifference and high levels of taxation, low food produce prices, competition of cheap food imports and food Aid, world recession, declining agricultural terms of trade and international debt. Attempts to promote rural development and investment in small-holder production by the World Bank have not, on the whole, succeeded and have been followed by structural adjustment programmes of the Bank and the IMF which have done little for agriculture. Few African countries can achieve food security by reliance on imports. Most need to increase production and reduce costs. Unfortunately, in the present political and economic situation it is hard to see how the required agricultural transformation can be achieved.

Muller J-P and Bocquier G 1986. Dissolution of kaolinites and accumulation of iron oxides in lateritic-ferruginous nodules: Mineralological and microstructural transformations. Geoderma, vol 37, pp 113-136.
In situ geochemical and structural microanalysis of non-disturbed samples of laterite and mineralogical identifications of microsamples demonstrate an orderly succession of mineralogical and structural transformations. These transformations result in the formation of Fe-nodules. They start from a micaceous phase whose micropores are occupied by haematite. Because the source of iron is external to micas this haematite corresponds to an absolute accumulation (in the meaning of Brewer, 1964). The following transformations constitute a succession of three mineral phases corresponding to relative accumulations with the removal of some components and in-situ reutilization of residual materials.

(1) Phase of Fe-kaolinite accumulation during which the structures inherited from micas are preserved.

(2) Phase of Al-haematite accumulation resulting from a dissolution of Fe-kaolinite, with development of pedoplasma and vesicular porosity.

(3) Phase of accumulation of more or less aluminous goethite which ultimately results in the crystallisation of geodes at the borders of voids.

Murthy Y S, Hugens W A and Sharaf El-Din S M 1984. Applicability of electromagnetic methods in groundwater investigations - a case study in Delden area, The Netherlands. Journal of the Association of Exploration Geophysicists, vol 5, pp 1-6.
A successful application of Electromagnetic Method in locating less conductive and water saturated sand layers in alternating clay-sand-clay succession is demonstrated. The field investigations were carried out near Delden village in the eastern part of the Netherlands. The surveys were carried out using both the horizontal and vertical loop configurations with intercoil separations of 10, 20 and 40 m. The EM data obtained along parallel profiles with three intercoil separations permit mapping of the target body laterally as well as in depth. The results of the Em surveys are analysed and compared with the vertical electrical sounding and well data.

Nahon D B 1991. Introduction to the Petrology of Soils and Chemical Weathering. John Wiley, New York.
pp228-23: Pedological Mantles of Tropical Landscapes with Altern ating Dry and Rainy Seasons.
The original surficial mantle with vertical differentiation of tropical humid countries can undergo transformation of its upper part through destruction of microaggregates under the effect of climatic change consisting of appearance of a dry season, namely, of a decrease in rainfall.

Chauvel (1976) estimated that the differentiation of a beige ferruginous soil at the expense of a red latosol requires an order of magnitude of time of a few thousand years. The previous examples of Casamance Senegal) are located at the boundary of the humid domain. If one moves northward from Casamance into Gambia, one moves away from this boundary zone between the permanent humid domain (equatorial in a broad sense) and the domain of alternating rainy and dry seasons, to reach zones where dry seasons are more accentuated and existed for a longer period of time.

In such a case, one frequently sees that the upper part of the pedologic mantle consists of ferruginous crust horizons. Whenever such horizons become generalized, they represent rapidly a major morphological feature of the landscape, showing that ferruginous crusts are characteristic of these particular bioclimatic conditions.

The destruction of microaggregates of latosols allows a separation of kaolinite from iron oxyhydroxides. Iron reconcentrates at short distances in the shape of mottles and glaebules. This process, repeated during a sufficiently long span of time, can generate a mottled clay at the top of which real ferruginous nodules can differentiate.

Consequently, through progressive lateral transformation, latosols are replaced by argillo-ferruginous horizons with mottles and nodules whose colours range from ochre yellow to purple red. In these horizons with lateral and vertical dynamic conditions solutions processes occur. Iron oxyhydroxides remain in these weakly soluble environments of the upper parts of profiles and undergo only very short transferes in the state of ferrous ions. This is the reason an abundance of concentrated iron oxyhydroxides can be directly related to richness in iron of the original parent-rock underlying the saprolite (Leprun, 1979).

Mottled clays, once differentiated, undergo their own evolution. At the surface, this horizon is continuously destroyed by the action of unsaturated rain water and of organic matter still present in this landscape of savanna with trees. Kaolinite is destroyed more rapidly than iron oxyhydroxides and oxides. The latter therefore concentrate relatively closer in the shape of purple-red, indurated ferruginous nodules consisting essentially of heamatite. Dissolution of kaolinite and accumulation of iron oxides as nodules are repeated in time, and an increasing concentration of iron oxides allows a greater dissolution of kaolinite at the places where nodules are formed. Gradually horizons with ferruginous nodules develop at the top of the pedologic mantle. With lowering of the topography, these ferruginous nodules increase in number and become anastomosed into a nodular ferruginous crust called conglomeratic. Kaolinite destroyed by solutions at the top of the profile precipitates as a new generation of kaolinite in the lower part of the mottled clay, and even in the upper part of the underlying saprolite. In conclusion, a mottled clay, a nodular ferruginous horizon, and an indurated ferruginous crust become differentiated above the saprolite itself a relic of an evolution in a more humid climate.

Such a derived sequence is identical to original sequences differentiated directly at the expense of the parent-rock under similar bioclimatic conditions. However, there is a difference: These original sequences displays a saprolite horizon thinner than that generated by the transformation of a pedologic mantle previously differentiated under a more humid climate (Fig xxx). In summary, under tropical climates with alternating rainy and dry seasons, a lateritic pedologic mantle, consisting of mottled clay horizons and ferruginous crusts, is differentiated.

Wetting predominates in horizons at the top of the pedologic mantle and controls the flat morphology characteristics of these regions. Wetting at depth is not sufficient to allow saprolite horizons to strongly develop at the expense of the parent-rock, consequently, weathering of parent minerals can allow smectites to appear as weathering plasma (Tardy, 1969). Therefore, solutions preferentially affect the upper part of profiles where iron oxyhydroxides undergo dissolutions, transfers and reprecipitations over short distances (a few millimetres to a few centimetres), whereas kaolinite is submitted to the same processes but over greater distances (a few decimeters to a few metres).

All over a geomorphic unit, solutions percolate and generate within iron crusts and mottled clay horizons, dissolutions, recrystallizations, transfers of materials, and neoformations, redistributing iron, alumina, and silica as new generations of iron oxyhydroxides, iron oxides, and kaolinite. New organizations replace earlier ones in crusts as well as in mottled clays.

Leached zones are adjacent to zones of accumulation. This is a state of constant disequilibrium, but in the long run, kaolineit has a tendency to concentrate in deeper and more downslope areas. Whitened and leached horizons with abundant quartzose skeleton can develop in places beneath iron crusts, undergo compaction, and lead to collapsing of the crust, which breaks up in-situ in individual blocks. Meanwhile, the crust itself through continuously repeated redistribution of iron generates pisolites, which progressively become separated from each other, forming a pebbly horizon. This horizon is expressed in the field by small depressions that allow the development of a local drainage and hence, in tome, the appearance of a linear erosional cut. Other portions of geomorphic units display an equilibrium between leaching and accumulation and allow a geochemical sinking of such portions without major discontinuities. Iron crusts develop at the expense of mottled clay horizons, and the latter at the expense of saprolites. Consequently, pedologic mantles with iron crusts display a morphology of asymmetric hills, showing the following features: roughly tabular tops with very low uniform inclination, rather steep concave slopes where the erosional cut is ocated, low angle slopes, slightly convex and concave when joining broad thalwegs.

Nair K M and Ramanathan R M 1985. Sedimentology, stratigraphy and palaeogeographical significance of Lower Cretaceous Gboko Limestone, Nigeria. Nigerian Journal of Mining and Geology, Vol 21, pp 203-210.
Sedimentologic and palaegeographic study of an eighty metres thick quarry section of Gboko limestone of the lower Cretaceous Asu River Group is presented. The lower 33 m are essentially composed of limestones and the upper 46 m are composed of alternations of shales and limestones. The limestones as a whole have both mud-supported and grain-supported textures in a 3:1 ratio and micrite forms over 75% of the bulk. Foraminifera, identifiable tiny skeletal grains and occasional ostracods, molluscs and oncolites are the grains in the rocks with mud-supported textures. Packstones are the grain-supported rocks and are highly micritic with no cement. Oncolites, pellets and thin walled stunted molluscs are the main grains in them. Carbonaceous particles, glauconite and pyrite occur in various forms in the limestone. Shales contain arenaceous and calcareous benthic foraminifera suggesting a possible Upper Aptian to Middle Albian age.

The sequence is thought to have been deposited in a lagoon formed during the first marine transgression into the Benue Trough. The lagoon had an initial hyposaline phase, an intermediate hypersaline, tectonically stable phase and a terminal hylosaline-hypersaline tectonically oscillatory

phase. The sequence as a whole indicates one transgressive-regressive cycle.

Nash C R, Rankin L R, Leeming P M and Harri L B 1996. Delineation of lithostructural domains in northern Orissa (India) from Landsat Thematic Mapper imagery. Tectonophysics, vol 260, pp 245-257.

Image based reconnaissance mapping at 1:100,000 scale using Landsat TM data has delineated a college of Precambrian lithostructural domains within a 50,000 km^2 region which encompasses the northern portion of Archean to Proterozoic granulite-grade Eastern Ghats Tectonic Province and the adjacent Archean-Mesoproterozoic Singbhum Craton. The domains identified in the present study display distinctive internal structures on satellite imagery. Most are bounded by clearly recognizable major shear zones and faults on imagery; displacement directions may frequently be ascertained through local reorientation of planar structures adjacent to large strike-slip shear zones and through juxta-position of domains with different structuring.

The macroscopic/megascopic structural overview provided by the Landsat interpretation, supported by preliminary field investigation, suggests that the N-S shortening (E-W fold/thrust packages with associated NE and NW strike-slip faulting), is the dominant structural style in the northernmost part of the Eastern Ghats Tectonic Province, followed by regional dextral transgression, expressed in the form of major strike-slip faults. The largest of these structures (Kerajang Fault), which may be traced for over 250 km, has demonstrable Palaeozoic-Mesozoic dextral motion associated with coal basin formation. A precursor Kerajang shear zone, with dextral movement in excess of 100 km of indeterminate age may also have been instrumental in juxtaposing the Singbhum Nucleus into its present position to the north of the Eastern Ghats Tectonic Province.

Nettleton L L 1976. Gravity and Magnetics in Oil Prospecting, McGraw-Hill.

Discusses the fundamentals of magnetism and the magnetism of the earth, diurnal corrections etc ... There is also a section on interpreting magnetic maps and some case examples.

Neuzil C E 1986. Groundwater flow in low-permeability environments. Water Resources Research, vol 22, pp 145-150.

Certain geologic media are known to have small permeability; subsurface environments composed of these media and lacking well developed secondary permeability have groundwater flow systems with many distinctive characteristics. Moreover, groundwater flow in these environments appears to influence the evolution of certain hydrologic, geologic, and geochemical systems, may affect the accumulation of petroleum and ores, and probably has a role in the structural evolution of parts of the crust. Such environments are also important in the context of waste disposal. This review attempts to synthesise the diverse contributions of various disciplines to the problem of flow in low-permeability environments. Problems hindering analysis are enumerated together with suggested approaches to overcoming them. A common thread running through the discussion is the significance of size- and time- scale limitations of the ability to directly observe flow behaviour and make measurements of parameters. These limitations have resulted in rather distinct small- and large- scale approaches to the problem. The first part of the review considers experimental investigations of low-permeability flow, including in situ testing; these are generally conducted on temporal and spatial scales which are relatively small compared with those of interest. Results from this work has provided increasingly detailed information about many aspects of the flow but leave certain questions unanswered. Recent advances in laboratory and in situ testing techniques have permitted measurements of permeability and storage properties in progressively "tighter" media and investigation of transient flow under these conditions. However, very large hydraulic gradients are still required for the tests; an observational gap exists for typical in situ gradients. The applicability of Darcy's law in this range is therefore untested, although claims of observed non-Darcian behaviour appear flawed. Two important non-hydraulic flow phenomena, osmosis and ultrafiltration, are experimentally well established in prepared clays but have been incompletely investigated, particularly in undisturbed geological media. Small scale experimental results form much of the basis for analyses of flow in low-permeability environments which occurs on scales of time and size too large to permit direct observation. Such large scale flow behaviour is the focus of the second part of the review. Extrapolation of small-scale experimental experience becomes an important and sometimes controversial problem in this context. In large flow systems under steady state conditions the regional permeability can sometimes be determined, but systems with transient flow are more difficult to analyse. The complexity of the problem is enhanced by the sensitivity of large-scale flow to the effects of slow geologic processes. One dimensional studies have begun to elucidate how simple burial or exhumation can generate transient flow conditions by changing the state of stress and temperature and by burial metamorphism. Investigation of the more complex problem of the interaction of geologic processes and flow in two and three dimensions is just beginning. Because these transient flow analyses have largely been based on flow in experimental scale systems or in relatively permeable systems, deformation in response to effective stress changes is generally treated as linearly elastic; however, this treatment creates difficulties for the long periods of interest because viscoelastic deformation is probably significant. Also, large scale flow simulations in argillaceous environments generally have neglected osmosis and ultrafiltration, in part because extrapolation of laboratory experience with coupled flow to large scales under in situ conditions is controversial. Nevertheless, the effects are potentially quite important because the coupled flow might cause ultra long lived transient conditions. The difficulties associated with analysis

are matched by those of characterising hydrologic conditions in tight environments; measurements of hydraulic head and sampling of pore fluids have been done only rarely because of the practical difficulties involved. These problems are also discussed in the second part of this paper.

Neuzil C E 1993. Low pressure within the Pierre Shale: A transient response to erosion. Water Resources Research, vol 29, pp 2007-2020.

Naturally transient flow (NTF) occurs when a groundwater regime fails to accommodate geologic changes. This paper describes a conspicuous NTF signature entirely within a low-permeability shale in an eroded basin. Flow in the shale appears to be a lagging hydrodynamic response to mechanical rebound and cooling from erosion; careful, long term pressure measurements revealed a consistent pattern of low hydraulic head with the minimum within the shale. Available data are sufficient to rule out alternative causes of the pressure regime, and to construct a meaningful quantitative model of the effects of erosion. The shale behaves as a Kelvin substance in tests, but theoretical considerations suggest that its deformation during erosion mimics elastic behaviour, permitting the model to be based on pore-elasticity. Pressure patterns similar to that observed can be produced by incorporating into the model independent estimates of the shale's hydraulic, mechanical, and thermal properties and a reconstruction of the area's erosion history. The results confirm that local permeability is between 10^{-21} and 10^{-20} m^2 (hydraulic conductivity between 10^{-14} and 10^{-13} ms^{-1}), in contrast to the higher regional permeability of 2×10^{-16} m^2 (hydraulic conductivity of 2×10^{-9} ms^{-1}) determined in an earlier study. Exploration techniques employed in this study could reveal similar NTF regimes in the future.

Neuzil C E 1994. How permeable are clays and shales? Water Resources Research, vol 30, pp 145-150.

The permeability of argillaceous formations, although rarely measured and poorly understood, is commonly a critical parameter in analyses of subsurface flow. Data now available suggest a regular relation between permeability and porosity in clays and shales and permeabilities that, even at large scales, are significantly lower than usually assumed. Permeabilities between 10^{-23} and 10^{-17} m^2 have been obtained at porosities between 0.1 and 0.4 in both laboratory and regional studies. Although it is clear that transmissive fractures or other heterogeneities control the large-scale hydraulic behaviour of certain argillaceous units, the permeability of many others is apparently scale independent. These results have significant implications for understanding fluid transport rates and abnormal pressure generation in basins, and could prove important for waste isolation efforts.

Niwas S and Singal D C 1981. Estimation of aquifer transmissivity from Dar-Zarrouk parameters in porous media. Journal of Hydrology, vol 50, pp 393-399.

A simple analytical relation is proposed between aquifer parameters and the Dar Zarrouk parameters. This uses ohms law and Darcy's law. The method is then verified by using data from Kelly. The relations are:

$$T = (K)/R$$

$$T = (K/)C$$

where T is the transmissivity, K the hydraulic conductivity is the electrical conductivity; and R and C are the transverse resistance and the longitudinal conductivity respectively. Which of these equations can be applied depends on the nature of the aquifer.

Novakowski K S Cherry J A 1988. Evaluating groundwater velocity in a low-permeability fractured shale. Proceedings of the technology transfer conference 1988 : November 28 and 29, 1988, Toronto, Ontario, pp 273-282

Many recent hydrogeological investigations in fractured rock have shown that there is considerable uncertainty in the accuracy of predictions of groundwater velocity in discrete fracture planes. Since many landfills and industrial sites in Southern Ontario are underlain by low-permeability shale bedrock pervaded by high-permeability fractures, a site was selected in the Meaford-Dundus shale with the intent to study velocity in one of the high-permeability features. A total of 7 boreholes were drilled in a 30 x 30 m area intersecting a single flat-lying fracture at a depth of about 10 m. Approximately 80 constant-head hydraulic tests were conducted to define the intersection of the fracture in each borehole. In addition, slug tests, pulse interference tests, pumping tests and injection-withdrawal and radial-convergent tracer tests were conducted in and between the boreholes to determine the average fracture aperture width and the lateral continuity of the fracture plane. The hydraulic test results show that the two fracture plane is characterized by a relatively uniform aperture width of about 120 um and 200 um (equivalent to about 10^{-6} m/s for K), but is continuous in only 4 of the 7 boreholes (present but closed in the others). The tracer test results suggest that the groundwater velocity predicted using the hydraulic test results may overestimate actual groundwater velocity by up to a factor of 4. The discrepancy in predictions is believed to be the result of unaccounted for tortuous flow pathways which influence the results of tracer experiments but not hydraulic tests.

Nguyen V and Pinder G F 1983. Direct calculation of aquifer parameters in slug test analysis. Water Resources Monograph, American Geophysical Union.

This paper provides a simple method for calculating aquifer properties from water level observations in a single well. All the mathematics are provided.

Nwachukwu S O 1972. The tectonic evolution of the southern portion of the Benue Trough, Nigeria. Geological Magazine, vol 109, pp 411-419.
A reconstruction of the tectonic history of part of the Benue trough is made from a study of marine transgressions and regressions in SE Nigeria. Two periods of deformation involving essentially the interaction of continental plates are suggested. The oceanic crust produced by crustal attenuation in the Benue rift is very minimal. Unstable tectonic conditions in the Benue Trough may have created conditions for the development of an evaporite sequence.

Nwajide C S 1982. Petrology and Palaeontology of the Makurdi Formation, Benue Trough. PhD thesis, University of Nigeria, Nsukka.

Nwajide C S and Hoque M 1985. Effects of diagenesis on the sandstones of the Makurdi Formation (Turonian), Nigeria. Nigerian Journal of Mining and Geology, vol 21, pp 143-150.
As composition and texture of a sedimentary deposit may undergo profound changes during the diagenetic phase, a full understanding of the degree and nature of post-depositional alterations of the components of the rock body is essential in evaluating its provenance and depositional history. The composition and maturity of fluvial sandstones of the Turonian Makurdi Formation of the central Benue valley is evaluated as an illustration of the above statement. The Makurdi Sandstones show features of several diagenetic effects. These diagenetic processes altered significantly the grain matrix ratio of the original detritus, and gave rise to a new assemblage of mineral components which should be assessed and classified in the light of the diagenetic stage of the sediment; otherwise an erroneous interpretation may be imported in the nomenclature of the sandstone and its maturity stage.

Diagenetic stage of the Makurdi Sandstones.
Various diagenetic features can be roughly related to early, intermediate and late stages of modification of sediments (Siever, 1959; Fairbridge, 1967). These modifications, occurring progressively, have been designated by Dapples (1962, 1967) as redoxomorphic (oxidation-reduction phase), locomorphic (cementation and mineral replacement phase) and phyllomorphic (phase of ion exchange with clays, micas and feldspars). Each of these geochemical stages is characterised by the appearance of specific minerals or features, analogous to metamorphic facies.

The criteria for recognising the redoxomorphic stage are those reduction-oxidation reactions dominating an early burial stage. The include Fe^{2+}, Fe^{3+} , biotite glauconite, biotite iron-oxides and clay minerals, biotite muscovite, and biotite to chlorite transformations. There is no evidence of such redox reactions in the exposed sections of the Makurdi Sandstones.

The locomorphic stage is marked by mineral replacement, e.g. quartz, chert, clay or feldspars by carbonates; feldspars by clays; aragonite by calcite; and calcite by dolomite. There are evidences in support of a locomorphic stage of diagenesis in the Makurdi Sandstones. These include precipitation of silica as overgrowths, alteration of feldspars to kaolinite, corrosion of quartz and feldspars by limonite, and predominance of concavoconvex contacts between framework grains. It does not appear that the sediment reached the phyllomorphic stage of diagenesis which is distinguished by unidirectional reactions involving changes of clay minerals to biotite of chlorite, authigenic development of chlorite or feldspars at elevated temperature and pressure.

Nwajide C S 1986. A systematic lithostratigraphy of the Makurdi Sandstones, Benue Trough. Nigerian Journal of Mining and Geology, vol 22, pp 9-23.
The Turonian Eze Aku Group, covering parts of the middle and lower Benue Trough, consists of shales, limestones and a large sandstone unit subdivisible into the Kana, the Makurdi, the Agala, the Ogoja and the Amaseri sandstones. The Makurdi Sandstones occur in over 1000 km^2 of territory astride the River Benue. The type area encompasses Makurdi and its immediate precincts. The sandstones are fluviatile in origin but sandwich a marine carbonate member - the Wadatta Limestone - in the type area. Identified, in the absence of an earlier designation, as the 48.3 m thick sequence of subarkosic arenite stretching from the water level at the southern abutment of the railway bridge to the premises of the former Benue Hotel. Because of the inadequacies of the type section five additional sections (hypostratotypes) located within and beyond Makurdi have been logged. In view of the mappability, practical lithologic homogeneity and the fact of containing a carbonate horizon distinguishable as a member, these sandstones should constitute a formation within the Eze Aku Group.

Nwajide C S 1988. Convergent mud drapes on some planar cross-beds in the fluvial Turonian sandstones of the Makurdi Formation, Benue Trough, Nigeria. Journal of African Earth Sciences, vol 7, pp 113-120.
Of the various stratigraphic structures characterising the sandstones of the Turonian Makurdi Formation of the Benue trough of Nigeria, a variety of planar tabular cross-bedding appears distinctive and has probably not been described hitherto. Poorly sorted feldspathic sandstone cross-beds rhythmically alternate with clay-silt laminae which extend beyond the toes of the cross-beds and coalesce with similar laminae to form a horizontally stratified and microrippled unit separating the cross-bedding sets.

The sandstone cross-beds are most probably the result of intermittent grain flow and avalanching on the lee side of solitary sand waves. The mud drapes may have originated by grain fall. An alternative suggestion is that the cross beds are the streamwise sequence of growth lobes with downstream fining consequent upon the intermittent waning of currents. The nonerosional mud drape surfaces may be regarded as reactivation surfaces with inclinations coincident with the dips of the cross-beds.

Nwajide C S 1990. Cretaceous sedimentation and palaeogeography of the Central Benue Trough. In: Ofoegbu, C. O., editor. The Benue Trough Structure and Evolution. Earth evolution series, Vieweg. pp 19-38.
The Benue trough is generally believed to have developed as a rift following the NE-SW oriented failed third arm of a radial crack system. The cessation of the mantle plume that induced the cracking resulted in tectonic subsidence and bilateral stratigraphic onlap subdivisible into three unconformity-bounded packages: pre-Aptian-Cenomanian, Turonian-Santonian, and Campanian-Maastrichtian.

In the central Benue Trough the pre-Aptian to Cenomanian succession consists of the Asu River Group (marine mudrocks and carbonates) and Bima Sandstone (alluvial fan and fluvial facies), all deposited during the rift stage of the trough. The Turonian-Santonian succession is dominated by the Eze-Aku Group whose component formations consist of marine shales and carbonates, deposited in the fully developed trough stage merging into the deformational stage. The Campanian-Maastrichtian succession consists of unfolded fluviatile sands of the Lafia Formation, deposited in the platform stage of trough evolution.

Obaje N G, Funtua I I, Ligouis B and Abaa S I 1996. Maceral associations, organic maturation and coal-derived hydrocarbon potential in the Cretaceous Awgu Formation, Middle Benue Trough, Nigeria. Journal of African Earth Sciences, vol 23, pp 89-94.
About 6,000 m of alternating marine, paralic, and continental sediments of Cretaceous - Tertiary ages have been deposited in the Benue Trough. Conspicuous amongst these are the coal beds and coal-bearing strata, of which those of the Awgu Formation in the Middle Benue Trough have attained a rank of high to medium volatile bituminous coal stage.

Maceral analysis on samples from the coal seams and some organic matter-rich interseam sediments obtained from four boreholes and two outcrop sections allows distinction of three petrographic facies which are related to the maceral associations, namely the vitrinite-fusinite coal facies, the trimaceritic coal facies and the shaly coal facies.

Vitrinite reflectance values measured on these samples generally increase with depth from 0.76 - 1.25%. At these values, usually large amounts of volatile matter are yielded in the form of methane, carbon dioxide and water as the primary products of progressive maturation and devolatisation of humic organic matter.

Obaje N G and Ligouis B 1996. Petrographic evaluation of the depositional environments of the Cretaceous Obi/Lafia coal deposits in the Benue trough of Nigeria. Journal of African Earth Sciences, vol 22, pp 159-171.
Paralic coal beds occur intercalated with the Cretaceous systems in the area around Obi/Lafia of the middle Benue trough of Nigeria. The petrographic compositions of the coal beds indicate three petrographic facies with different depositional environments. The coal beds at the bottom of the stratigraphical sequence, termed the vitrinite-fusinite coal facies, are rich in vitrinite, poor in liptinite with variable amounts of inertinite and low mineral matter content. Those at the top, the trimaceritic coal facies, have well represented amounts of vitrinite, lipinite and inertinite. Their mineral matter content is also low. Below, between and above these two coal facies occur the shaly coal facies with a very high content of mineral matter and variable amounts of vitrinite, liptinite and inertite.

Correlation of the distribution of microfossils in the interseam sediments with the maceral associations, mineral matter contents and the petrographic indicies, indicates that the vitrinite-fusinite coal facies was deposited in a telmatic wet forest swamp subenvironment along and within lagoons; the trimaceritic facies in a limno-telmatic clastic marsh subenvironment in lower delta plains. The shaly coal facies shows characteristics of different subenvironments, but tends to be more marine.

Obe P A I and Daagu J 1991. Report on rapid reconnaissance survey in Oju LGA, Benue State. RUSAFIYA PROJECT, (UNDP - Assisted Rural Water Supply and Sanitation Project NIR/87/011). Unpublished Report.
Describes a survey undertaken of over 400 villages in Oju LGA. They found that the major source of water in the dry season was ponds. Streams dry up quickly in the dry season. No feeling of ownership amongst communities for government boreholes. Population for the district was very high (calculated from households).

Obi M E and Asiegbu B O 1980. The physical properties of some eroded soils of south-eastern Nigeria. Soil Science, vol 130, pp 39-48.
We studied the physical properties of some eroded soils of the rain forest and savannah zones of south-eastern Nigeria. These soils were on slopes of 4 to 22 percent, and the degree of erosion varied from very slight to catastrophic. Texturally, the top soils were sand and loamy sand, and most profiles were uniform to considerable depths. Their total porosities ranged from 40 to 61 percent, macropores constituting 35 to 60 percent of these. Infiltration rates ranged from 10.1 to 357.1 centimetres per hour, and saturated hydraulic

conductivities of the top layers ranged from 7.1 to 33.1 centimetres per hour. Water release curves showed considerable loss of water (41 to 67 percent) between 0 and 80 centimetres of water tension, in conformity with the textural and organic matter status of the soils. An erodibility rating curve showed the Onicha-Mbaise and Agulu soils to be the most erodable and the Nsukka soils to be most stable. The implication of these findings for soil management practices and cropping patterns are discussed.

Obiora S C and Umeji A C 1995. Alkaline intrusive and extrusive rocks from areas west of the Anyim River, south-eastern Benue Trough. Journal of Mining and Geology, vol 31, pp 9-19.

Twenty-one outcrops of igneous bodies were studied in a small area (ca. 335 km^2) of folded sediments west of Anyim River in the lower Benue rift. The extrusives occur mainly as basaltic to trachybasaltic tuffs and lapilli tuffs. The minor intrusives are found as basaltic and dolerite sills composed essentially of plagioclase (An_{37}) and augite with or without olivine. The major intrusives are dioritic small bodies consisting of sodic plagioclase (An_{38}), biotite and/or hornblende, and rarely nepheline. Common accessory minerals in these rocks are magnetite, pyrite, apatite, sphene and quartz. Calcite appears to be secondary, and biotite, in some cases, is a pseudomorph after hornblende.

The rocks are mostly alkaline, total alkali ranges from 3.21 to 9.92% with Na_2, 2.62 to 6.55% and K_2O <3.76%. In an alkali-silica diagram, 80% of the analyses plot is alkalic. These lower Benue rocks are also aluminous, Al_2O_3 ranges from 12.96 to 19.95%. In an alkali-alumina diagram, the Benue rocks compares well with those of the Baikal Rift, Siberia and differ from those of the rocks from Eastern Uganda, East African Rift. The aluminous character of the Benue rocks studied suggest crustal contamination. The occurrence of alkalic suite in a divergent rift setting is considered to be a derivation from an upper mantle alkaline olivine-basalt magma through fractional crystallisation

Offodile M E 1976. The Geology of the Middle Benue, Nigeria. Palaeotological Institution of the University of Uppsala, Special Volume 4, pp 166.

The Middle Benue, as represented by the Kana-Awe area of the Benue and Plateau states of Nigeria, comprises, essentially, six geological formations - the Asu River, Awe Kana, Eze-Aku, Awgu and Lafia Formations. The Asu River Formation consists of shales and siltstones of marine origin, representing the first Middle Albian transgression into the Benue Valley and marked by species of the Ammonite genus Oxytropidoceras. The Awe Formation marks the beginning of the regressive phase of the Albian sea, with transition beds of sandstones and shales. It is overlain by continental fluviatile sands of the Kana Formation followed by the marine strata of the Eze-Aku and Awgu Formations, indicative of the Late Cenomanian - Turonian and Coniacian transgressions respectively. Continental conditions prevailed after the Coniacian with the barring of the Benue trans-Saharan seaway by, probably, the intensive Santonian tectonic activity. Continental beds of the Lafia Formation were thinly deposited and appear to have thickened southwards.

The determination, in this part of the country, of the Late Cenomanian at the lowermost Eze-Aku Formation, with Kanabiceras septemseriatum (Cragin), followed subsequently by typical north-eastern Nigerian Turonian ammonites, as described by Barber (1957), is new for Nigeria. This confirms the Late Cenomanian connection with the Tethys transgression, and brings this aspect of the geological history of Nigeria into line with many other parts of the world.

The structural framework of the area coincides with the set up in the Benue Valley as a whole, with the Santonian parallel to sub-parallel folds (northeast-south-west trend) apparently affected by a later post-Maastrichtian folding episode, acting at right angles, and giving a regional characteristic sinuosity to the fold axes. The dominance of the Kana anticline and its possible relationship to the medial positive gravity anomaly of the Benue Valley are underlined. The various hypotheses on the origin of the Benue Valley are considered in the light of some field observations and the need for a systematic study of the Benue margins for regional fracture systems are suggested.

The economic importance of the region is studied with particular reference to the occurrence of brines, which are thought to be marine in origin and possibly associated with evaporites. Other minerals of economic interest considered include limestone, barytes, coal and hydrocarbons. The hydrogeology of the area has also been briefly studied and the need for an elaborate water-supply investigation programme emphasised in view of the poor aquifer properties of some of the formations and the menace of saline and acidic waters in some of the aquifers.

Offodile M E 1982. Aspects of the hydrogeological characteristics of the sandstone aquifer of the Lafia sub-basin of the Middle Benue. Nigerian Journal of Mining and Geology, vol 19, pp 162-188, Special issue, 20th Anniversary Proceedings of the Nigerian Mining and Geosciences Society.

The problematic hydrogeological situation in the middle Benue Valley arises from the generally limited lateral and vertical extents of its aquifers, resulting from the rapid facies changes associated with the variations in the environments of deposition of the sediments. As a results, the aquifers occur in isolated, or sometimes, hydrologically, interconnected pockets within formations.

The case study of the Lafia Sub-basin, indicates the hydrogeological properties of the fine to very coarse, highly permeable, sandstone aquifers of the Lafia and Awgu Formations. Pilot boreholes, preceded by electrical resistivity depth probes, and drilled into the sand body, gave a range of

coefficients of transmissivity of between 100 m^2/day to 400 m^2/day; values thought to be promising for the middle Benue Valley. The deeper sandy beds in the Awgu Formations, usually too fine and thin, alternating rapidly with clays, shales and limestones, gave coefficients of transmissivity less than 5 m^2/day, indicating poorer aquifer characteristics.

Offodile M E 1982. The geology and tectonics of Awe brine field. Nigerian Journal of Mining and Geology, vol 19, pp 189-203, Special issue, 20th Anniversary Proceedings of the Nigerian Mining and Geosciences Society.
Recent studies of the Azara and Awe brine fields of the Middle Benue valley have revealed interesting structural developments deserving closer study. The Awe brine-field, like the Azara occurrence, is underlain by Cretaceous sedimentary rocks of the Asu River, Awe, Kana and Eze-aku Formations. The brine, whose origin is, so far enigmatic, issues from the transitional beds of the Awe Formation which have been exposed by differential erosion on a local anticlinal structure.

The partial dome feature, mapped around the old town of Awe, reveals dis of 16 to 30 to the north and south, rounding off to the north-east at smaller dips of 4 to 10 in the direction. Longitudinal strike-slip faults parallel to the major fold axis, dominate the tectonics. Typically, close conjugate joint systems infilled by silica, reflect the same pattern as the faulting.

Offodile M E 1989. A review of the geology of the Cretaceous of the Benue Valley. In: Kogbe, C.A. (ed) Geology of Nigeria, Rock View (Nigeria) Ltd, second edition 1989, pp 365-376.
This chapter attempts to summarise all available geological information on the Benue Valley. This information was found to be very scanty and the need for some more organised work in the area is urgent. The valley is characteristically linear in shape and its sedimentary formations are continuous with the Nigerian Coastal basin. Structurally, it has been described as trough like and hitherto had been thought to be an ordinary rift valley. But, recently, Burke and others have attempted to explain its origin in the light of new ocean spreading and Plate tectonics theory. Their explanation appears inconclusive in the face of obvious insufficient data.

The Benue valley is marked by a lot of igneous activity. It is also economically important, with the occurrence of lead-zinc, brine, barytes and a large reserve of good quality limestones. It is hoped that the interest generated by these minerals and probably other occurrences, will instigate some more detailed study of the trough.

Ofoegbu C O 1984. Aeromagnetic anomalies over the Lower and Middle Benue Trough, Nigeria. Nigerian Journal of Mining and Geology, vol 21, pp 103-108.
An aeromagnetic map of the Lower and Middle Benue Trough of Nigeria has been compiled. Regions of high and low magnetic anomalies have been delineated and a qualitative description of the anomalies carried out. A detailed analysis of the trend of the aeromagnetic anomalies over the Lower and Middle Benue has been carried out in an effort to trace a possible origin of the anomalies. Preliminary interpretation of these anomalies was solely in terms of a metamorphic basement of variable topography. Such an interpretation however leads to a basement having too high a magnetisation, too thick a sedimentary sequence in some regions of the trough and outcrops of the basement not in agreement with the known geology of the trough. It is therefore thought that variation in the basement topography could contribute to the observed anomalies, but such changes cannot in themselves fully account for the observed anomalies.

Ofoegbu C O 1985. A review of the geology of the Benue Trough, Nigeria. Journal of African Earth Sciences, vol 3, pp 283-291.
The geology of the Benue Trough, though better known than the geology of many other areas of Africa, cannot be said to be well known, as not much published information on the trough exists. The absence of detailed information on some aspects of the geology of the Benue Trough has inhibited would be researchers on different aspects of the through and has presented the most serious limitations on geophysical interpretation of the area. An attempt is therefore made to assemble a review of the known geology of the Benue trough in general and for the Lower and Middle Benue Trough in particular, based on the few published papers and on oral discussions with geologists and geophysicists interested in the area. It is thought that the present work should contribute towards a general and broad understanding of the geology of the Benue Trough.

Ofoegbu C O 1990. The Benue Trough: Structure and Evolution. Earth evolution series, Vieweg.

Ofoegbu C O and Odigi M I 1990. Basement structures and ore mineralization in the Benue Trough. In: OFOEGBU, C. O., editor. The Benue Trough Structure and Evolution. Earth evolution series, Vieweg. pp 239-248.
The Benue Trough is an intra-continental rift basin within whose deformed Cretaceous sediments Pb-Zn ore deposits are localised. Mineralisation in the Benue Trough is here related to the basement structure beneath the trough. Major zones of mineralization appear related and coincide with ancient fracture systems in the trough. These lineaments outline a "tin-columbite and Pb-Zn province" and apparently acted as mineralization ducts. Lineaments in the Benue

Trough are dominantly N-S and NE-SW and often cross one another to give rise to a strong network of shearing fissures and fractures. The resultant increase in the amount of pore spaces gives rise to a better circulation of hydrothermal fluids and consequently the deposition of mineral ores.

Ofoegbu C O and Onuoha K M 1991. Analysis of magnetic data over the Abakaliki anticlinorium of the Lower Benue Trough, Nigeria. Marine and Petroleum Geology, vol 8, pp 174-183.

Two-dimensional spectral analysis of aeromagnetic data has been used to determine the mean depths to buried magnetic basement rocks in the Abakaliki Anticlinorium of the Lower Benue Trough in Nigeria. The average thickness of sedimentary cover overlying the basement which may contain petroleum reservoirs has thus been determined. The results indicate a two depth source model with the depth to the deeper sources (identified with the crystalline basement) varying between 1200 and 2500 m. Isolated linear magnetic features which are prominent on the aeromagnetic maps were also studied in detail. The anomalies over such features (which in many cases have spatial dimensions that are greater than 10 km), were modelled in terms of dyke-like bodies using non-linear optimization techniques. The results obtained from these studies compare favourably with those from gravity and ground magnetic investigations carried out in the area. The sediment thickness in the area, the occurrence of numerous intrusive bodies and the deformational history of the sedimentary rock sequences in the Abakaliki Anticlinorium suggest that this part of the Benue Trough may not hold much promise in terms of hydrocarbon accumulation.

Ofoezie I E, Imevbore A M A and Bolton P 1993. Evaluation of health and environmental hazards in small irrigation schemes Northern Nigeria. Findings of preliminary surveys on schistomiasis, onchocerciasis and malaria. Hydraulics Research Report No. OD/TN 64.

Ogunsanwo O 1989. CBR and shear strengths of compacted laterite soils from south-western Nigeria. Vol 22, pp 317-328.

Laterite soils derived from the basement complex and sedimentary areas of southwestern Nigeria are compacted at the energy of the standard Proctor. The compacted laterite soils possess unsoaked and soaked California bearing ratio values that make them adequate for use as sub-base materials. Their shear strengths are quite high under total and effective stress conditions and thus with their acceptable permeability level the soils are suitable for use in the construction of embankments and dams

Ojiako G U 1985. Nigerian Water Resources and Their Management. Water International, vol 10, pp 64-72.

The potentiality and management of the water resources of Nigeria are examined and early achievements of the authorities charged with the multi-purpose development of this resource are reviewed. The annual mean rainfall distribution ranges from about 157.5 inches at the coast to practically zero at the northern border and an average annual mean of 47.2 inches for the whole country. Surface sources include the River Niger, the third largest river in Africa. In addition there are also the River Benue, Cross River, Imo, Sokoto, Ogun, Anambra, and Kaduna Rivers together with several streams and channels, lakes and ponds which provide a nationwide web of drainage basins. The quantities of runoff from the drainage basins vary widely and depend upon a large number of factors the most important of which are the amount and intensity of rainfall, the climate and vegetation as well as geological, geographical and topographical features of the area. Major ground water reserves exist in numerous localities all over the country and have been conservatively estimated as 30 times the level of surface flows. The establishment of River Basin Authorities remains in Nigeria the greatest landmark made since independence in the development of the economy. The accelerating agricultural activities of the Authorities will return the country to its original position of an agricultural based economy capable of earning substantial foreign exchange and reducing overdependence on oil exports. The problems which face the Basin Authorities and tend to reduce their pace of development, such as financial constraints in fundings, and insufficiency of adequately trained technical and administrative manpower, can easily be overcome with the cooperation of developed countries and the goodwill of international organizations. At home, the tasks of the Authorities will be made easier with the cooperation of local financial houses, local industries, State Governments and organizations with interests in water development as well as institutions of higher learning.

Ojoh K A 1990. Cretaceous dynamic evolution of the southern part of the Benue Trough (Nigeria) in the equatorial domain of the South Atlantic. Stratigraphy, basin analysis and palaeo-oceanography. Bull, Centres Rech. Explor. -Prod. Elf-Aquitaine, vol 14, pp 419-442.

The Benue Trough is a geological megastructure that extends from the northern limit of the Tertiary Niger Delta to Lake Chad for over 1000 km north-eastwards, in the African plate. The Albian to Coniacian sedimentary series of the Lower Benue Trough has been subdivided into eight stratigraphic units based on new biostratigraphic and sedimentological data. It is comprised of two major sedimentary cycles. The first cycle is characterised by subaqueous gravity dynamics with megaslumps and turbidites. As an integral part of the Medio-African Rift System (MARS) in the proximity of the proto-Gulf of Guinea, basin instability or paroxysm was preponderant in the Albian basin with resediments. Rapid subsidence, initially localised in the deep asymmetric Abakaliki basin during the Albian, evolved to a slow rate in the lower Cenomanian, simultaneously with basin infilling and eustatic fall of sea-level.

The second sedimentary cycle is from the upper Cenomanian to Coniacian. It corresponds to the installation of an extensive platform due to differential subsidence on the western part of the basin, dominated by shelf sedimentation. The upper Cretaceous eustatic rise of sea-level is documented from condensed sections, tempestites and tidalites, during the convergence of the Tethysian trans-Sahara seaway and the south Atlantic on the entire Benue Trough.

The rapidly subsiding asymmetric Albian basin with magmatic intrusions evolved to a matured platform stage during the Turonian and Coniacian, penecontemporaneous with the migration of new depocentres to the west in the Anambra Basin. After the Santonian structural inversion phase, the uplifted Abakaliki region was then subjected to an important erosional phase during the Campanian.

The Cretaceous rifting and initiation, shelf installation and stabilisation, then deformation of these intra-Benue basins, represent the evolutionary stages of an aulacogen. They have been influenced mainly by subsidence, sea-level changes and the rifting-drifting of south America from Africa in the equatorial domain of the South Atlantic, within the scope of global plate tectonics.

Okagbue C O 1988. Hydrology and Chemical characteristics of surface and groundwater resources of the Okigwi Area and Environs, Imo State, Nigeria. In: Ofoegbu, C. O., editor. Groundwater and mineral resources of Nigeria, Vieweg, pp 85-100.
The study area is to the southwest of Oju. Asu River group, Eze Aku Shale and Awgu Shale are all present. The most important aquifers in the area are from the younger Benin Formation. Water is high in Iron and is slightly acidic. They give some data on surface water quantity and quality. They paper discusses only the Benin Formation.

Okereke C S 1988. Contrasting modes of rifting: the Benue trough and Cameroon volcanic line, West Africa. Tectonics, vol 7, pp 775-784
The Benue trough of west Africa is commonly believed to be a rift feature that originated in the Cretaceous at about the time that Africa and South America began to separate. Bouguer gravity and available geological data in the trough indicate that its formation was probably the result of regional horizontal stresses in the lithosphere, causing crustal extension and surface subsidence. By contrast, the data for the adjoining Cameroon volcanic line suggests that the associated tensional stresses relate to mantle upwarp causing thinning of the lithosphere and regional crustal uplift similar to that associated with the Kenyan rift. Thus the association of passive and active rifts seen in the Afro-Arabia rift system is also a feature of the Cretaceous rift system in west Africa.

Olade M A 1975. Evolution of Nigeria's Benue Trough (aulacogen): a tectonic model. Geological Magazine, vol 112, pp 575-583.
The tectonic evolution of Nigeria's Benue trough has recently been the focus of investigations, especially in relation to continental drift and opening of the South Atlantic Ocean during Cretaceous times. Most of the tectonic models presented for the Benue depression have placed undue emphasis on certain plate tectonic concepts which are inconsistent with the salient geological features of the trough. A possible model, involving the rise and cessation of mantle upwelling beneath a Cretaceous hot spot, and attendant patterns of doming, rifting, sedimentation, magmatism and tectonism, is proposed for the Benue aulacogen

Olade M A 1978. Early Cretaceous basalt volcanism and initial continental rifting in Benue Trough, Nigeria. Nature, vol 273, pp 458-459.

Olade M A 1979. The Abakaliki pyroclastics of southern Benue Trough Nigeria: their petrology and tectonic significance. Nigerian Journal of Mining and Geology, vol 16, pp 17-25.
Evidence from petrographic and petrochemical studies has shown that the Abakaliki pyroclastics are not 'andesitic lavas and tuffs' as earlier suggested (Burke et al, 1971), but degraded alkali basalt and related pyroclastic flows, tuffs and agglomerates. These rocks represent the earliest phase of Cretaceous volcanism in the Benue Trough.

Using chemical variation diagrams of petrotectonic significance, it is shown that the Abakaliki volcanic rocks are products of hotspot activity related to initial continental rifting preceding the separation of Africa from South America during Albian times. The mildly alkaline rather than tholeiitic affinity of the volcanic rocks suggest that the early evolution of the Cretaceous Benue rift involved mainly vertical crustal movements with little or no lateral separation.

Olaniran O J 1991. Rainfall Anomaly Patterns in Dry and Wet Years over Nigeria. International Journal of Climatology, vol 11, pp177-204.
Some researchers interested in the description of climatic anomalies or the understanding of their causal mechanisms have analysed climatic data separately for dry and wet years in relation to the long-term mean conditions. Rainfall amount and rainfall frequency for five individual dry and five individual wet years were compared with the 1941-1987 averages for Nigeria. Five spatial-anomaly types were found to emerge for dry years, namely above-average rainfall in southern Nigeria but below-average rainfall in northern Nigeria (spatial type I), above-average rainfall in the centre but below-average rainfall in the coastal and extreme northern parts of the country (spatial type II), and below-average rainfall in southern Nigeria but above-average rainfall in northern Nigeria (spatial type III). The other two

anomaly types are country-wide occurrence of below-average rainfall (spatial type IV) and above-average rainfall (spatial type V). These spatial-anomaly types also hold true for wet years, except that the spatial type II is replaced by the occurrence of below-average rainfall in the centre but above-average rainfall in the coastal and extreme northern parts of the country (spatial type VI). The spatial type I and II anomalies support the hypothesis of a restricted northward advance of the Inter Tropical Discontinuity (ITD) in dry years and on a complementary basis the spatial patterns for the rainfall amount anomaly (RAA) and the rainfall frequency anomaly (RFA) depicted these two anomaly types in 40% of the monthly periods for the set of dry years considered. The spatial type IV anomaly, which occurs during the peak of the rainy season, supports the hypothesis of a weakening of the rainy season intensity and on a complementary basis the spatial patterns for the RAA and the RFA depicted this pattern in 30% of the monthly periods for the dry years studied. This shows that both hypotheses are valid for explaining dry years in subtropical West Africa. The spatial type III and V anomalies support the hypothesis of a considerable northward incursion of the ITD in wet years. It was found that the spatial patterns of the RAA depicted these anomaly types in 53.3% of the monthly periods while the spatial patterns of the RFA depicted the anomaly types in 66.7% of the monthly periods for the set of wet years considered.

Olaniran O J and Sumner G N 1989. A study of Climatic Variability in Nigeria Based on the Onset, Retreat, and Length of the Rainy Season. International Journal of Climatology, vol 9, pp 253-269.
The long-term variability of rainfall conditions in Nigeria in terms of the onset, retreat, and length of the rainy season has been analysed, using pentad data for the period 1919-1985. Data were grouped into four areas, arranged in a south-north transect; the Coastal, Guinea-Savanna, Midland and Sahelian Zones (Oju is in the Guinea Savanna area). The series for retreat of rainfall showed evidence for quasi-triennial and quasi-6-year oscillations, while that for rainy season length displayed quasi-biennial and quasi-triennial oscillations. No consistent spectral peaks emerged for changes in the date of onset of the rainy season. There is spatial coherence in variation in the date of the retreat of rainfall over the whole country, while for the date of onset, of the season, spatial coherence is limited to southern Nigeria (Coastal and Guinea-Savanna Zones). Northern Nigeria (Midland and Sahelian Zones) and southern Nigeria (Coastal and Guinea-Savanna) emerge as distinct areas in terms of spatial coherence in the variation of the length of the rainy season. There is also evidence for a secular change in the date of the retreat of rainfall for the whole country during the period 1939-1985, and in the date of onset of rainfall for southern Nigeria for 1968-1985.

Olayinka I A 1990. Electromagnetic profiling for groundwater in Precambrian Basement Complex areas of Nigeria. Nordic Hydrology, pp 205-216.
EM34-3 was used to identify areas of high conductivity within the basement. Apparent conductivities are generally lower than 60 mmho/m. They found a good correlation between high conductivity and good yields (>1 l/s). High conductivity due to deep weathering and sharp anomalies dues to dykes or vertical fractures. They used horizontal dipoles (penetration 15 m); occasionally vertical dipole (penetration 30 m). Only qualitative interpretation of data. They used Offset Wenner to give a quantitative description. They performed a grid over an area that had good boreholes. They mention the problems of distinguishing clay from higher permeability.

Olayinka A I 1992. Geophysical siting of boreholes in crystalline basement areas of Africa. Journal of African Earth Sciences, vol 14, pp 197-207.
This paper assesses the effectiveness of surface geophysical methods namely electrical resistivity, electromagnetic, seismic refraction, magnetic, gravity and induced polarization for groundwater exploration in crystalline basement complex areas. Most of these geophysical techniques can provide quantitative information on the characteristics of the weathered zone which relate to the occurrence of an economic aquifer. The critical factors in the choice of a particular method include the local geological setting, the initial and maintenance costs of the equipment, the speed of surveying, the manpower required as field crew, the degree of sophistication entailed in data processing to enable a geologically meaningful interpretation, and anomaly resolution. The particular advantages and limitations of each technique are highlighted.

Several case histories from Nigeria and the rest of Africa indicate that electrical resistivity (both vertical sounding and horizontal profiling) is the most widely used, followed by electromagnetic traversing. These are often employed in combination to improve upon the percentage of successful boreholes. Due to the high cost of equipment, large scale of the field operations and difficulties in data interpretation, seismic refraction is not widely adopted in commercial-type surveys. Similarly, magnetic, gravity and induced polarization are used only sparingly.

Olayinka A and Barker R 1990. Borehole siting in crystalline basement areas of Nigeria with a microprocessor controlled resistivity traversing system. Groundwater, vol 28, pp 178-183.
Describes the use of one of the first MRT systems for generating electrical pseudo sections. Wenner profiling is used (since it is less affected by surface noise than dipole-dipole). It is applied to Kwara State in Western Nigeria which is weathered basement. There was a strong correlation between low resistivity and highly productive boreholes. Concludes that the technique is good for deeply weathered basement areas, since good coverage (unlike conventional

VES) and also good detail (unlike other methods e.g. EM). Soundings conducted near to deeply steeping structures are strongly affected by lateral effects making interpretation difficult, MRT can account for this. The most productive borehole were found in regolith with conductivity of 60-90 ohms.

Olorunfemi M O and Fasuyi S A 1993. Aquifer types and the geoelectric/hydrogeologic characteristics of part of the central basement terrain of Nigeria (Niger State). Journal of African Earth Sciences, vol 16, pp 309-317.
A study of lithological logs from forty (40) wells drilled in twelve (12) localities in parts of Niger State of Nigeria and the interpretation results of the parametric vertical electrical soundings (VES) were carried out to identify the geoelectric/hydrogeologic characteristics of the basement complex area. Five (5) aquifer types were identified. These include the weathered aquifer; the weathered/fractured (unconfined) aquifer; the weathered/fractured (confined) aquifer; the weathered/fractured (unconfined)/fractured (confined) aquifer and the fractured (confined) aquifer. The mean groundwater yield for the aquifer types varies from 0.83 ls-1 for the weathered layer aquifer to 3.0 l/s-1 for the weathered/fractured (unconfined)/fractured (confined) aquifer.

The fracture frequency increases with depth and reaches a maximum at between 25-35 m for granite, gneiss and schist but decreases with further increase in depth. The cumulative fracture frequency is maximum in granite and minimum in schist.

The fracture thicknesses are maximum (greater than 3 m) and occur most frequently within the depths of 10-40 m. Minimum fracture thicknesses ($\leq$ 1 m) occur most frequently between the depths of 50-70 m. Fractures rarely occur at depths greater than 90 m. An optimum borehole depth for the study area is 60-70 m.

Olorunfemi M O, Dan-Hassan M A and Ojo J S 1995. On the scope and limitations of the electromagnetic method in groundwater prospecting in a Precambrian terrain - a Nigerian case study. Journal of African Earth Sciences, vol 20, pp 151-160.
A pre-drilling, geophysical investigation for groundwater development in the Proterozoic basement of the northern central part of Kaduna State, Nigeria, involved the electromagnetic (EM) method. The amplitude of the EM conductivity measurements correlates more with the weathered layer conductivity than with the overburden thickness. The anomaly amplitude is a poor index of the overburden thickness.

The prediction of groundwater yield from the EM conductivity amplitude is also not feasible as no clearly defined relationship is established between these parameters. Although shallow, water bearing, unconfined fractures are easily delineated by the EM method, the method is not amenable to the mapping of confined fractures that are concealed beneath fresh and infinitely resistive basement rocks.

Olsen H W 1962. Hydraulic flow through saturated clays. Clays and Clay Minerals, vol 9, pp 131-161.
The factors: (1) possible violations of Darcy's law, (2) electrokinetic coupling, (3) high viscosity, (4) tortuous flow paths, and (5) unequal pore sizes have been suggested as possible explanations for the differences between hydraulic flow rates in liquid saturated clays and sands. The effects of these factors on hydraulic flow rates through saturated clays were investigated. Hydraulic flow rates, electrical conductivities, and streaming potentials were measured on natural, sodium, and calcium samples of kaolinite, illite and Boston blue clay. Date were taken after increments of one-dimensional consolidation and rebound over the pressure range from one-sixteenth to 156 atm.

The influences of electrokinetic coupling on the hydraulic flow rates were calculated from irreversible thermodynamic relationships together with the hydraulic and electrical data. The other factors were studied by examining the extent to which each factor explains the discrepancies between measured flow rates and those predicted from Darcy's law and the Kozeny-Carman equation.

The results show that: (1) the possible violations of Darcy's law and electrokinetic coupling are insignificant, (2) high viscosity and/or tortuous flow paths fail completely to account for the discrepancies between measured and predicted flow rates in clays, and (3) unequal pore sizes can explain all the discrepancies.

Omorinbola E O 1982. Verification of some geohydrological implications of deep weathering in the basement complex of Nigeria. Journal of Hydrology, vol 56, pp 347-368.
The subsurface hydrology in four areas of the Nigerian Basement Complex was studied with emphasis on the depth and pattern of weathering. Mean weathering depths (in m) were: Dan Mongu, 31.19; Ife, 20.32; Middle Osun Valley, 13.20; and Middle Ose Valley, 12.94. Mean saturated zone thicknesses (in m) were: Dan Mongu, 10.38; Ife, 13,85; Middle Osun Valley, 8.20; and Middle Ose Valley, 9.72. This region was characterized by a generally widespread saturated zone in the regolith rather than a series of isolated groundwater compartments as would be expected from the basin and dome weathering pattern. The saturated zone thickness and weathering depth were strongly correlated. The temporal variation pattern of saturated zone thickness conformed to the seasonal pattern of rainfall distribution typical of most parts of the country. Conditions necessary for the above geohydrological conditions are thick and widespread regolith, flat or gently undulating terrains with minimal overland flow and subaerial regolith erosion, and

adequate rainfall. The major rivers in the Basement Complex derive a proportion (as yet unknown) of baseflow from the saturated regolith. In this region it is not relevant to look for basins of decomposition for siting wells in deeply weathered landscapes. The success of a well may be readily estimated prior to digging or drilling. Wells should be sunk during the dry season to ensure greatest reliability and yield throughout the year.

The geomorphologic process of deep weathering in crystalline rocks of the Nigerian Basement Complex gives rise to a number of important geohydrological implications of which verification is needed for a proper understanding of the subsurface hydrology. The specific implications of the depth and pattern of weathering in four areas were verified in this study, using appropriate statistical and section-drawing methods. The main findings are:

(1) prevalence of a generally widespread saturated zone in the regolith rather than a series of isolated groundwater compartments implied by the basin-and-dome weathering pattern.
(2) A strong correlation between saturated-zone thickness and weathering depth that enables the former to be reliably predicted from the latter.
(3) A temporal variation pattern between saturated zone thickness that conforms with the seasonal pattern of rainfall distribution typical of most parts of the country.

The environmental factors favouring the identified geohydrologic conditions appear to be a thick and generally widespread regolith, flat or gently undulating terrains on which overland flow and subaerial erosion of regolith are minimal, and a humid climate to supply the rain water needed for adequate groundwater recharge in the overburden. Variations in one or more of these factors in specific areas may therefore be used to explain the resultant or likely deviations from the geohydrologic characteristics established in this study.

The findings indicate, among other things, that the major rivers in the Basement Complex derive from saturated regolith baseflow components of which magnitude further studies are required to determine. Some outstanding practical aspects of the findings with particular reference to the more humid areas include the non-relevance of searching for basins of decomposition as well sites in deeply weathered landscapes, the ability to estimate the success ratio of wells prior to the actual digging or drilling operations, and the desirability of sinking wells in the dry season and to the basal rock surface to make them more reliable and relatively high yielding.

Omorinbola E O 1982. Systematic decline of groundwater level in regolith of the Nigerian basement complex due to human activities. In: Improvements of methods of long term prediction of variations in groundwater resources and regimes due to human activities (Proceedings of the Exeter Symposium, July 1982). IAHS Publication No 136, 111-119.
Measured water levels in 50 hand dug wells. The wells were monitored for a long period of time and were used for sacred purposes so there was negligible water abstracted from them. They found systematic lowering of the water table. Three reasons were proposed: (1) reduced recharge in urban areas; (2) increased runoff due to land clearance; and (3) uncontrolled well sinking in rural areas. The data look quite convincing - what about rainfall changes?

Omorinbola E O 1987. Climatic Variability and Regolith Groundwater Regime in Southwestern Nigeria. In: The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources, (Proceedings of the Vancouver Symposium, August 1987). IAHS Publication No. 168, pp 525-534.
The regolith groundwater regime in the Basement Complex of southwestern Nigeria and its spontaneous response to the variability of the prevailing humid tropical climate is illustrated. Similarity in degree of variability of rainfall and the groundwater regimes are observed. A highly significant inverse correlation between the mean monthly rainfall and the mean monthly depth to the water table, with a coefficient of about -0.80 and a relationship aptly described by simple linear regression equations, is noted. The monthly variation pattern of depth to the regolith groundwater table is optimally described by polynomial regression equations. The applicability of the study results is specified in respect to predicting mean depths to the water table at given points in time, determining groundwater level fluctuation rates by differential calculus, estimating the proportion of the available rainfall used in groundwater replenishment, and the correct timing of well-sinking operations so as to increase their success ratios and ensure adequate and perennial well yields.

Onuohoa K M and Mbazi F C C 1988. Aquifer transmissivity from Electrical Sounding Data: the case of Ajali Sandstone aquifers, southeast of Enugu, Nigeria. In Ofoegbu, C. O. (Ed) Groundwater and mineral resources of Nigeria: Vieweg-Verlag, pp 17-30.
The case study is to the south of Enugu. VES were undertaken using the Schlumberger configuration. Three distinctive geoelectric layers were found overlying a resistive bedrock.

Onyeagocha A C and Agwunobi E O 1978. Geology of Ameka Owo area near Workum Hills, Benue State. Journal of Mining and Geology, vol 15, pp 115-117.
Rock units mapped around Ameka in Oju (Igede) local government area in the Benue State are Albian Shales of the Asu River Group, gabbro porphyry, basalts, trachytic andesites and diorite porphyry. All the igneous rocks have undergone extensive alteration. The composition of plagioclase crystals, alteration of pyroxenes to chlorite and haematite and the infilling of vesicles with calcite and

zeolites indicate that the igneous rocks have been albitized. The pillow like structures in the Odemu Hill trachytic andesite, which appear to have formed due to magmatic extrusion into wet sediments under marine conditions, may suggest an earlier, perhaps Albian, magmatism in this area.

Oomkens E 1974. Lithofacies relations in the Late Quaternary Niger Delta. Sedimentology, vol 21, pp 195-222.

A study of cores from thirty-three coreholes drilled in various parts of the Niger delta has shown tidal channel sand to be the dominant lithofacies type in the uppermost 30 m of the delta complex. Below 30 m fluviatile sand becomes predominant. Coastal barrier sand is present in the uppermost 5 m of the present coastal belt, but chances for preservation of this lithofacies appear to be small.

The Post-Glacial deltaic sands can be divided into three units:-

(1) Alluvial valley-fill sands and conglomerates deposited during the strong Post-Glacial seal level rise.

(2) An onlapping complex of lower coastal plain deposits which contains a lower member of fine grained lagoonal and mangrove swamp deposits and an upper member of tidal channel and coastal barrier sands. This complex is thought to have been deposited during the strong Post-Glacial rise in sea level and is locally as much as 25 m thick.

(3) An offlapping complex of fluviomarine and coastal deposits which contains a lower member of marine clay and silt and an upper member of tidal channel and coastal barrier sand. The presence of this late Holocene complex indicates that deltaic progradation was resumed as soon as the rapid rise in sea level slowed down. The offlapping complex is locally as much as 35 m thick.

Orajaka I P and Umenwaliri S 1989. Diagenetic alteration of volcaniclastic rocks from Abakaliki area, south-eastern Nigeria. Journal of Mining and Geology, vol 25, pp 97-102.

Volcaniclastic rocks form elongated and dome-like outcrops within Abakaliki township and environs. These rocks are composed mostly of agglomerates and tuffs. Reaction of tuffaceous material with percolating groundwater in open hydrologic system produced a wide variety of diagenetic minerals. Zeolitization, silicification and calcitization are the common diagenetic processes that altered the sediments. In some of the samples studied glass has been completely replaced by diagenetic minerals. The authigenic minerals identified by x-ray powder diffraction analysis are clinoptilolite, mordenite, smectite, opal, calcite and minor amounts of chabazite.

Percolating saline groundwater draining through the Abakaliki tuffaceous beds produced a distinct authigenic mineral zonation. Opal is restricted to the Juju Hill; clinoptilolite and mordenite are the abundant authigenic minerals at the Hossana Hill, calcite and zeolite minerals, clinoptilolite and mordenite are present at the Percuno Mineral Industrial Quarry; calcite is the dominant alteration mineral at a quarry west of the Ministry of Works Quarry. Smectite group minerals are ubiquitous in all the altered tuffs.

Orajaka S 1964. Geology of the Obudu Area, Ogoja Province, Eastern Nigeria. Naturaliste Canadien, vol 16, pp 73-98.

Park S K and Dickey S K 1989. Accurate estimation of the conductivity of water from geoelectrical measurements - a new way to correct for clays. Groundwater, vol 27, pp 786-792.

They discuss a method of correcting for clay content for Archie's Law. Consequently Archie's law can be applied and the porosity or pore conductivity can be estimated more accurately. Th e model involves calibrating with well data and relies on the fact that phase shift in AC current source applied to the earth is solely due to clay.

Peart, R. J. 1981. Botswana: the use and misuse of surface hydrogeophysical techniques. Report GS10/3 Department of Geological Survey, Republic of Botswana.

Report discusses the use of geophysics within Botswana in searching for groundwater. Applicable to Oju is the techniques looking for faults. Initially Landsat and aerial photographs should be used to locate potential zones. The most efficient form of traversing is resistivity and magnetics. Em methods were discussed but at the time of writing were not fully established techniques. EM also suffers from skin effect problems at high conductivity (ie it is difficult to look through highly conductive layers.

Dolerite intrusions have a generally high magnetic susceptibility and are therefore easily picked up from magnetic surveys. He reports that the indurated upper contact of dolerite sills is often a useful aquifer. Shows a diagram quoted from a paper by Enslin 1955 which shows the yield of boreholes in Karro sediments as a function of distance from vertical dyke. The yield fell away quickly within 3 m. High yields were found very close to the dykes - therefore important to calculate the dip of the dykes.

Peart R J 1996. Unconsolidated sedimentary aquifers: review no 10 - applications of surface and airborne geophysics. British Geological Survey Technical Report WC/96/10. 90 pp

Discusses the physical principles of gravity, seismic refraction and reflection, DC, IP em methods, EKS, ground penetrating radar and magnetics. The applications of the techniques are then discussed.

Peart R J, Beamish D and Davies J 1996. Electrokinetic soundings to locate zones of enhanced porosity/permeability in manmade sediment traps at the former empress nickel mine, Zimbabwe. British Geological Survey Technical Report WC/96/18C.
At one site the technique identified a highly permeable zone but placed it quite deep. This highlights the poor resolution of the technique with a high wavelength (20 m) source. At another site there was very little voltage returned - possible due to the large observation network (100 m). The report details the background of the technique and two case studies.

Petters S W 1978. Mid-Cretaceous palaeoenvironments and biostratigraphy of the Benue Trough, Nigeria. Geological Society of America Bulletin, vol 89, pp 151-154.
The epiric sea that flooded the Benue Trough attained a maximum depth of about 30 m during late Turonian time. It encroached from the south and shoaled northward with evaporites and carbonates accumulating at the distal end.
Discussion: Foraminiferal microfaunas from the middle Cretaceous rocks of the Benue Trough are strongly reminiscent of coeval assemblages from the Western Interior Cretaceous seaway of North America (Eicher and Worstell, 1970) and from Europe (Douglas and Rankin, 1969). Eicher and Worstell concluded that the lower part of the Greenhorn Formation, which is nearly devoid of benthic foraminifera, was deposited under euxinic conditions when the sea was deepening and silled. It would be erroneous, however, to infer deep and silled depositional conditions from the black shales at the top of the Awgu Shale, although these shales were deposited under anaerobic conditions. Unlike the lower planktonic zone of the Greenhorn Formation, the upper part of the Awgu Shale does not contain diverse planktonic fauna with keeled taxa. Rather, the microfauna is monospecific and comprises only small hedbergellids. Thus the microfauna of the upper Awgu Shale heralds the beginning of a regressive cycle with diminishing open marine influence and increasing shoaling caused by the onset of tectonic movements in the Benue Trough. Foul bottom conditions were generated by a large influx of organic matter.

Reyment (1969) and Reyment and Tait (1972) argued that maximum marine transgression from across the Sahara occurred in the Benue Trough during early Turonian time. Foraminiferal ages and the palaeoecology do not support this view. Age diagnostic planktonic foraminifera show that maximum transgression occurred in late Turonian time when the lower Awgu Shale was deposited, whereas the underlying lower Turonian Eze-Aku Formation and the Pindiga Formation in the northeast are shoal-water deposits.

The general direction of shoaling in the Benue Trough was north-eastward. Planktonic foraminifera show a north-eastward depletion trend so that keeled species and other typically Tethyan forms such as *Hedbergella delrioensis, H. portsdownensis*, and *Clavihedbergella* do not occur in the Pindiga Formation. Thus the planktonic foraminifera in the Benue Trough must have been derived from a southern provenance and not through a trans-Saharan seaway. What this implies is that the equatorial Atlantic was sufficiently open by late Turonian time so that oceanic circulation could supply planktonic foraminifera from the North Atlantic.

Petters S W 1978. Stratigraphic evolution of the Benue Trough and its implications for the Upper Cretaceous palaeogeography of West Africa. Journal of Geology, vol 86, pp 311-322.
The main stages of tectonic evolution of the Benue Trough are well documented in the stratigraphic succession, basically comprising three depositional sequences: An Albian-Cenomanian pyroclastic, parallic, shallow marine, and fluviatile sequence corresponding to the graben and transitional tectonic stages; A Turonian-Coniacian parallic, marine, and fluviatile sequence that resulted from down warping and a consequent widespread marine transgression; and a Companion-Maastrichtian paralic, marine and fluviatile offlao sequence which followed the Santonia compressional deformation episode that displace the depositional axis westward. Sedimentation in the trough was strongly influenced by the Late Cretaceous eustatic rise of sea level. The palaeogeography of the Benue trough in the late Albian was similar to that of the Gulg of Tajura of the Afar triple junction. Thus, the equatorial and Southern Atlantic Oceans were open at that time and an embayment projected into the Benue Trough. Palaeobiogeographic evidence and regional facies distribution in the Sahara and north-east Benue Trough do not support an open connection between the Late Cretaceous Saharan sea and the Benue Trough.

Ponzini G, Ostroman A and Molinari M 1984. Empirical relation between electrical transverse resistance and hydraulic transmissivity. Geoexploration, vol 22, pp1-15.
Direct relationship found between the two. As the transmissivity increase so does the transverse resistance. Not a linear relation. Using VES. Empirical relationship for this one example - alluvial rocks.

Popoff M, Wiedmann J and De Klasz I 1986. The Mid-Cretaceous Gongila and Pindiga Formations, Northern Nigeria: subdivisions, age, stratigraphic correlations and palaeographic implications. Eclogae Geologicae Helvetiae, vol 79, pp 343-363.

Potts I W 1990. Use of the EM-34 Instrument in groundwater exploration in the Shepparton Region. Australian Journal of Soil Research, vol 28, pp 433-42.
The EM 34 has proved very useful at locating shallow sand aquifers. The used the horizontal dipole method at 20 m spacings and could cover up to 7500 m per day. It is used as the main geophysics tool for ground water exploration.

Price D G 1995. Weathering and weathering processes. Quarterly Journal of Engineering Geology, vol 28, pp 243-252.
Definitions of weathering are examined and a definition of weathering for geotechnical purposes is proposed. Weathering is achieved by weathering processes, which depend upon the nature of the new equipment to which the geological materials are introduced. Weathering processes are reviewed with particular reference to examples from engineering practice. The weathering product, the modified geological material and mass, is a consequence of the interaction of the weathering processes and the geological materials and mass on which the weathering processes act. Modes of weathering of particular rock types are reviewed. The paper concludes with a discussion of classification policy, recommending simplification

Radstake F, Geirnaert W, Kleinendorst T W and Terhell J C 1991. Application of forward modelling to resistivity profiles. Ground Water vol 29, pp 13-17.
Discusses the use of a numerical model for Wenner and Schlumberger profiling and then applies it to Burkino Faso. The model can predict the response over presumed geology. This allows the electrode spacing etc. to be known optimised.

Rahman A 1993. Water entry, retention and movement in soils of warm humid regions. Hydrology of Warm Humid regions (Proceedings of the Yokohoma Symposium, July 1993). IAHS Publications no 216, Wallingford.
Experiments in near surface hydrological processes in Singapore. Infiltration rates were measured at sites with different geology and land use patterns using "multiple ring flooding type infiltrometers".

Rastogi R G 1989. The Equatorial Electrojet: magnetosphere and ionic effects. In: Geomagnetism J. A. Jacobs (editor), vol 3, Academic Press.

Rebelle M 1990. The marine transgression in the Benue Trough (N.E. Nigeria): a palaeogeographic interpretation of the Gongila Formation. Journal of African Earth Sciences, vol 10, pp 543-655.
Upper Cretaceous Gongila Formation in Benue Trough (NE Nigeria) is investigated. Through a detailed sedimentological study, a lithologic log is proposed with 22 different levels for a 20 m thick section. Both palaeontological and petrogrphical results are used to describe the diagenetic history of Gongila limestones. A sedimentologic interpretation is thus suggested, illustrating the close relationships between sedimentation and regional tectonics. Occurrence of a Trans-Saharan seaway is finally discussed. The palaeontological affinities between Sahara and Nigeria faunas have to be supported by sedimentological observations in order to conclude with assurance on the existence of such a seaway during the Cenomanian and Lower Turonian.

Reyment R A 1956. On the stratigraphy and palaeontology of the Cretaceous of Nigeria and the Cameroons, British West Africa. Geologiska Foreningens Forhandlingar, vol 78, pp 17-96.
The stratigraphical subdivision of the Nigerian Cretaceous, based mainly on ammonite faunas, is studied. A zonal scheme for the Cretaceous and basal Tertiary is proposed and the problem of recognition of the Danian in Africa is discussed. The phylogeny of the Cretaceous ammonoid families occurring in Nigeria is considered in the light of published and unpublished investigations by the author. The vertical distribution of a number of West African Upper Cretaceous lamellibranchs is reviewed. An attempt is made to reconstruct the main palaeogeographical changes in southern Nigeria and the southern Cameroons.

Reyment R A 1957. On the occurrence of the Santonian in North-Eastern Nigeria. Acta University of Stockholm, Stockholm Contrib. Geolo., vol 1, pp 35-39.
The presence of the ammonite *Texanites* aff. *bourcqi* COLLIGNON in the Sekule Formation of northeastern Nigeria shows part of this formation to be of Lower Santonian age.

Reyment R A 1964. Review of Nigerian Cretaceous Cenozoic stratigraphy. Journal of Mining and Geology, vol 1, pp 61-80.
The Nigerian sedimentary sequence begins with Lower Cretaceous which lies directly on Precambrian. Outcropping Lower Cretaceous occurs in Eastern Nigeria and Northern Nigeria (Benue Valley). Between the end of Lower Cretaceous and the beginning of Campanian time, these sediments were folded. The Upper Cretaceous was at first marked by a regressive period followed by an extensive Lower Turonian transgression. There was a gradual recession and deposits of undoubted Upper Turonian age have not yet been encountered. Coniacian is found in Eastern and North-eastern Nigeria, as also Santonian; undoubted lower Campanian does not seem to occur. Beds once regarded as lower Maastrichtian may be partly of Upper Campanian age. The Maastrichtian and Upper Campanian? mark a period of wide transgression which continued into the Palaeocene with a slight regression in Western Nigeria but probably now in Eastern and \north-eastern Nigeria. The Eocene is regressive; it is partly marine and partly non-marine. Definite Miocene is known from the Nigerian-Cameroon boundary region and Western Nigeria. The Upper Cretaceous is in places faulted and there are gentle warps, but not stronger folding. The Cenozoic deposits are virtually undisturbed by folding; Neogene sediments are in places faulted. The stratigraphy of the Cretaceous is based on ammonites and that of the Palaeogene on foraminifera and ostracods. The Cretaceous

stratigraphy can be tidies up with the international standards. International correlation of the Palaeocene is possible with the aid of planktonic foraminifera, while ostracods have proved useful for interafrican correlation. Thus, it is possible to correlate with the sequence in Libya, Senegal, Cameroon, Ivory Coast, Dahomey, Togo and Sudan.

Reynolds J M 1987. The role of surface geophysics in the assessment of regional groundwater potential in northern Nigeria. In Culshaw, M. B., Bell, F. G., Cripps, J. C. And O'Hara, M. (editors) Planning and Engineering Geology. Geological Society Engineering Geology Special Publication, pp185-190.

Part of the large programme undertaken in Kano State during the 1980s. Geophysics highlighted the areas that drilling could be undertaken relatively successful yin while the more problematic areas were studied. Wildcat drilling without geophysics gave success rates of 30%. With geophysics the rate rose to 68%. Project target was 1000 wells each costing £15 000.

They found cellular laterite had very high resistivity (5000 ohm-m); iron rich layer beneath it 120- 750. Beneath this is a clay with <30 ohm-m.

When using Em they found that unambiguous anomalies were rare. They looked for conductivity highs. But found problems using only one spacing.

Righi D and Meunier A 1995. Origin of clays by rock weathering and soil formation. In: Velde, B. (editor). Origin and Mineralogy of Clays: Clays and the Environment. Springer. pp 43-161.

General Conclusions: Weathering of rocks and paedogenesis are major processes for clay mineral formation at the Earth's surface. They are essentially water-rock interaction processes. In this specific surface environment, only a limited number of variables govern the amount and type of clays which form. These are *rock composition, water/rock ratio, temperature and time*. Water/rock ratio and rock composition are certainly the most important in determining the type of clay mineral which forms. Time and temperature are kinetic factors which determine the rate at which the chemical process proceeds. Basically, the water/rock ratio is determined bt the amount of rainfall. Large amounts of rainfall produce high water/rock ratios and, in a freely drained system, solutions are diluted as they are rapidly renewed. This stands only as a general statement. Indeed, the effective water/rock ratio can be strongly modified by permeability and topographic effects. In the early stages of weathering, water penetrates the rock only through small fissures, permeability is low, water flow is slow and the residence time of solution in contact with rock is long: a low effective water/rock ratio is reached, even in regions with large rainfall. With increased weathering, porosity increases, leading to higher water/rock ratios. A maximum porosity is generally reached by which the soil is a totally open system. In the soil system topographic effects are important. In addition to permeability, slope also controls the effective water/rock ratio. The displacement of the aqueous solution over the soil profile is more rapid if the slope is greater. This shortens the solution residence-time and prevents extensive water-rock interaction, thus the soil solution chemistry appears to be one of a high water/rock ratio. In flatter areas, the residence-time of solutions increases and low water/rock ratios are reached. Moreover, in lowland positions, undery dry climate, evaporation may concentrate solutions and make them similar to those which circulate in slightly weathered rock. Therefore, the importance of rock composition is greater in sites where the effective water/rock ratio is low, i.e. sites with either, low permeability, a flat topographic position or low rainfall. With reference to these variables (porosity, slope, climate) it is possible to explain schematically the occurrence of some major clay species. Although in variable quantities, *kaolinite* is found in most of the weathering and soil profiles. This mineral forms where solutions have low silica and alkaline cation activities. This can be reached in the early stages of weathering by the destabilization of an individual aluminous primary mineral, such as plagioclase in granite or garnet in amphibolite. Increasing chemical weathering (progressive leaching of silica and alkali cations) and higher water/rock ratios also favour the formation of kaolinite: this clay mineral is found in the large fissures where the water flow is high, and also in soils on steep slopes in which the residence times of solutions is low. The thick mantle of kaolinite which covers the tropical wet zones is the result of very humid climatic conditions acting over a long period of time.

Except in tropical dry zones, *smectites*, either di- or trioctahedral, are found only in the lower parts of the weathering profiles, i.e. sites where the rock composition has a greater influence on the chemistry of the whole system. For example, saonite, a trioctahedral, highly magnesian smectite, is formed by destabilization of serpentine, pyroxene and talc in ultrabasic-rock saprocks. In the soil where magnesium is leached to a great extent, saponite is replaced by nontronite, indicating the greater stability of dioctahedral smectites in sites with higher water/rock ratios. In acid rocks, *beidellite-montmorillonite* (aluminous smectites) commonly forms by destabilization of orthoclase in the slightly-weathered rock zone. In tropical dry and arid climates, low water/rock ratios and high silica and alkali cation activities are caused by low rainfall and the concentration of solutions through evaporation. Beidellite is the dominant clay mineral in soils in downslope and lowland areas.

Because most of soils developed in the temperate zone are developed from phyllosilicate-bearing rocks, they contain complex mixtures of inherited and partially transformed phyllosilicates. *Complex mixed layers and intergrade clay minerals* dominate the clay assemblage in temperate soils. Sediments like loess or glacial tills, form which many temperate soils have developed, contain large proportions of muscovite, biotite and chlorite. These phyllosilicates are unstable under the surface conditions but tend to remain in

the soil-clay fraction as metastable relicts. The result is a mixture of primary minerals with newly formed clays which have a rather similar structure and chemistry. The primary phyllosilicates are destabilized in a stepwise process, the interlayer spaces being first affected. Biotite is progressively transformed into vermiculite through abstraction of interlayered potassium. The brucite sheet of chlorite progressively dissolves and minerals with intergrade properties between vermiculite and chlorite are found as relicts of the initial chlorite. Because, in a single phyllosilicate particle, not all the layers are weathered, mixed layer minerals are formed; e.g. mica/vermiculite, ilite/smectite, chlorite/vermiculite (smectite). These minerals are difficult to identify because several stages of change are found in the same soil clay sample. However, they are dominant clays in temperate soils, which are the most concerned with agricultural and/or industrial pollution. Their chemical (exchange capacity, adsorption) and physical (swelling) properties must be established in order to assess their control on the environment.

Roy K K, Gebru B and Mahatsente R 1992. Combined resistivity and IP sounding for groundwater exploration. Indian Journal of Earth Sciences, vol 19, pp 28-40.
They used resistivity and Induced Polarization studies (IP) to study a Quaternary sand/shale sequence in West Bengal, India. Deals primarily with IP surveying and is relatively theoretical.

Ruprecht J K and Schofield N J 1993. Infiltration Characteristics of a Complex Lateritic Soil Profile. Hydrological Processes, vol 7, pp 87-97.
Large infiltration ponds (10-15 sq m) were used, in conjunction with a ring infiltrometer and a well permeameter, to determine the infiltration characteristics of complex lateritic soil profiles in the jarrah (Eucalyptus marginata) forest of Western Australia. Simultaneous measurements of soil water content and soil water potential allowed a description of the infiltration and redistribution in the soil profile. The infiltration ponds effectively measured the conductivity of a subsurface lateritic duricrust which was found to have a relatively high saturated hydraulic conductivity (Ks) of 2.7 m/d, despite its apparently massive and extensive nature. Removal of the topsoil identified large (about 1 sq m) infilled holes penetrating the duricrust over about 6% by area. Measurements indicated that these large 'holes' had a high Ks value (about 10 m/d), whereas the remaining duricrust had a lower Ks value (about 2 m/d). These results have implications for probable maximum flood design calculations and assessing the hydrological impact of extensive open-cut bauxite mining.

Salama R B, Tapley I, Ishii T and Hawkes G 1994. Identification of areas of recharge and discharge using Landsat-TM satellite imagery and aerial photography mapping techniques. Journal of Hydrology vol 162,pp 119-141.
Aerial photographs and Landsat Colour Composites were used to map to map an area. Many different features are identified including laterite duricrusts, streams, channels lakes, dykes, lineaments. Recharge occurs around granite plutons and in highly permeable areas in sand plains. AP was most useful for geomorphic classification, TM for lineaments

Sander P, Chesley M M and Minor T B 1996. Groundwater assessment using remote sensing and GIS in a rural groundwater project in Ghana: Lessons learned. Hydrogeology Journal, vol 4, pp 40-49.
A rural groundwater project within the Voltaian Sedimentary Basin in central Ghana was the focus of a study to develop better well-sitting strategies, based in interpretations of remote-sensing data and Geographic Information System (GIS) analyses. The drilling success rate of the project had been low due to low primary porosity and the restriction of groundwater to secondary structural features. Remote sensing data that were incorporated in the study include Landsat Thermatic Mapper (TM), SPOT, and infrared aerial photography. These data were interpreted for linear vegetation, drainage, and bedrock features that would indicate underlying transmissive fracture zones. Lineaments were examined in the field and integrated with information from several hundred GPS-positioned boreholes. GIS analyses focused on the identification of phenomena that contributed to successful wells, in order to develop optimal strategies for future well siting. Remote-sensing data allowed effective mapping of features that are conducive to groundwater development. Lineaments identified on Landsat TM imagery had the greatest correspondence to well success. The integration of data in a GIS was valuable for effective analyses but also exposed the necessity of accounting for spatial reference and accuracy of data from different sources. GPS technology proved very useful to increase the spatial accuracy of the various data integrated in the GIS.

Scheidegger A E and Ajakaiye D E 1985. Geodynamics of Nigerian shield areas. Journal of African Earth Sciences, vol 3, pp 461-470.
A geodynamic study was made of the shield areas of Nigeria, with particular attention being paid to the origin and development of the Benue Trough. First, the various open problems regarding its genesis put forward in the literature are reviewed. Then it is shown that the results of field studies, mainly of joint orientations, definitely favour the existence of a present-day sinistral shear in the Benue Trough (Pelusium megashear). However, the regional intraplate stress orientation is such that the Benue Trough must have originated at a much earlier time in a different stress system. In the neotectonic stress field the Benue Trough acts as a boundary condition by being a zone of weakness; this produces the observed features.

Schreiner H D and Gourley C S 1995. Description of moisture content in soil profiling. Quarterly Journal of Engineering Geology, vol 28, pp 195-198.
The description of moisture content in soils during soil profiling generally follows the scale devised by Jennings *et al.* Another guide, published as part of the Engineering Geology Group Working Party Report on Tropical Residual Soils, provides some diagnostic characteristics for determining soil moisture categories. However, neither of these systems is fully satisfactory since much is left to subjective judgement. This Technical Note describes a more comprehensive method of description which includes diagnostic characteristics such as stickiness, dustiness, resistance to moulding, strength changes and colour changes and which also clarifies the relation of the terms to the optimum moisture content. This guidance should assist in making the field description of moisture content in soils less subjective.

Sen M A and Abbot M A W 1991. Hydrogeological investigation of a fault in clay. Quarterly Journal of Engineering Geology vol 24, pp 413-426.
Examined the effect of a fault on the hydraulic properties of the Oxford Clay. The found that hydraulic conductivity of the fault zone was 1-2 orders of magnitude grater than the undisturbed clay. They found that when the clay was exposed weathering removed subtle variations in lithology down to a depth of about 5 m. Therefore it was difficult to locate faults and fractures. They measured hydraulic conductivity in the mudstones using pulse tests and in the aquifers using slug and constant rate tests. Packers were used to isolate the different units. In undisturbed clay and mudstone, $K = 10^{-8}$ - 10^{-12} m/s and Specific Storage 10^{-3} - 10^{-5} m^{-1}. They found that slug tests in fractured rock can overestimate T and underestimate S. They encountered two problems with low K research: (1) how quickly do mudrocks respond to changing stress; (2) how important are coupled processes.

Sharma M L, Barron R J W and Fernie M S 1987. Areal distribution of infiltration parameters and some soil physical properties in lateritic catchments. Journal of Hydrology vol 94, pp 109-127.
This paper examines the spatial distribution, dependence and variability of infiltration parameters (sorptivity S and saturated hydraulic conductivity K_s) measured in situ at two grid spacings of 1 x 1 m and 100 x 150 m in two adjacent lateritic catchments near Collie, Western Australia. An exponential semivariogram with trend was required to describe the spacial structure, and due to the presence of nested structures, the zone of influence could not be specified precisely.

Using a correspondence analysis based on infiltration properties, the surface soils of a 94 ha catchment were classified into seven classes. However, this classification did not correspond with the existing classification into soil units or hydrologic provinces. It is suggested that the existing soil classifications will be of limited value in assessing the infiltration capacity of soils in this region.

The lateritic soils have very high infiltration rates particularly in the forested catchment. For one soil unit, two years after a change in land use from forest to pasture, the infiltration rate was retarded significantly (K by 10 times and S by a factor of 3). Despite this, considering the rainfall characteristics of the region, it is concluded that in most conditions the infiltration capacity of surface soils will not be limiting, and there is little probability of direct surface runoff. The dominant mechanism of runoff generation in the agricultural land appears to be saturation of surface soils through subsurface flow due to enhanced recharge after forest clearing.

Sharma M L, Barron R J W, Williamson D R 1987. Soil Water Dynamics of Lateritic Catchments as Affected by Forest Clearing for Pasture. Journal of Hydrology, vol 94, pp 29-46.
Aspects of soil water dynamics as affected by land use changes were examined over a period of 5 years (1974-79) in 2 groups of adjacent catchments located in 1200 mm/yr and 800 mm/yr rainfall zones near Collie, Western Australia. In the summer of 1976/77, after 3 yr of calibration, 100% of one high rainfall catchment, Wights, and 53% of one lower rainfall catchment, Lemon, was cleared of native eucalyptus forest and replaced with pasture. The soil water storage down to 6 m was measured in-situ using a neutron probe in 15 access tubes located at 5 stratified sites in each catchment. Considerable spatial variability in soil water storage was encountered within a site, between sites within a catchment, and between paired catchments; the dominant variability being between sites. Comparisons between the pre-and postclearing states within a catchment and between the cleared and uncleared control catchments were used to evaluate the effect of change in land use on soil water dynamics. Within 2 yrs of the change from forest to pasture, a significant increase in soil water storage had occurred in the profiles in both cleared catchments. Concurrently, there was a small decrease in the uncleared control catchments. The increases following clearing were greater in the higher than in the lower rainfall catchment, more pronounced in the first year than in the second year, and occurred mostly at depths greater than 2 m. In Wights catchment, the increase in summer minimum soil water storage in the first and second years amounted to 220 and 58 mm respectively, while for Lemon catchment the increase for the first year was < 50 mm. This increased soil water storage was due to a substantially lower evapotranspiration from the shallow-rooted, seasonally active pasture which extracts water from the top 1 m or so, compared with the perennial native eucalyptus forest which extracts water from depths

down to 6 m and beyond. Due to the relatively low water holding capacity of the surface lateritic soils, the drainage beyond 1 m is substantially increased under pasture, and this results in an increased recharge to the underlying aquifer.

Singer A 1980. The palaeoclimatic interpretation of clay minerals in soils and weathering profiles. Earth-Science Reviews, vol 15, pp 303-326.

The interpretation of palaeoclays for palaeoclimatic purposes is based on five major assumptions: (1) clay mineral formation is directly related to climatic parameters; (2) once formed in the weathering milieu, clay minerals are stable and do not change any more as long as the climate remains stable (pre-burial stability); (3) clay mineral assemblages are uniform throughout the weathering profile; (4) once formed or deposited and buried, clay minerals are stable (post-burial stability); (5) the sensitivity of clay minerals towards environmental factors is uniform. All these assumptions have only limited validity. Clay mineral formation is in a few cases directly related to climatic parameters, nor do clay minerals always represent the stable end products in equilibrium with environmental factors. The vertical distribution pattern of authigenically formed clay minerals is seldom monomineralic. Post depositional changes are not infrequent. The sensitivity of clay minerals to environmental factors is variable. The use of palaeoclays occurring in palaeosols and weathering profiles is reviewed. Plaeoclays occurring in palaeosols or weathering profiles are, in well-defined situations, suitable for palaoclimatic interpretation. At our present state of knowledge, references as to the nature of climates of the past that are based solely on interpretation of palaeoclays are warranted only in exceptional cases. Authigenic occurrences of clay minerals with limited stability fields that can be used as "marker minerals" and the isotopic composition of palaeoclay minerals promise, with further research, to increase the value of palaeoclays as palaeoclimatic indicators.

Singer A 1984. The palaeoclimatic interpretation of clay minerals in sediments - a review. Earth-Science Reviews, vol 21, pp 251-293.

The application of palaeoclimatic interpretation to clay minerals from continental and marine sediments is reviewed and the advantages of this method are indicated. Levels relatively rich in chlorite, illite, palygorskite and quartz are interpreted as corresponding to relatively dry periods, while more humid periods lead to more intensive weathering and consequently to the dominance of clay minerals more advanced in their relative stability scale, such as kaolinite. Smectite is taken to indicate a climate with contrasting seasons and a pronounced dry season.

Using this and similar scenes, the palaeoclimates of areas adjoining the Mediterranean Basin, North Sea, North Atlantic, Southern Arctic, Equatorial and North-west Pacific, and North Philippine Sea are reconstructed.

Clay minerals in sediments, particularly marine sediments, can be useful indicators of palaeoclimatic conditions. While they do not produce direct indications of climatic parameters, they provide integrated records of overall climatic impact. Occasionally, they may be superior to more conventional palaeoclimatic methods, such as pollen or oxygen-isotope analysis.

The limitations imposed on the palaeoclimatic interpretation of clay minerals in sediments are discussed on the basis of examples. The distinction between authigenic and detrital clay minerals is shown to be problematic, particularly with regard to smectite. The relationship between climatic parameters and clay-mineral formation is complicated by the intervention of extra-climatic factors such as topography, geomorphology, lithology and time. Post-depositional diagenetic changes may not be recognised. Differentiation during transport, due to size sorting or differential flocculation may over-lap climate-induced differentiation. The association of clay-mineral assemblages with specific source areas presents difficulties due to dispersal pathways that are affected by type of transport agency, i.e. water, ice or wind. Transport agencies are not constant with time. By an interdisciplinary approach, with the palaeoclimatic information derived from clay minerals being correlated with that obtained from the analysis of microfossils and oxygen isotope data, many of these limitations can be overcome.

Sowa A H O and Ibe Sr K M 1992. The interaction of human activities and geological processes: a geo-environmental study of South-eastern Nigeria (Owerri urban area). Journal of African Earth Sciences, vol 14, pp 539-544.

The aim of this study is to analyse the mechanisms of interaction between the factors human activity, water, vegetation and related geological processes, like gully erosion or filling up of river beds. A surface water and land pollution survey of Owerri urban area, Nigeria, has been carried out in order to establish the current levels of pollution. An attempt has been made to show the relationships between population density, industrial and agricultural activities, environmental contamination, and soil erodibility. The spatial distribution of pollutants due to poor land use system and human activities were investigated, thus emphasising the need for integrated planning development as a preventive measure for reducing environmental impacts in fast-growing urban centres of developing countries.

Sreedhar Murthy Y 1985. First results on the direct detection of groundwater by seismoelectric effect - A field experiment. 4th ASEG conference.

The seismoelectric effect is defined as the development of a potential difference between two adjacent points in a liquid bearing solid when an elastic wave passes through them. This is a short paper sketching out some preliminary results.

Tahal Consultants (Nigeria) Ltd 1982. Benue Water Supply Project. Project Oriented Master Plan for Water Supply, Water Resources Development and Related Hydrological Studies.

Tanjime H 1993. Geology and intercepts of multiple regression models as an index of baseflow. Hydrology of Warm Humid regions (Proceedings of the Yokohoma Symposium, July 1993). IAHS Publications No 216, Wallingford.
Baseflow was calculated by regressing runoff against rainfall. The intercept can provide the baseflow. A good correlation was found between baseflow and geology type for five different geologies. Lowest baseflow was measured for Paleozoic rocks and highest for Quaternary volcanics.

Tanyileke G Z, Kusakabe M and Evans W C 1996. Chemical and isotopic characteristics of fluids along the Cameroon Volcanic Line, Cameroon. Journal of African Earth Sciences, vol 22, pp 433-441.
Results of the chemical and isotopic analysis of the water and gases discharged from volcanic crater lakes and soda springs located along the Cameroon Volcanic Line were used to characterise and infer their genetic relationships. Variations in the solute compositions of the waters indicate the dominant influence of silicate hydrolysis. Na^+ (40-95%) constitutes the major cation in the springs while Fe^{2+} + Mg^{2+} (70%) dominate in the CO_2 -rich lakes. The principal anion is HCO_3. (90%), excep thin the coastal springs where Cl. predominates. Lakes Nyos and Monoun have Fe-Mg-Ca-HCO_3. type signatures; the soda springs are essentially Na-HCO_3. type, while all other lakes show similar ionic compositions to dilute surface waters. Dissolved gases show essentially CO_2 (>90%), with small amounts of Ar and N_2 while CH_4 constitutes the principal component of the non-gassy lakes. Active volcanic gases are generally absent, except in the Lobe Spring with detectable H_2S. Stable isotope ratio evidence indicates that the bicarbonate waters are essentially of meteoric origin. CO_2 ($\delta^{13}C$=-2 to -8‰) and He ($^3He/^4He$ = 1 to 5.6 R_a) infer a mantle contribution to the total CO_2. CH_4 has a biogenic source, while Ar and N2 are essentially atmospheric in origin, but mixing is quite common.

Taylor R K 1988. Coal Measures mudrocks: composition, classification and weathering processes. Quarterly Journal of Engineering Geology, vol 21, pp 85-99.
British Coal Measures mudrocks are dominantly non-marine, mature sediments with a high average clay minerals content of over 75%. A geological classification based on quartz content does not differentiate the dominant durable mudrocks from the non-durable types and overconsolidated clays in the formation. A uniaxial compressive strength greater than 3.6 MN/m2 with a three cycle slake durability value of over 60% is suggested as an appropriate division between durable and non-durable mudrocks of this age. Physical breakdown, which acts as a control on chemical weathering triggered by pyrite oxidation, is considered to be governed by incidence of sedimentary structures, slaking and expandable mixed layer content.

Shear strength reduction during post-glacial weathering can be significant. A tentative fully weathered effective stress peak strength for the weakest mudrocks and clays is deduced to be Φ'=22° (c'=0). Colliery tip investigations indicate that chemical weathering effects on shear strength of mudrocks is small. A diagenetic rank factor applies both to peak shear strength and slake durability of mudrocks excavated from UK coal mines.

Teeuw R M 1995. Groundwater exploration using remote sensing and a low-cost geographical information system. Hydrogeology Journal, vol 3, pp 21-30.
Now that personal computers (pc's) have become more powerful, portable, and affordable, geoscientists can make full use of developments in computer aided mapping, particularly Geographical Information Systems (GIS). The *IDRISI* GIS was used to: (1) carry out image processing on satellite images; (2) assess the reliability of the interpreted lineaments; (3) create maps showing individual lineament lengths; and (4) incorporate socio-economic factors, by creating maps that show the proximity of villages to sites considered favourable for boreholes. The exact location of each site for drilling was decided on the basis of geophysical surveys over the areas that had been targeted by the remote sensing and GIS analysis. Most of the remote sensing and GIS work was carried out in Ghana in two weeks, during which the 'ground truth' of lineament maps was checked. The total cost of the hardware and software used in this project (16 colour laptop PC, portable colour printer, and *IDRISI* was slightly less than US$2,600. The relatively low cost and ease of use of this system make it a technology that is readily transferable to developing countries.

Telford W M, Geldart L P and Sheriff R E 1990. Applied Geophysics, Second Edition. Cambridge University Press, Cambridge.
Detailed book on applied geophysics methods. Quite mathematical and theoretical. Chapters on em, res and mag.

Tijani M N 1994. Hydrogeochemical assessment of groundwater in Moro area, Kwara State, Nigeria. Environmental Geology, vol 24, pp 194-202.
Detailed study of chemical analysis results of several groundwater samples (UNICEF-Assisted Water project, Kwara state, Nigeria) were carried out in an attempt to assess the quality and usability of groundwaters in the Moro area. Chemical analysis results indicate higher concentrations of Ca^{2+}, Mg^{2+}, and HCO_3- as compared to Na^+, K^+, Cl-, and SO_4^{2-}. With exception of few locations where Fe is relatively higher, the concentrations of these ions together with other

water quality parameters are all within permissible limits of the domestic and agricultural standards.

On the basis of the analytical results, groundwaters in the study area are largely characterised as Ca-(Mg)-HCO_3 type reflecting (possibly) young facies with limited migratory history. The occurrence of Ca-(Mg)-Na-HCO_3 water type in certain areas is attributed to cation exchange processes. In addition, the observed scattered relationship between the TDS and the thickness of weathered horizons in the boreholes indicates the contribution of precipitation (recharge) to the ionic inputs in the groundwaters in addition to the weathering and dissolution processes.

Tijani M N, Loehnert E P and Uma K O 1996. Origin of saline groundwaters in the Ogoja area, Lower Benue Trough, Nigeria. Journal of African Earth Sciences, vol 23, pp. 237-252.
Although there is no proof of the existence of salt-beds in the Benue Trough, outcrops of saline groundwaters are common features associated with the anticlinal structures in this trough. The outcrops in the Ogoja area, referred to here as "the Ogoja Brine Field", situated at the eastern margin of the Lower Benue Trough, are presented as a case study. The saline groundwaters in this brine field, which occur as ponds and in dug-wells, support an age old local salt production in this area.

The saline waters are characterised as Na-Cl type with Na^+ constituting 78-85% of the cations and Cl^- accounting for at least 85% of the anions. Ogoja brines display specific straight-line relationships between chloride and alkaline-earth metals, especially with lithium. Barium and strontium appear to be enriched, the former due to an environment free of sulphate. On the other hand, the observed depletion of the underground saline waters with respect to tritium (< 1.5 TU) and stable isotopes of oxygen and hydrogen (<-3.5‰ ^{18} and <-10.5‰ δ^2H) suggests little or no surface input (or near surface mixing) relative to those of the surface saline ponds (-0.15 to -3.3‰ ^{18} and -6 to -10.4‰ δ^2H).

The combination of hydrochemical and isotope data, coupled with the analyses of the stratigraphic setting of the area suggests that the brines are marine in origin, related to palaeo/fossil sea water embedded within the transgressive marine sediments, and/or disseminated (precipitated) salts formed within the regressive interbeds during the sedimentation cycle.

Tovey N K and Hounslow M W 1995, Quantitative micro-porosity and orientation analysis in soils and sediments. The Journal of the Geological Society, vol 152, pp 119-130.
A technique to quantify the fabric of soils and sediments involving image processing and analysis is described in this paper. Such techniques are becoming popular in the Earth Sciences, but unlike most other studies which investigate porosity of coarse grained sediments, this method examines the fine porosity between clay sized particles to be investigated. The usual problems associated with thresholding a grey-level image to provide the necessary binary image for analysis are partly overcome by the use of Wiener filtering methods to remove much of the degradation inherent in all imaging systems. A new algorithm based on the relative contrast histogram method is then used to determine the optimum value at which to set the threshold. The micro-porosity determined is in good agreement with gravimetric porosity measurements. Unlike normal methods, once the procedure has been initiated, no further action is required from the operator and the method can thus be used for batch processing of large numbers of images thereby enhancing the statistical reliability of the results.

Extensions of the technique allow for the variation in micro-porosity from one region of a specimen to another to be studied. Further, by segmenting the original image into domains of sub-parallel particles, it is possible to examine the intra-domain porosity. Contrary to expectations, the porosity in horizontal domains is greater than in the vertical domains.

Tricart J 1965. The Landforms of the Humid Tropics, Forests and Savannas. Longman. (Translated by C. J. K. de Jonge, 1972).

Trolard F, Bourrie G, Jeanroy E, Herbillon A J and Martin H 1995. Trace metals in natural iron oxides from laterites: A study using selective kinetic extraction. Geochimica et Cosmochimica Acta, vol 59, pp 1285-1297.
To determine the extent of metal association in natural iron oxides, a combination of XRD and chemical selective dissolution techniques was applied to four samples from laterites developed on peridotites in East Africa. The reagents used were dithionite-citrate-bicarbonate (DCB), citrate-bicarbonate (CB), hydroxylamine hydrochloride (HH), and oxalic acid-oxalate (Tamm). From the results obtained, it appears that: (1) the difference DCB minus CB is a better estimator of the metal fraction in Fe oxides than the difference DCB minus oxalic acid-oxalate, especially in the presence of gibbsite; (2) the use of HH allows to be distinguished the specific contribution of Mn oxide; and (3) geochemical models for goethite must provide for the existence of ternary solid solutions (Fe, Al, Cr).

With regard to the geochemical properties of the elements, it can be concluded that: (1) Cr substitutes for Fe in the same proportions in goethite, haematite, maghaemite; (2) in contrast, Al substitutes largely for Fe in goethite, little in haematite, and not at all in maghaemite; (3) Mn substitutes partly for Fe, but forms discrete phases when total Mn content is high; (4) Ti substitutes for Fe in haematite, but not in goethite; (5) the major Cu-bearing phase is a spinel; and (6) Ni is closely associated with goethite and not with Mn.

Tsujimura M, Tanaka T and Kayane I 1993. Behaviour of subsurface water and solute transport in a steep forested mountainous basin, Japan. Hydrology of Warm Humid regions (Proceedings of the Yokohoma Symposium, July 1993). IAHS Publications No 216, Wallingford.

Seasonal change in soil moisture content was low. The physical and chemical properties of the soil especially at a depth of 0.7 - 1 m have a significant affect on oil water movement and solute transport.

Uko E D, Ekine A S, Ebeniro J O and Ofoegbu C O 1992. Weathering structure of the east-central Niger Delta, Nigeria. Geophysics, vol 57, pp 1228-1233.

Refraction experiments were conducted over parts of the east-central Niger Delta in an attempt to provide an interpretation of the region's weathering structure. The velocity and depth of the weathered layer and the velocity of the refractor were calculated from critically refracted arrivals using flat-layer models. An interpretation of the data, carried out using the time intercept method, shows that the thickness of the low velocity weathered layer in the region is highly variable, from between about 2.9 m and 45.5 m, with a regional average of about 20.0 m. The weathered layer and the refractor beneath it have an average compressional-wave velocity of about 500.0 ms^{-1} and 1732.0 ms^{-1} respectively. The knowledge of this weathering structure can be applied in oil and groundwater exploration in the area of study. It is also expected that this structure could be used by groups interested in civil engineering.

Uma K O and Kehinde M O 1992. Quantitative assessment of the groundwater potential of small basins in parts of south-eastern Nigeria. Hydrological Sciences Journal, vol 37, pp 359-374.

The baseflow characteristics of some of the numerous small basins of south-eastern Nigeria have been analysed to estimate the developable groundwater in the basins. It is shown that from 5.62 x 10^4 to 1.59 x 10^6 m^3 of groundwater can be developed per square kilometre of basin per annum. The relationship between the baseflow characteristics and other attributes of the basins, such as geology and stream density, were studied statistically, leading to the development of empirical equations for predicting the hydrological features of the several ungauged streams in the region. It is shown, for example, that the basin geology (represented as the percentage of sands), the drainage density, the basin area, the baseflow depletion rate and the total groundwater stored in the basin, Q, are related by the equation:

$Q = -1.85 \times 10^9 - 7.96 \times 10^8 dd + 4.18 \times 10^7 gf - 2.01 \times 10^6 df + 6.25 \times 10^5 wa$

They mention that there is a real dearth of hydrogeological data since tests are too expensive; also a complete lack of observation and monitoring boreholes. Also that the stream density is low on the sandy horizons but high in the clay-shale terrains.

Uma K O and Onuoha K M 1988. Groundwater fluxes and gully development in S E Nigeria. In: Ofoegbu, C. O., editor. Groundwater and mineral resources of Nigeria, Vieweg, pp 39 - 59.

Study area is Enugu and Owerri. Three types of gullies identified: accelerated erosion, bank erosion and mass wasting. They discuss the third type which are the deepest (>20 m) and offer the greatest threat to life. They identify the main problem as high water-table within the slope sides which lead to landslip.

Uma K O and Onuoha K M 1990. Groundwater resources of the Lower Benue Trough, Southern Nigeria. In: Ofoegbu, C. O., editor. The Benue Trough Structure and Evolution. Earth evolution series, Vieweg. pp 77-91.

Two hydrogeologic groups have been identified in the lower Benue Trough of Nigeria. The first group occurs to the east of the north-south trending Okaba-Enugu-Okigwi escarpment, while the second underlies the hummocky terrains to the west of this escarpment. The first hydrogeologic group comprises thin, shallow and continuous regional aquifers, with localised deep, confined aquifers. The second group to the west has mainly an unconfined aquifer that is deep, thick (not less than 50 m) and highly prolific.

Except where the localised confined aquifer of the first group occurs, it may be economically unwise to exploit the thin aquifers of this group by means of motorised pumps. Small discontinuous abstractions such as is obtained from hand-pumped boreholes or sanitary dug wells should be emphasised for the shallow aquifers.

Splits the area into two hydrogeological provinces, one to the east of the Enugu ridge and one to the west. Describes the units and also gives some data. The Cretaceous rocks are overlain by 2-20 m of weathered material. In the shaly hydrogeology area there is a thin shallow unconfined aquifer; the top weathered horizon is in continuity with the fractured shales and sandstones. In general the depth to water level is less than 20 m (data from Oju ranged from 3.6 - 9.2 m). Saturated thickness varied from 1.3 - 20 m. Motorised pumps generally dry up after a few hours. The Asu river group has the highest yields. In Asu river well recovery took 5 hours while in the others it took 9-13 hours.

Saline groundwater is found in the area associated with NE-SW lineaments in the Benue Trough (See Uma K O et al, Hydrochemical facies and origin of saline waters in the western flank of the Cross River Basin , Nigeria - same volume). Salinities of 5-30 g/l were recorded.

Uma K O, Onuoha K M and Egboka B C E 1990. Hydrochemical facies, groundwater flow pattern and origin of saline waters in parts of the western flank of the Cross River Basin, Nigeria. In: Ofoegbu, C. O., editor.

The Benue Trough Structure and Evolution. Earth evolution series, Vieweg. pp 115-134.
The western flank of the Cross River Basin between Abakaliki and Afikpo is underlain mainly by argillaceous sediments of Middle Cretaceous age. There is a preponderance of thick shale units with minor siltstone and calcareous sandstone beds. Water supply is a problem in the area as a result of drying up of many streams during the dry season and the presence of saline groundwater in parts of the limited aquiferous horizons. Analysis of field data have shown that the occurrences of saline water in the area are not randomly distributed, but are strongly influenced by the orientation of dominant tectonic fractures. The near surface argillaceous materials are not generally salt rich as often believed. They are only saline in the vicinity of fractures and this salinity is due to the lateral migration of contaminants from saline water upwelling in those fractures aided, perhaps, by the effects of evapotranspiration at the surface.

Soluble ions from the saline waters in the fractures are not solely responsible for the high percentage of dissolved solids in the groundwaters of the area. A detailed analysis of the contaminant hydrogeology of the area shows that concentrations of total dissolved solids (TDS) less than 400 mg^{-1} are caused by solution of carbonates in the matrix of the rock materials, while higher TDS concentrations are due to contamination with saline groundwater from the fractures. Areas underlain by contaminated groundwater appear restricted to within 100 m of the saline linear fractures. These is evidence to suggest that diastrophic forces are largely responsible for the development and structure of the salt horizons at depth.

This area is to the southwest of the Oju LGA.

Umeji A C and Caen-Vachette M 1983. Rb-Sr isochron from Gboko and Ikuyen rhyolites and its implication for the age and evolution of the Benue Trough, Nigeria. Geological Magazine, vol 20, pp 529-533.

Umeji A C and Caen-Vachette M 1991. Geochronology of a rhyolite dyke from Nassarawa-Egon in central Nigeria. Geologische Rundschau, vol 80, pp 171-177.

Umeji O P 1985. Subtidal shelf sedimentation: an example from the Turonian Eze-Aku formation on Nkalagu, south-eastern Nigeria. Nigerian Journal of Mining and Geology, vol 22, pp 119-124.

The Eze Aku Formation in the Nkalagu area consists of cross-bedded quartz-cemented sandstones at the base, bioturbated calcite-cemented siltstones with sandy variations and laminated black shale with bands of bioclastic limestone at the top. The sandstone is cross-bedded and contains vertically oriented cylindrical burrows and laminated grey shale partings. The siltstone is cross-laminated and intensively burrowed so that most of the lamination has been obliterated. It also contains lenses of oolitic and coquinoid grainstones. Large concentrations of ammonites and turritellid gastropods occur in some horizons. The black shale is fissile and micaceous. It is also calcareous and concretionary and becomes grey towards the top. The limestones are bioclastic and are interbedded with black shale. They are also found as lenses in the sandstones and siltstones and range in texture from grainstone to mudstone. The contain concentrations of fragmented ammonites and pelecypods.

The sandstones resulted from sudden sand transport into a quiet water marine environment below wave-base with subsequent reworking by longshore currents. The siltstones are assumed to have been deposited by slow and continuous settling of fine materials over a long period while its sandy variations indicate storm deposits in a subtidal environment. The black shale was deposited further offshore than the siltstone in a quiet euxinic basin, and the interbedded limestone the storm generated mass flow deposits transported from nearshore into an euxinic shelf. The depth range of the shelf, estimated at 15 th 150 metres, is inner shelf to inner slope.

Umo A J and Ajakaiye D E 1993. Statistics of geophysical activity in Nigeria (1975-1984). Journal of African Earth Sciences, vol 17, pp 571-576.
A summary of geophysical activity in Nigeria. Very much focussing on the oil industry and taking samples from other sectors, e.g. Kano state water board.

UNDP/WB 1993. Rural Water Supply and Sanitation Demonstration Project (RUSAFIYA), Terminal Report, UNDP/WB Water Supply and Sanitation Programme.

UNDTCD 1988. Groundwater in North and West Africa. Natural Resources/ Water Series, vol 18. ST/TCD/5. Nigeria, pp 300-309.

UNICEF 1995. Water and environmental Sanitation programme - the way forward: pp 1997-2001 plan of operations. Unpublished report.
Describes the background of UNICEF's work in Nigeria and also their new initiative. Their objectives are to strengthen Federal Government, eradicate guinea worm, improve functionality of sources - 10 000 sources in the next 5 years.

Uzuakpunwa A B 1974. The Abakaliki pyroclastics - Eastern Nigeria: new age and tectonic implications. Geological Magazine, vol 111, pp 65-70.
Basic to intermediate pyroclastic rocks of pre-Albian age are overlain by the Abakaliki shale of Asu River Group in

Eastern Nigeria. The shale has been assigned Albian age on the basis of abundant (Middle Albian?) ammonites found in it. It was folded (together with the pyroclastics) about a NE-SW trending anticlinal axis during the Santonian time. This new evidence of an early Cretaceous volcanism supports a pre-Albian rifting of the African shield prior to the opening of the Southern Atlantic. The latter event took place (probably in stages) during Albian time (i.e. less than 110 Ma ago), with a widespread marine transgression in West Africa and South America.

Van Houten F B Iron oxides in red beds. Geological Society of America Bulletin, vol 79, pp 399-416.
This study focuses on: (1) grains of black oxides, (2) pigment in matrix and cement, and (3) natural remnant magnetization in red beds. Black oxides in 13 samples of soils, 26 samples of alluvium in transit and Recent nonmarine deposits, 103 red and drab units in red bed sequences ranging in age from Precambrian to Pleistocene, and I 9 ancient nonmarine drab sequences, were identified by X-ray analysis, supplemented by polished-surface microscopy. The data and pertinent published information support the following conclusions:

(1) Magnetite and ilmenite and their various intergrowths predominate in igneous and metamorphic source rocks, and they are delivered relatively unaltered to nonmarine and paralic environments. In oxidizing areas, inherited grains of oxide begin to alter to black haematite and leucoxene. Oxidation continues long after burial, so that successively older red beds contain relatively more haematite. In reducing environments, inherited oxide grains begin to dissolve. Loss of more easily destroyed magnetite increases the relative amounts of ilmenite and black haematite. The latter apparently developed en route or in a preceding oxidizing episode.

(2) Muddy alluvium commonly contains brown amorphous and hydrated ferric oxide pigment which begins to age and also dehydrated to red haematite in oxidising environments. Sandy alluvium with little matrix, after having accumulated in desert basins, acquires haematite pigment largely by post depositional in situ alteration of iron-bearing silicates.

(3) Most detrital red beds possess chemical remnant magnetization (CRM) which was imposed on some of the black grains of haematite after their post depositional oxidation. Any detrital remnant magnetization (DRM) initially lodged in inherited black oxide grains is destroyed by small scale organic and inorganic disturbance, as well as by the intrastratal haematization. Red pigment in matrix and cement may also acquire CRM as the developing haematite grows through critical crystal sizes; in haematite-cemented quartz arenites this is the principal component of natural remnant magnetization (NRM).

Van Kuijk K J M J, Haak A M and Ritsema I L 1987. Reduction of equivalence in layer-model interpretation by combination of electrical resistivity soundings and electromagnetic conductivity measurements; some case histories in groundwater survey. Journal of African Earth Sciences, vol 6, pp 379-384.
An interactive programme for microcomputers has been developed and has been used for rapid interpretation of electrical resistivity soundings (conventional Schlumberger configuration) and frequency domain electromagnetic conductivity measurements at low induction numbers (vertical and horizontal loop configuration; Geonics EM 34-3).

Layer model interpretation can be improved by simultaneously calculating the electrical resistivity sounding response and the electromagnetic conductivity response. Whenever discrepancies occur between the measured electromagnetic data and the calculated data the resistivity layer-model interpretation has to be matched, until a model has been found that fits both the electrical and the electromagnetic measurements. In this way, equivalence in interpretation of electrical soundings can be reduced.

Calculation of 'imaginary EM 34-3 soundings curves' makes it possible for the surveyor to predetermine the optimal configuration of the electromagnetic system of measuring variations in thickness or conductivity of a target layer. An example is given.

Two recent case histories are discussed in which equivalence was eliminated: one concerning the delineation of a pollution plume (The Netherlands), the second concerning the determination of depth to basement (Sudan). For groundwater surveys in basement areas of Africa the combined application of electrical resistivity soundings and an electromagnetic system operating at low induction numbers can be useful; the survey target in general is shallow and the electrical resistivities of the crystalline bedrock are high.

Velde B 1992. Introduction to clay minerals, Chapman and Hall, London.
Useful introduction to clays. See literature review for more details.

Venkatswara R B and Briz-Kishore B H 1991. A methodology for locating potential aquifers in a typical semi-arid region in Indi using resistivity and hydrogeologic parameters. Geoexploration, vol 27, pp 55-64.
Develop a groundwater potential index using physical and geophysical parameters. Schlumberger arrays were used and interpreted. Six parameters: res aquifer (3) depth to basement (5) res of top layer (1) topography (2) recharge (2) soil (1).

Ventriss H B, Collett D B and Boyd D W 1982. Relationship between groundwater occurrence and a dolerite dyke in the Northampton area of Western Australia. AWRC Conference, Groundwater in Fractured Rock, pp 217-227.
Observations showed that water bearing zone was found from 30 to 60 m east of a dolerite dyke and from 20 to 40 m below ground surface. The country rock was granulite. Two explanations possible: (1) fractures caused by heating and cooling of the host rock due to the dyke (2) fractures there previously due to the tension - the deeper fractures were intruded with dolerite.

Wellside Limited 1991. Water supply in Benue State. A report prepared for the British Water Sector Aid Mission.

West G and Dumbleton M J 1967. The mineralogy of tropical weathering illustrated by some west Malaysian soils. Quarterly Journal of Engineering Geology, vol 3, pp 25-40.
The mineralogy of the processes leading to the formation of soils by the tropical weathering and leaching of rocks is reviewed, and illustrated by the results of an investigation into the formation, mineralogy and plasticity properties of some soils formed on basalt, granite, shale and sandstone in west Malaysia.

It is shown that hydrolysis followed by differential solution can account for the formation of the samples studied. Kaolinite was always present and generally the dominant clay mineral, although it gave place to gibbsite under severe weathering, and illite was also present in some of the less weathered soils on granite and shale. Quartz was prominent in soils on granite and sedimentary rocks, which are rich in this mineral. Iron oxide generally occurred, usually as goethite in the soils but as haematite in the nodules which were generally present in the soils selected for study, although gibbsite (hydrated aluminium oxide) was the main constituent of the nodules in one case. The observed mineralogical composition and clay content of the soils is consistent with the range of plasticity properties observed. The activity of some soils was reduced by the presence of gibbsite or goethite in the clay-sized fraction.

Wilkinson W B 1968. Constant head in situ permeability tests in clay strata. Geotechnique, vol 18, pp 172-194.
Discusses the problems of piezometers: smearing, headloss, trapped air and leakage. Describes quite a complicated system using paraffin for constant head tests.

Williams R E and Farvolden R N 1967. The influence of joints on the movement of groundwater through glacial till. Journal of Hydrology, vol 5, pp 163-170.

Williamson D 1996. WaterAid Nigeria, Oju Water and Sanitation project: Engineering consultants report. Internal report WaterAid Nigeria.
Discusses the visit of the WaterAid Engineering consultant to Oju. Suggests that old reticulated schemes should be revised and suggest a design for hand dug wells.

Wilson D C 1954. Fluoride content of some Nigerian waters. Nature, No 4398, pp 305.

Wilson D C 1954. Goitre in Ceylon and Nigeria, British Journal of Nutrition, vol 8, pp 90-99.
1. This paper describes the incidence of endemic goitre in the island of Ceylon and in the territory of Nigeria and relates the incidence to diet, to quality of drinking water, and to geological formation. 2. In the wet areas of Ceylon, where the incidence of enlarged thyroids in school girls is high, the iodine content of drinking waters is low (1.4-2.7 µg/l.) and the usual diet poor. In Nigeria, the distribution of goitre is associated with water supplies of very low iodine content (0.6-0.7 µg/l.) from pre-Cambrian granites. 3. In both areas a lack of iodine in food and water appeared to be of primary aetiological importance.

Wozny E and Kogbe C A 1983. Further evidence of marine Cenomanian, Lower Turonian and Maastrichtian in the Upper Benue Basin of Nigeria (West Africa). Cretaceous Research, vol 4, pp. 95-99.
Field investigations in the Upper Benue rift basin of Nigeria highlight the necessity for a review of the Cenomanian-Turonian biostratigraphy of the area. Three ammonite zones of *Vascoceras bulbosum* (Reyment), *Paravascoceras costatum* (Reyment) and *Pseudotissotia (Bauchioceras) nigeriensis* (Woods) have been recognised at sections exposed at the quarry of the cement factory near the village of Ashaka. The sediments within the *Vascoceras bulbosum* zone also contain specimens of *Exogyra olisiponensis* (Sharpe), *Kanabiceras septemseriatum* (Cragin) and *Epengonoceras dumbli* (Cragin). These are all indicative of an uppermost Cenomanian age and reveal that at least the lower portion of the Gongila Formation as exposed at Ashaka is faunistically equivalent to the Pindiga Formation as exposed in the type section at Pindiga.

The shales in the Gombe region in which *Libycoceras ismaeli* (Zittel) was found are probably part of the Maastrichtian Fika shales outcropping extensively in the northern part of the area. The discovery of *Cyclolithes* nov. sp. within Gombe sandstones at Dakiti near Kumo confirm that they are at least partially marine in origin and Maastrichtian in age. This could be considered as an additional evidence in favour of the presence of marine waters in the Upper Benue during the last part of the Cretaceous.

Wright E P and Burgess W G (Editors) 1992. The hydrogeology of crystalline basement Africa. Geological Society Special Publication Number 66.
A collection of 12 papers pertaining to the hydrogeology of weathered crystalline rocks throughout Africa. Some general papers also some on hydrology, geology, hydrogeology and geophysics. Also a collection of case studies taken from Nigeria, Malawi, Zimbabwe, Burkino Faso.

Wright J B 1968. South Atlantic continental drift and the Benue Trough. Tectonophysics, vol 6, pp 301-310.
Opening of the South Atlantic was probably initiated by separation of Africa and South America along a fracture which opened from the south during the Late Jurassic and Lower Cretaceous, and reached Nigeria by Mid-Cretaceous times. There is evidence that the two continents at first remained joined along the present east-west coastal segment of Africa, however, so that the African continental plate was subjected to slight but increasingly significant distortion.

The Benue Trough, now situated on the bend between the east-west and north-south trending coastlines, originated as a northeast-southwest tensional graben system. It is filled with several thousand feet of Middle Albian to Sentonian sediments, which were folded in the Maastrichtian mainly about axes parallel to the trough. The trough and its sediment filling are believed to owe their origin to partial relief of the distorting stresses, which accumulated as the southern portions of the continents were wedged apart. When Africa and South America finally separated, the southern half of Africa tended to swing back, so that the hitherto stretched Benue Trough region was transformed into a minor compressional belt, folding the sediments within it. This interpretation requires that final separation of the two continents occurred in the Late Senonian, about 80 million years ago.

Other fracture and flexible systems in Africa can be plausibly linked with the foregoing sequence of events, including the Cameroon rift valley, the middle Niger lineament, and the Chad and Congo Basins, as well as the elongate domical uplift related to the extensive Cenozoic rifting and alkaline vulcanism of eastern Africa.

If recent claims that there has been little drift since the Late Eocene have any validity, separation of Africa and South America 80 million years ago require a Late Cretaceous-Early Tertiary sea floor spreading rate in the order of 6-8 cm/year. This approaches figures recently deduced for northward drift of India during the same period.

Wright J B 1989. Review of the origin and evolution of the Benue Trough in Nigeria. In: Kogbe, C.A. (editor) Geology of Nigeria, Rock View (Nigeria) Ltd, second edition 1989, pp 359-364.
A case is presented for regarding the Benue trough as having been a tensional feature throughout its entire history. Finding in the trough is seen as the result of differential block faulting in the underlying basement, the principal supporting evidence being straight lines discernable on ERTS imagery of some fold structures. The trough is envisaged as being due to a combination of downwarping and riftlike faulting of an attenuated sialic crust, with subsidence enhanced as a result of isostatic loading by the sediments filling the trough, and overlapping the marginal trough.

The case for a seafloor spreading/subduction cycle in the trough is again briefly reviewed and dismissed, as are the more recent applications of major transcurrent faulting and membrane tectonics to the structural history of the basin. The Benue trough has been wholly ensialic throughout its evolution. Little new published information is available on the magmatic activity, but this is shown to be consistent with an overall tensional regime throughout. The origin of the lead-zinc mineralization can not be more confidently attributed to the circulation of heated brines leaching base metals from sediments and underlying basement - much as in the present-day Red Sea.

Considerable work still remains to correlate the different phase of uplift and folding with marine transgressions and regressions into and out of the trough, and to link these with the global eustatic sea-level changes that characterise the Upper Cretaceous. This can only be done by careful field mapping and it will help to decide whether or not the folding did take place in a predominantly tensional regime. While the \afar depression remains probably the best present day analogue of the Benue Trough, there are several features of the latter that have their counterparts in other rifted depressions, notably those of East Africa and the Midland Valley of Scotland.

Young A, Low P F and McLatchie A S 1964. Permeability studies of argillaceous rocks. Journal of Geophysical Research, vol 69, pp 4237-4245.
Because the rate of water movement in argillaceous rocks depends considerably on the conditions of measurement, the only permeability measurements of practical field significance for these rocks are those obtained while the sample was held at temperatures and pressures that duplicated natural subsurface conditions as closely as possible. In laboratory measurements described in this report, the permeabilities of argillaceous rocks from the lower Cretaceous of Western Canada ranged from 10^{-7} to 10^{-4} millidarcy decreasing as the rocks become more clayey. Since argillaceous rocks tend to be compressible, flow rates through these rocks were dependent upon the difference between confining and average fluid pressures. Furthermore, the flow rates changed more with temperature than would be expected from the normal changes of water viscosity with temperature. This anomalous flow behaviour suggests that the water in clayey rocks has a structure that is different from the structure of bulk water.

Younger P L 1993. Simple generalised methods for estimating aquifer storage parameters. Quarterly Journal of Engineering Geology, vol 26, pp 127-136

In many practical applications, hydrogeologists are called upon to predict aquifer behaviour in areas devoid of pumping test data. Estimations of transmissivity may sometimes be made from specific capacity records, but in general storage parameters (specific yield and storativity) are not readily obtainable. Existing methods for estimating these parameters are few and inaccurate, especially for storativity (S). By returning to the basic definition of confined aquifer storage, a simple method has been developed for estimating S as a function of aquifer lithology and thickness alone. Variations in aquifer porosity (which are often difficult to quantify) are neglected in this formulation and numerical experiments have shown that the errors introduced by this assumption are negligible except for indurated aquifers of low compressibility ($<10^{-10}ms^2/kg$). Porosity can be more easily determined for these aquifers than for unconsolidated aquifers of higher compressibility and a more accurate calculation of S can thus be made. This method has been tested against storativities derived from pumping test data for wells in the Altiplano of Bolivia and a good correlation between estimates and field values was found. The importance of obtaining good estimates of S is illustrated by reference to a typical problem encountered in a development project in the Altiplano, where the increased accuracy obtained using the new method (instead of older less rigorous methods) has beneficial consequences for the local community.

Zaborski P M P 1987. Lower Turonian (Cretaceous) ammonites from south-east Nigeria. Bulletin of the British Museum of Natural History (Geology), vol 41, pp. 31-66.

Within most of Nigeria's Benue Trough uppermost Cenomanian and Lower Turonian strata are dominated by vascoceratid ammonite faunas of Tethyan affinities. Such assemblages range as far south as the Ezillo region in south-east Nigeria where *Nigericeras, Paravascoceras, Fagesia, Thomasites* and *Wrightoceras* occur. Barely 60 km south, however, at Lokpatana, the Lower Turonian contains faunas more easily correlated with those of the western interior of the United States and north-west Europe. The basal Turonian here is mainly characterised by *Watinoceras* spp., while the upper part of the Lower Turonian contains *Pachydesmoceras, Mammites nodosoides* (Schluter), *Kamerunoceras, Fagesia, Neoptychites, Herrickiceras*? and *Hoplioides latefundatus* sp. nov. This last form appears to provide an evolutionary link between *Wrightoceras* and typical *Hoplitoides*. The absence of vascoceratid-rich faunas at Lokpanta is probably because of palaeoenvironmental factors.

Zalasiewicz J A, Mathers S J And Cornwell J D 1985. The application of ground conductivity measurements to geological mapping. Quarterly Journal of Engineering Geology, vol 18, pp 139-148.

Clay and clay rich sediments can rapidly be distinguished from sands , sandstones and limestones. The EM31 was used and examples are given from throughout England.

Zaltsberg E 1985. Estimation of hydrogeologic parameters and groundwater-balance components based on fluctuations of the water tables. Canadian Journal of Earth Sciences, vol 22, pp 1803-1812.

The Wilson Creek experimental basin is located on the slope of the Manitoba Escarpment, southwestern Manitoba. Observations of groundwater regime, weather conditions, and stream discharge were carried out in this basin from 1965 to 1980. Using groundwater fluctuations in observation wells, it was found that the values of the specific yield of till range from 0.03 to 0.04 and the specific yield of shale is equal to 0.04. Calculated vertical hydraulic conductivity of till ranges from 0.0002 to 0.0003 m/day. On the basis of these determinations, groundwater balances for separate segments of the watershed and for the whole of the basin were calculated. Considering the basin as a whole, it was found that the average values of groundwater-balance components during spring-summer seasons were as follows: infiltration, 111 mm or 30% of precipitation; evaporation, 58 mm or 19% of precipitation; and groundwater runoff, 61 mm or 20% or precipitation.

The shales of the Pierre formation are quite permeable; there are creek valleys in the catchment which are bounded by high unstable walls of weathered shale bedrock. The shale is non-calcareous with numerous thin interbeds of siltstone and soft bentonitic shale.

Zeil P, Volk P, Saradeth P, 1991. Geophysical methods for lineaments studies in groundwater exploration. A case study from SE Botswana. Geoexploration, vol 27, pp 165-177.

Exploration for village supplies has shown that groundwater occurrence is restricted to lineaments. They overlaid aeromagnetic data and Landsat data which gave a greater chance of finding lineaments. Lineaments were identified on the aeromagnetic data by disruptions of the regional trend or linear sharp boundaries. Gridded data was found better than contoured data. They then used em site boreholes - this avoided problems created by bad contacts. They looked for resistivity lows with Shlumberger traversing. HLEM was used at 50, 75, 100 m. They used nomograms to interpret the presence of deeply dipping structures.

BSC THESES HELD AT DEPARTMENT OF GEOLOGY, UNIVERSITY OF NIGERIA, NSUKKA.

1. Aiyetan, O. A., 1992. Geology of Oju-Ibilla area, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 88/51865. (8 -20'E:6 -55'N / 8 -25'E:6 -50'N)
The sedimentary cycle in the Lower Benue Trough started with the deposition of a thick series of marine shale. In the mapped area, this is represented by the Albian Asu River Group - the Anyiogbu Shale unit. This shale unit is greyish - black or brown when weathered. Globigerina foraminifera is noted. The Asu River Group is overlain unconformably by the Eze-Aku Formation. Locally it is referred to as the Ainu-Ochimode and Utabegi - Ogodudu shale units. These units for intercalations of shale and siltstones. The Egga Limestone is highly rich in fossils. Cenomanian deposits were restricted to the Calabar flank. A second depositional phase was initiated by an extensive Turonian transgression which resulted in the deposition of thick unconformable marine sequence of argillites and carbonates of the Eze-Aku formation in the mapped area. A post-Albian but Pre-Turonian deformation has been proposed to explain a regressive Cenomanian stage and the formation of the Albian folds. Igneous activity of the surrounding hills gave rise to bakes shale in the study area, resulting in folding , faulting, arching and jointing of the litho-units. Details studies based on petrographic, sedimentological and structural analyses were used to reconstruct the palaeoecological history of the study area.
Contacts: Chief Idiku - second paramount chief of Igede, Chief Onwoke - chief of Egga village.
Notes: Clays are typified by a thick vegetative cover with swampy conditions where as sandstones have a sparse vegetative cover.
Asu River Group - largely composed of olive brown sandy shale, fine grained micaceous sandstone and micaceous mudstone, bluish-grey or olive-brown shale that weather to brown colour.
1. Anyiogbu Shale (Ogiriga)
Greyish-black slatey highly compacted shales
2. Oju-Ibilla Centre shale
Bluish-grey shale when fresh, variegated and light brown ferric oxide derived colours when weathered, composed of pyrite, muscovite and plagioclase with some globigerina oolite, shallow marine environment.
Eze-Aku Formation - calcareous shales, micaceous fine to medium sandstones with occasional limestones composed of oyster brash with marly beds.
1. Ainu-Ochimode shale
Grey-black, fissile, silty and hard, at Ogodudu fissile shales interbedded with mudstones, at Ainu and Onyike hard compact shales are overlain by sandstones.
2. Egga limestone
Thin grey fossiliferous limestones are interbedded with shales and siltstones
3. Ikom-Ororu siltstone
Laminated to flaggy siltstones
4. Ochimode-Ogodudu sandstone
50% of the area is underlain by this medium to fine grained sandstone with out-crops at Ogodudu, Oru, Ainu, Ochmode and Utabegi. Grey-brown to black where weathered, white to brownish white where fresh. Two main parts - calcareous sandstone and a non-calcareous sandstone. Generally coarsens upwards, may be interbedded with shale - coarse grained feldspathic sandstone with mica, silty matrix and magnetite cement.
5. Utabeji-Oru sandstone
Medium feldspathic sandstone with mica and calcite cement
Hydrogeology: Boreholes located at Ibilla and Ogodudu, with hand dug wells at Egga and Ekpong, with analyses of water samples at these sites.

2. Anyanwu, M.C., 1992. Geology of Adum and Ito, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 88/51662. (8-20E:7-00N/8-25E:6-55N) (Map and photos ok)
The mapped area lies within the Benue Trough of Nigeria. It lies between 7°00'N and 6°55'N and longitudes 8°20'E and 8°25'E and on a moderate elevation traversed by seasonal streams.
The sedimentary deposits of the area belongs to the Eze-Aku Formation which is of Turonian age. The sequence comprises calcareous sandstones and siltstones, shales with black shales, micaceous black shales with silty lenses, shales with minor sequences of limestone boulders and sub-arkos arenites. Pelecypods, gastropods and ostracods are abundant. The sandstones are generally moderately to poorly sorted aquant, lepto to mesokurtosis and with skewness generally less than 1, and the bouldered limestones are highly fossiliferous and fall into biomicrite wackestone class.
The dips of the entire area generally range from 9° to 23° northwest except where local deformation influences an area. The north-south trending joins in the sandstone units, the northeast - southwest trending synclines and faults are evidence of post Turonian deformation in the area.
The bedform structures of the sandstone are parting lineations, symmetric and asymmetric ripples, ripple bedding stratification, flat bedding and micrcross lamination with slump structures and pot-holes.
The water table is generally shallow. The water quality evaluation entails that there is slightly high iron content, bacterial contaminated water and moderately hard to hard water. Sands and sandstones, clays and laterites ate the main economic mineral deposits of the area.
A shallow marine to fluviatile environment which is oxygen deficient in the south and more aerobic in the north-east is postulated for the deposits. The sediments were deposited during the first sedimentary cycle that dominated the southern Nigeria area during the Albian - Santonian time.

3. Anyanwuocha, E.L., 1991. Geology of the Ameka-Owo area, in Oju Local Government Area, Benue State, and Iddah LGA in Cross River State, Nigeria. BSc thesis No. 87/48201. (8-25E:6-50N/8-30E:6-45N) (map ok)
No abstract collected

4. Ikuomola, A.O., 1992. Geology of the Ogore-Ito Area around Oju Local Government Area, Benue State, Nigeria. Bsc thesis No. 88/51737. (8-15E:7-00N/8-20E:6-55N)
No abstract nor map collected

5. Iyioku, M.U., 1992. Geology of Obugbehe and environs, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 88/51773. (8-15E:6-55N/8-20E:6-50N)
The mapped area covers the whole part of Obusa District, about 19 km east *(west?)* of Oju Local Government Area of Benue State. It is located at 8°15'E to 8°20'E and longitudes 6°50'N to 6°55'N.
The area belongs to the two stratigraphic sequence of the Lower Benue Trough namely:
Awgu Shales: Santonian in age
Eze-Aku Formation: early Turonian in age.
The Eze-Aku formation consists of three units. The sandstone unit, the siltstone unit and the shale/limestone unit, while the Awgu Shales consists of only one unit; the shale unit.
Detailed petrographic analysis and laboratory analysis were made in order to classify the rocks. While, the ammonites collected from the field were sriticall y analysed in order to name the ammonite and also, we used it to date the studied area by comparing them with the already studied ammonite assemblage of Benue Trough.
Structural, economic and hydrogeological studies were made. The structural features were as a result of changes that accompanied the santonian episode. Aquifer type was observed and analysis of groundwater was critically analysed.

6. Manu, L.C., 1992. Geology of Ikoku and environs, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 88/51772. (8-20E:6-50N/8-25E:6-45N) (Map)
No abstract collected

7. Metieh, R.E., 1991. Geology of Onike and environs, north-east of Ejekwe, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 82/32947. (8-25E:6-55N/8-30E:6-50N) (very poor map)
No abstract collected

8. Nwaghanata, O.A., 1992. Geology of Adum East and environs, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 88/51775. (8-20E:7-00N/8-25E:6-55N) (Poor copy of map but same as earlier, No.2).
No abstract collected

9. Obike, I.G., 1992. Geology of Uwuokwu, in Oju Local Government Area, Benue State and adjoining part of Izzi LGA in Enugu State, Nigeria. BSc thesis No. 88/51829. (8-15E:6-50N/8-20E:6-45N) (map)
The area lies within the Benue Trough of Nigeria. The area is bounded by latitudes 6°45'N and 6°50'N and longitudes 8°15'E and 8°20'E. It covers an area extent of 87 km^2. The relief of the terrain ranges from 150 ft on the topographic low to 400 ft on the topographic high which is part of the Workum Hill.
The rock units in the map area fall into two groups; sedimentary rocks and igneous rocks. The sedimentary sequences belong to the Asu River Group and the Eze-Aku Shale. The igneous rocks belong to the Asu River Group and igneous activity started during late ans post-Albian times and ceased by the end of the Turonian.
The Asu River Group (Albian) in the area consist the Iyuma Sandstone and Ojekwe Shale. The Iyuma Sandstone is dark grey in colour. It is a fine grained, compacted and micaceous sandstone. The Ojekwe Shale is brownish red to greyish in colour. It is massive, laminated, jointed and fissile. These sediments are affected by a number of intrusions which baked their contacts with the intrusions. A moderately deep marine depositional environment has been postulated for the Asu-River Group sediments.
The Eze-Aku Shale (Turonian) consists of the Ogori Shaly limestone which is exposed in the bank of the Onyongo River and shows an intercalation of shale and limestone beds. The shale member is dark brown, laminated, fissile and highly weathered with clay lenses at intervals. The limestone is dark grey in colour. It is highly fractured and fossiliferous. The Obusa sandstone also belongs to this formation. The type section revealed at River Onyongo contains five sub-units of sandstone, siltstone and shale intercalation.
The igneous rocks of the area are mostly of intermediate composition. Their emplacement was controlled by pre-existing anticlines of the Santonian folding that affected the area. From perographic studies, the igneous rocks were named Ojokwe Hornblende diorite, Iyuma microdiorite and Iyuma diorite respectively.
A number of sedimentary structures were found in the area which include fissility beddings and lamination which are syndepositional. Others are fold, joints and mudcracks which are post-depositional.
The economic deposits of the area are clay, limestone, construction materials, agriculture and water resources. The surface water in the area is bacteriologically contaminated and the iron content is high.

10. Odum, G.N., 1992. Geology of Otakini and environs, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 88/51838. (8-15E:6-55N/8-20E:6-50N) (map only)
No abstract collected.

11. Offor, M.C., 1992. Geology of Ikoku and its environs, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 88/51665. (8-20E:6-50N/8-25E:6-45N) (map)

The area lies between latitudes 6°45'N and 6°50'N and longitudes 8°20'E and 8°25'E. Rock units mapped in the area are Albian shales, sandstones and siltstones of the Asu River Group, hornblende diorites and hypersthene andesites. The sedimentary rocks have been baked while the igneous rocks have undergone extensive alteration. The dips of the Asu River Group rock units are from 10° to 30°, while the igneous rocks have plagioclase compositions ranging from An_{35} - An_{50}.

Ammonite fossil moulds in the shale suggest a Mid-Albian, shallow marine deposition. The presence of jint systems, rock brecciation, and quartz recrystallisation as well as anticlinal axes in the area shows that the area was involved in a major deformational episode.

Scour marks indicate a SW towards NE palaeocurrent direction during deposition of the Asu River Group sediments. Pillow like structures on the andesites, which appear to have been formed due to magmatic extrusion into wet sediments under marine conditions, may suggest that magmatism began immediately after sedimentation

12. Ogosi, C.D., 1992. Geology of Oju and its environs, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 88/51666. (8-20E:6-55N/8-25E:6-50N) (map)
No abstract collected

13. Owere, B.M., 1992. Geology of Uwuokwu district in Oju Local Government Area, Benue State, and adjoining part of Abakaliki in Enugu state, Nigeria. BSc thesis No. 88/51866. (8-15E:6-50N/8-20E:6-45N)
No map nor abstract collected

14. Ubanwa, R.C., 1991. Geology of Obaichita - Ukpa and environs, in Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 86/45579. (8-25E:7-00N/8-30E:6-55N) (Map)
No abstract collected

15. Umeh, A.O., 1992. Geoloy of the Ogore-Ito area, Oju Local Government Area, Benue State, Nigeria. BSc thesis No. 88/51836. (8-15E:7-00N/8-20E:6-55N) (map)
No abstract collected, but much of thesis.

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