# CHAPTER 4 GEOLOGY

## 4.1 General Geology

Understanding the geology of the study area is the most important prerequisite to study the groundwater-bearing basin. The geological history of the southern Africa, including the study area, is also important to understand the groundwater conditions by drawing hydrogeological cross sections and piezometric contour lines to develop a hydrogeological map. Table 4.1-1 was made for this purpose and several papers and project reports were used. However, most of the work depended greatly on “Geology of Botswana”(J. N. Carney et al., 1994).

The Damara Sequence, the Nama Group and the Dwyka Group are regarded as the basement rocks of the study area because they serve as an impermeable layer from a hydrogeological point of view. The Damara Sequence and the Nama Group were formed through the Pan–African Orogeny or Movement. The Dwyka Group consists of glacial sediments that were deposited in the late Carboniferous to the early Permian Period (280 million years ago).

The Nossob and the Auob members as the major aquifers in the study area are included in the Prince Albert Formation that consists mainly of non-marine sediments that were deposited in the early Permian Period. It is an interesting fact that the African continent was a part of the Gondwana Supercontinent together with the South American continent at that time. Both continents drifted to their present position through continental drift, which began in the Jurassic (180 million years ago) as still continues today. Faults and dolerite dykes or sills were occurred in the Prince Albert Formation by the early rifting activity. The Kalkrand Basalts erupted in the northwestern part of the study area, namely the north of Mariental. The Kalahari Beds were deposited on an erosional landscape known as the “African Surface” into which a deep “Pre-Kalahari Valley” was eroded in the late Cretaceous (from 65 million years ago). Kalahari deposition took place during Tertiary.

Table 4.1-1 Stratigraphy of the Stampriet Artesian Basin

| Era | Period | Formation | Lithology | Thickness | Note |
|---|---|---|---|---|---|
| Cenozoic | Quaternary<br>2Ma<br>Tertiary<br>65Ma | **Kalahari Beds** | Sand, gravel, calcrete,calcrete-cemented conglomerate | 0 (W)-290 (E) | "Kalahari Beds" is an informal lithostratigraphical term. They rest on an erosional landscape known as the "African surface" (Pre-Kalahari Valley) . |
| Mesozoic | Cretaceous<br>143Ma | | - | - | - |
| | Jurassic | Karoo Dolerite (180 Ma) | Dolerite | 100? | Many of the faults in the Karoo Sequence have been intruded by dolerite dykes. |
| | | Kalkrand Basalt (180Ma)<br>Karoo Dolerite (180 Ma) | Basalt; thin interbeded pan sandstone and sandy limestone with abundant gypsum casts. Equivalent age intrusive dolerite dykes and sills | 0-370 | Rifting of the Gondwana supercontinent (180 Ma in eastern South Africa; 128 Ma in Namibia) |
| | 212Ma<br>Triassic<br>247Ma | Karoo Sequence<br>Ecca Group<br>Unconformity | - | - | - |
| Paleozoic | Permian | Karoo Sequence<br>Ecca Group<br>Prince Albert Formation<br>Rietmond member | Multicolored sandstone (mainly brown), shale, yellow shale, coal, black shale | 50-100 | Lower Ecca subgroup was deposited in lakes and deltas in the post-glacial environment following the retreat of the Dwyka glaciers. The middle and upper subgroups were mostly formed in rivers and deltas under subarctic to cool temperature climatic conditions and include the coal-bearing formations. Regional unconformity exists between Dwyka Group and Nossob member. |
| | | Auob member | Upper sandstone, upper coal, middle sandstone, lower or Impala coal, lower sandstone | 27-153 | |
| | | Mukarob member | Upper interbedded white siltstone and grey shale. Lower dark grey to black shale | 57-102 | |
| | | Nossob member | Two coarsening upward sandstone units | 6-36 | |
| | 289Ma<br>Carboniferous | Karoo Sequence<br>Dwyka Group | Complex succession of lithofacies, commencing with a basal tillite followed by glaciomarine mudstones with dropstones and minor, local glaciofluvial sandstone | | The western margin of the glacial "Kalahari Basin" was inundated by the arm of a shallow sea. |
| | 367Ma<br>Devonian<br>415Ma<br>Silurian<br>446Ma<br>Ordovician<br>500Ma | Unconformity | - | - | - |
| | Cambrian | Nama Group<br>Upper Nama Group | Thick alternating units of red, distal molasse sandstone and shale. 545 - 530 Ma. | - | The sediments were folded during later Pan-African movement until 420Ma. Nama G. have been affected by northeast-trending faults that define a half-graven structure. ACP21 reached to fine-grained Nama quartzite in Aranos. |
| | 575Ma | Lower Nama Group<br>Unconformity | Basal sandstone, black shell limestone, upper grey shales with sheet sandstones. 650 - 545 Ma | | |
| Proterozoic | Pre-Cambrian | **Damara Sequence** | Complex orogenic succession of sedimentary and volcanic rocks; deformed, metamorphosed and intruded by granite during Pan-African Orogeny. 900 - 505 Ma | - | "Damara Sequence" The various units were accumulated between about 900Ma and 530Ma and were folded and faulted during the Pan-African deformation. |

## 4.2 Geological Description

This report covers the area underlain by the sandstones of the subartesian to artesian Nossob and Auob Members. Although many of the units to be described and discussed are given member status in SACS (1980), they can be subdivided internally into different units and are laterally extensive.

The following description and analysis is based on mapping by Heath (1972), an unpublished report on the Karoo system in Namibia (Martin, 1963?), an analysis by Kingsley (1985) of the coal drilling programmes of CDM Mineral Surveys (CDM, 1982, 1983; McDaid, 1983, 1984); Gold Fields Prospecting (Castelyn, 1983) and Agip Carbone (1982, 1983), and the analysis of the logs of over 1 000 water boreholes. The Kingsley and CDM Mineral Survey reports provided very detailed logs of core boreholes into the Auob Member and a few into the Nossob Member and thus have given a far better insight into these formations than previous reports.

A geological map of the study area is illustrated in Fig. 4.2-1 based on the geological map of Namibia (1:1,000,000, Geological Survey of Namibia (1980)) Lineaments in the map came from the results of satellite and aeromagnetic image analysis as well as borehole analysis in this study. The stratigraphic sequence will therefore be described from the base to upwards.

### 4.2.1 Pre-Karoo Basement

Red sandstones and shales of the Fish River Subgroup of the upper Nama Group underlie the Karoo succession throughout most of the basin. They outcrop to the west and south. They have been intersected below the Karoo in boreholes in the southwestern part of degree sheet 2519 and in the deep Vreda core borehole (Wilson, 1965) in sheet 2419. North of 24°S the Karoo is underlain by various shales, quartzites and limstones of the Schwarzrand Subgroup of the lower Nama Group and pink arkosic quartzites of the early Damaran Kamtsas Formation (800 – 900 m.y.). Very few of the water boreholes have been drilled through the Karoo into this northern basement.

### 4.2.2 Karoo Sequence

The Karoo Sequence in the Stampriet basin, in terms of the SACS (1980) nomenclature, consists of a basal Dwyka Group, overlain successively by the Prince Albert Formation, the Rietmond Member and the Whitehill Member. Mapping has shown that each of these units, with the exception of the Whitehill Member, consists of several laterally continuous and readily mappable subunits. An elevation of stratigraphic status is therefore justified and necessary. In this report, the Dwyka and Prince Albert (the latter extending from the Nossob Member to the Rietmond Member) have been elevated to group status with the individual subunits, previously members, given formation status. The Rietmond Member is included as a formation at the top of the Prince Albert Group. Many of these formations consist of distinctly mappable subunits which could be given member status, e.g. Gründorn, Keichamchab and Auob Members. The Whitehill Member remains a formation on its own at the top of the succession in accordance with the 1:1 million geological map of Namibia since it overlies the Rietmond Member conformably (Heath, 1972). However, part of the Lower Rietmond shale in the southeast Kalahari Artesian Basin may well be a lateral equivalent of the White Hill Formation.

### 1) Dwyka Group

The Dwyka Group is uppermost Carboniferous in age and is subdivided into seven formations following Heath (1972). The Dwyka Group thickens significantly to the south, being 100 m thick in the Mariental area and 210 m thick in the Asab area.

Although most of the shale units above the basal tillite are greenish to yellowish in outcrop, drilling has shown all to be dark grey to black in depth. Like the Nossob, Mukorob and Auob Members, the upper 22 m of the Dwyka Group sediments in the Vreda well (mainly shales) contain small fragments of carbonaceous matter some of which are partly replaced by pyrite.

However, the dark Dywka shales can be distinguished from similar looking Mukorob shales by the presence in places in the former of paper-thin pyrite lamellae on bedding-plane partings to a depth of about 70 m below the base of the Nossob sandstone. Dropstones are also a distinguishing feature of the Dwyka shales.

At striking aspect of the Dwyka succession is the remarkable sub-parallelism of various palaeocurrent indicators such as orientation of elongate pebbles in the tillite and fluvioglacial deposits, glacial striae on glacial pavements and in the tillite, current ripples and cross bedding. These point to an average transport direction 20° west of south (Heath, 1972). Thus, the Dwyka Group is proximal in the north and distal in the south. Kingsley (1985) describes the Dwyka succession as glacial outwash sediment deposited in a marine environment. In the lower Dwyka, shale-sandstone alternations displaying wavy bedding, abundant load casts and *Cruziana* bioturbation indicating rapid deposition in a prodelta setting. Overlying mudstones with dropstones are indicative of a shelf environment (Kingsley, 1985).

### 2) Nossob Member

The Nossob Member as described by Heath (1972) is presented in Table 4.2-1. The base of the Nossob sandstone marks a regional unconformity and the highest stratigraphic unit of the Dwyka Group, the Kameelhaar Formation, is cut out northwards by this unconformity.

The change from Dwyka to Nossob depositional conditions was abrupt and the base of the Nossob Member is marked in places by a distinct scour surface on which a thin, pebbly sandstone up to 54 cm thick with pebbles derived from the underlying Dwyka sediments was deposited in places.

Heath (1972) divides the Nossob Member into three units as shown in the below table. Kingsley (1985) describes the same succession in terms of two coarsening-upward units in which Heath's middle shale unit is the fine-grained base of the second coarsening-upward unit.

Table 4.2-1 Description of Nossob Member

| **Formation** | | **Lithology** |
|---|---|---|
| Nossob Member | Upper | **Upper Sandstone**: White, medium-grained sandstone weathering light yellowish brown. Grains well rounded and well sorted; accessory biotite; calcite cement; less porous and permeable than lowest unit. Lower part well bedded with current ripples, upper part more massive with occasional cross beds, rare slump structures, isolated clay pellets up to 2 cm F. Abundant brown black, calcareous concretions up to 4.5 m F, particularly abundant towards the top where they in places coalesce to form an almost continuous layer looking like black sandy limestone. |
| | Middle | **Middle Shale**: Light brownish yellow, well bedded shale; becomes sandy E of Mariental. Very rare erratics up to 1.5 m F. Yellowish brown, calcareous concretions south of 25°S, concentrated near the base, up to 38 cm F, contain abundant cone-in-cone structures. |
| | Lower | **Lower Sandstone**: Massive, white, medium to coarse-grained sandstone that weathers pale yellow. Poorly bedded near top with current and oscillation ripples. Slump structures common, sole marks on basal contact, clay pellets up to 1 cmF near base. Grains well rounded and well sorted. Good porosity and permeability. Some pebbles; larger are facetted, rare striations, i.e. reworked glacial pebbles. Two types of concretions: one brownish black, calcareous and the other Fe-rich. |

The dominant palaeocurrent direction in the Nossob Member is SSW (Heath, 1972). The coincidence with the main depositional direction in the underlying Dwyka Group is remarkable.

Kingsley (1985) interprets the Nossob Member as being deposited as a prograding delta-front sand sheet during a few pulses of sedimentation.

In the Weissrand Escarpment several natural springs seep out in the escarpment face at the base of the Nossob Member or a few metres down in the shales below the sandstone.

### 3) Mukorob Member

Although vertical facies changes occur from the Nossob sandstone into the largely pelitic Mukorob Member and from this into the overlying Auob Member, for the purposes of this report, the Mukorob Member will be taken as the shale-siltstone-sandstone succession between the top sandstone of the Nossob Member and the scoured base of the medium- to coarse-grained Auob Member following the subdivision of Kingsley (1985).

The upper part of Mukorob Member is marked in several places by a gradual transition over about 20 m through an interbedded siltstone and shale succession above the Nossob sandstone to dark grey to black, plane bedded shales deposited from suspension and below wave base in a shelf setting (Kingsley, 1985). An important marker at or near the top of the shale-dominated lower part of the Mukorob Member, is a very thin but widespread, grey limestone or calcareous siltstone or shale layer between 2 and 36 cm thick.

The upper part of the Mukorob Member is marked by a gradual progradation and coarsening upward over as much as 40 m of section through thin, highly micaceous fining-upward siltstone-shale cycles into fine-grained sandstone-siltstone cycles with or without shaley tops

For the purposes of this study it may be necessary to consider the medium- to coarse-grained upper part of the Mukorob Member to be part of the aquifer and possibly even the underlying fine-grained sandstones where they are essentially shale free and porous.

It appears likely that most of the palaeocurrent measurements that Heath (1972) ascribes to the Auob Member are from the rather well exposed top of the upper Mukorob Member. These indicate depositional flow in a SSE to SSW direction, very similar to that for the Nossob Member.

### 4) Auob Member

On the basis of the detailed logs of the cored coal wells, the Auob Member can be divided into five units, (A1) a lower sandstone, (A2) a lower bituminous shale and coal, (A3) a middle sandstone, (A4) an upper bituminous shale and coal, and (A5) an upper sandstone. Each will be described separately. Neither the shale nor the coal horizons crop out and it is therefore uncertain which of the sandstone horizons the outcropping sandstone represents. Evaluation of the shale horizons is considered important as they may form significant barriers to flow between the three sandstone horizons.

Table 4.2-2 Description of Auob Member

| **Formation** | | **Lithology** |
|---|---|---|
| Auob Member | Upper Sandstone (A5) | White, massive sandstone weathering light yellow. Coarse-grained to locally gritty; high porosity and permeability; accessory biotite; cross beds and clay pellets up to 13 mmF. Common brownish black, calcareous concretions up to 3.6 mF, in places coalescing to form a continuous layer; |
| | Upper Auob Bituminous Shale and Coal (A4) | |
| | Middle Sandstone (A3) | Light grey to light brown, well bedded, fine to medium-grained sandstone; sand grains well rounded and well sorted; accessory biotite; isolated clay pellets. Petrified wood, often inside elongate, calcareous concretions in a layer of red, Fe-rich or yellowish white clayey sandstone; logs up to 50 cmF, 23 m long. Wood – Dadoxylon porosum and Phyllocladopitys capensis mainly, also Abietopitys perforata, Dadoxylon rangei, Medullopitys sclerotica; leaf impressions – Glossopteris, Cordaites hislopi. |
| | Lower Bituminous Shale and Coal (A2) | |
| | Lower Sandstone (A1) | Medium to coarse-grained, white to cream-coloured, thick bedded, faintly cross bedded channel sandstones. Mainly multistory channel sands up to 30 m thick. Thickness 5 to 30 m |

(1) Lower Auob Sandstone (A1)

The lower Auob sandstone rests on the Mukorob Member with a scoured contact. The change from the medium- to fine-grained, light brown, thinly cross bedded deltaic sands of the upper Mukorob Member to the medium- to coarse-grained, immature, feldspathic, more massive to thickly cross bedded, white to cream-coloured channel sands of the lower Auob sandstone is marked. In the cored coal wells the lower Auob sandstone is largely a medium- to coarse-grained, immature, arkosic sandstone made up of porous, conspicuously cross bedded channel sands. The unit is largely built up of multistory channel sands up to 30 m thick. In some wells channel, foreshore, shoreface and crevasse splay sands are interbedded. Thickness of the unit varies from 5 to 30 m but there are places where the unit appears to be missing having pinched out or been removed by pre-Kalahari erosion.

### (2) Lower Auob Bituminous Shale and Coal (A2)

Widespread swampy conditions appear to have developed rather abruptly. Swamp and marsh deposits of bituminous shale and coaly material are interbedded in places with thin, distal crevasse splay deposits consisting of thin fining-upward cycles of fine-grained sandstone, siltstones and dark, often carbonaceous shales.

### (3) Middle Auob Sandstone (A3)

This sandstone gradually coarsens upwards. Carbonaceous shales and silts at the base gradually pass upwards into increasingly coarser and thicker upward-fining cycles of intertidal deposits and crevasse splays with wavy and ripple lamination of micaceous sandstone, siltstone and shale that become more and more proximal upwards. Beach sands are common in places and channel sands are scattered through the sequence but become more abundant towards the top. Widespread bioturbation is indicative of shallow water conditions. Numerous thin coaly and micaceous laminae occur in these sediments indicating the proximity of swampy conditions.

Facies changes over relatively short distances appear to be a characteristic of this middle sandstone. Distal crevasse splays passed laterally in to swampy depressions in which coal and carbonaceous shale deposits accumulated. These are commonly overlain by both distal and proximal crevasse splays. Channel switching and erosion of lower lying units appears to have been common as many of the sandstones contain shale and coal fragments.

### (4) The upper Auob Bituminous Shale and Coal (A4)

This marks a second event of widespread swamp, marsh and possibly lagoon deposition with associated coals. Thin, bioturbated, fine-grained, coarsening-upward crevasse splay sandstones and possible beach sandstones are interbedded with the black, bituminous swamp shales and coals. Wavy and ripple laminated sandstone-shale tidal deposits may also be present. The coal in this unit is approximately 50 m above the lower coals. As with the lower shale and coal unit, thickness varies significantly from just a metre or two to 36 m. The unit is not as laterally continuous as the lower shale and coal unit and correlation from well to well is not always straightforward. In places, scour and erosion by the overlying channel sandstones has removed the upper shale and coal unit completely and the middle and upper Auob sandstone merge into one thick unit.

(5) Upper Auob Sandstone (A5)

This horizon consists of stacked, coarse-grained channels sandstones, often with lag deposits, and associated proximal splay deposits of fining-upward cycles of medium- and fine-grained sandstone. A thin black, bituminous shale layer up to 4 m thick occurs in this unit. Kingsley (1985) ascribes this horizon to a major regression event. Preserved thickness has been severely affected by thick Karoo dolerite sills that intrude the upper Auob sandstone and by pre-Kalahari erosion which cuts deep into this and lower units in places. Preserved thickness varies from 0 to 61 m.

5) Rietmond Member

The Rietmond Formation consists of two units, a Lower Rietmond Formation consisting of shale and an Upper Rietmond Formation consisting mainly of sandstone with some shale layers. The Upper Rietmond rests unconformably on the Lower Rietmond.

(1) Lower Rietmond Formation

The Lower Rietmond Formation shale appears to rest conformably on the Auob Formation sandstones. It crops out east of Mariental on the farm Rietmond 118 and east of Asab on the farms Goamus 70 and Salami 239. It weathers to light and dark grey tones but below the Kalahari unconformity it has weathered to a yellow colour. In borehole cuttings where it is fresh, the colour varies from grey to blue grey, dark grey and almost black. In borehole logs it has often been described as “blue shale”. In several places below the Upper Rietmond unconformity, the Lower Rietmond shale is deeply weathered to a yellow colour. However, the erosion that preceded deposition of the Upper Rietmond Formation also removed this yellow weathered capping in places so that one also finds the Upper Rietmond sandstones resting directly on grey Lower Rietmond shales.

The Lower Rietmond shale was deposited over the whole basin but was partly or completely removed in many areas by two periods of erosion, one preceding deposition of the Upper Rietmond Formation and the other preceding deposition of the Kalahari succession. Where best developed, it is over 100 m thick but because of the above erosion, thickness varies erratically in the areas where it is present.

The Lower Rietmond Formation is the impervious cap and the main aquitard to the Auob artesian sandstone. However, it can happen, although very rarely, that a borehole drilled to near the base of the Lower Rietmond shale, but not right through it, becomes artesian due to fractures in the basal part if the shale providing connectivity to the underlying sandstone (e.g. borehole WW 39874).

### (2) Post-Lower Rietmond – Pre-Upper Rietmond erosion

Prior to deposition of the Upper Rietmond Formation, the Lower Rietmond sediments were uplifted, exposed and eroded. In the northern and southwestern parts of the basin, this erosion removed very little of the Lower Rietmond shales and thicknesses are generally in excess of 50 m (Fig. 3.6-3). In places in these areas, this period of weathering and erosion caused strong alteration of the top part of the shale to a yellow colour. Elsewhere in the basin, erosion removed most or all of the shale. This erosion left a highly dissected landscape so that the remaining Lower Rietmond shale, where present, is highly variable in thickness, even between closely spaced boreholes. Where the erosion removed the Lower Rietmond shale completely, the Upper Rietmond sandstones rest directly on the Auob Formation sandstones.

### (3) Upper Rietmond Formation

This rests unconformably on the underlying rocks. It crops out on the farms Neu Lore 97, Helpmekaar 588 and Doornboompan 542 west of Leonardville, in the Nossob River valley at Leonardville and north and south of the town and in road cuttings at Stampriet. It is not know to crop out anywhere else. Although reaching 180 m in thickness, the thickness of the Upper Rietmond Formation is highly variable due to pre-Kalahari erosion which cut deeply into the Karoo succession, and at its deepest, cut right through both Rietmond and Auob Formations into the underlying Mukorob shales.

The Upper Reitmond Formation is highly variable in character. Athough consisting mainly of sandstones, it contains layers of interbedded shale in places which vary in number from one to six (e.g. six in WW 10869, Elbow 392, 2318CB). It is rare for shale to exceed sandstone in amount but in a few places shale makes up 70% of the Upper Rietmond succession (e.g. WW 820, Schurfpenz 120, 2418 AB; WW 696, Helgoland 117, 2418 CB).

Characteristically, the Upper Rietmond sandstones have a reddish brown colour which is relatively light at higher stratigraphic levels but usually deepens in intensity with increasing depth. However, white, brown, orange, purple, red, pink, green, grey and yellow sandstone layers are also commonly recorded in the borehole logs. Where exposed, bedding tends to be thin to very thin. Grain size varies continuously, often on a small scale, and coarse- to medium-grained sandstones often have a thin cover of very fine-grained, highly micaceous sandstone or siltstone. Many of the sandstone layers are highly micaceous whereas others are less micaceous. Porosity of the sandstones is highly variable and often porous layers are bounded by highly micaceous layers with low porosity.

The interbedded shales are also highly variable in colour and although often grey when fresh, red, brown, reddish brown, purple, pink, yellow, white and black coloured shales have been recorded in borehole logs. Locally thin coal lenses are interbedded with the dark grey to black shale layers.

Rather than consisting of continuous layers, the succession appears to consist of stacked lenses of shale and sandstone of differing grain size and mica content.

In the absence of the Lower Rietmond Formation shale, it can be difficult distinguishing the sandstones and grey shales of the Upper Rietmond Formation from the grey shales and sandstones of the Auob Formation. However, characteristic for the Upper Rietmond sandstones are their reddish brown colour and the high mica content of many of the layers.

The water table in borholes drilled only into the Upper Rietmond Formation is highly variable and deeper than the Auob water table in nearby boreholes that go all the way down into the Auob Formation.

There appears to be minimal lateral and vertical permeability within the Upper Rietmond Formation due to the lithological variability, the lensoid nature of individual layers, the high mica content and the highly variable water table levels. The Upper Rietmond Formation, therefore, despite it consisting mainly of sandstone, appears to be an effective aquitard where it lies directly on the Auob sandstones. Any large-scale connectivity between the Rietmond and Auob sandstones would be reflected in the Rietmond and Auob having the same water table elevation over large areas and this is not the case. In a few boreholes that were drilled to near the base of the Upper Rietmond Formation where it rests directly on the Auob Formation, the Rietmond water table is the same as that in nearby boreholes than went into the Auob Formation. This indicates a fracture connectivity between the basal Rietmond sandstones and Auob Formation in a few isolated cases.

### 6) Whitehill Member

The White Hill Formation is know to occur with certainty in only one place in the area of investigation on the farms Dorndaberas 16 and Gross Daberas 17 east of Asab. The 1:1 million scale Geological Map of Namibia shows the White Hill Formation here to occur in a succession of shale overlying the Auob sandstones. Part of the Lower Rietmond Formation must therefore be the lateral equivalent of the White Hill

Formation but nothing in the rock chips or the geophysical logs of the JICA boreholes indicates exactly which part of the Lower Rietmond Formation would be equivalent to the White Hill Formation.

7) Kalkrand Basalt

The distribution of the Kalkrand Basalt is shown on the 1:1 million geological map of Namibia. (see Fig. 4.2-1) Dated at 180 million years, the basalts are Triassic in age. There is thus a large time gap between the Rietmond Member and Kalkrand Basalts. The basalts rest unconformably on the Rietmond Member on the farm Rietmond 116 east of Mariental and then transgress westwards across each of the underlying formations in turn until they rest directly on the red beds of the pre-Karoo Fish River Subgroup northwest of the Stampriet Basin.

The Kalkrand succession consists of stacked basalt flows with or without fragmented bases and tops. Tops of flows are invariably more vesicular and amygdaloidal than further down. In places, red, fine-grained palaeosoils are present which penetrate downwards into that fragmented tops of the underlying flows. Scattered over much of the exposed part of the basalt succession are several thin interbeds of limited lateral extent of well bedded pan deposits consisting of basalt-derived sandstones and gritstones and white fresh-water limestones. The sandstones also contain well rounded quartz grains of aeolian origin. Casts of gypsum roseates are common.

The basalt succession is up to 370 m thick. Since many of the water boreholes struck water within the basalt succession, some of them were clearly in the interbedded pan deposits based on the descriptions of the cuttings, very few were drilled through to the underlying rocks.

8) Karoo Dolerite Sills

Karoo dolerite sills intrude the top of the Karoo Sequence and in places cut out the whole of the Rietmond Member and most of the Auob Member. The dolerite may consist of more than one intrusion since Karoo sediments are often interbedded with dolerite. South of 26° S, many of the faults in the Karoo Sequence have been intruded by dolerite dykes. Many of these dykes must be feeders to the dolerite sills. Faults and feeder dykes must be expected below the Kalahari cover in the main Stampriet Basin. Only the aero magnetic data is likely to show the location of such faults and dykes.

### 4.2.3 Kalahari Beds

The Kalahari Beds forms a continental deposit made up of unsorted fluviatile deposits, aeolian sands and local pan accumulations all variously cemented by calcrete and minor silcrete. The base of the Kalahari Beds is made up of poorly sorted, small-pebble, partly imbricated conglomeratic fan-deposits thoroughly cemented by calcrete. Where the top of these calcretes is exposed for considerable areas (e.g. on top of the Weissrand escarpment south of Mariental), a karst topography has developed. The age of this karsting is uncertain but since water strikes are often made in the calcretes at the base of the Kalahari it is likely that this karsting is extensive underneath the younger Kalahari sediments. The overlying Kalahari deposits are largely poorly sorted sands of fluvial origin and better sorted aeolian sands. Gritty zones can be either aeolian lag deposits or fluvial in origin. Calcrete cement varies in abundance in these sands. Silcretes are reported from some of the water boreholes but tend to be relatively rare in the southern Kalahari.

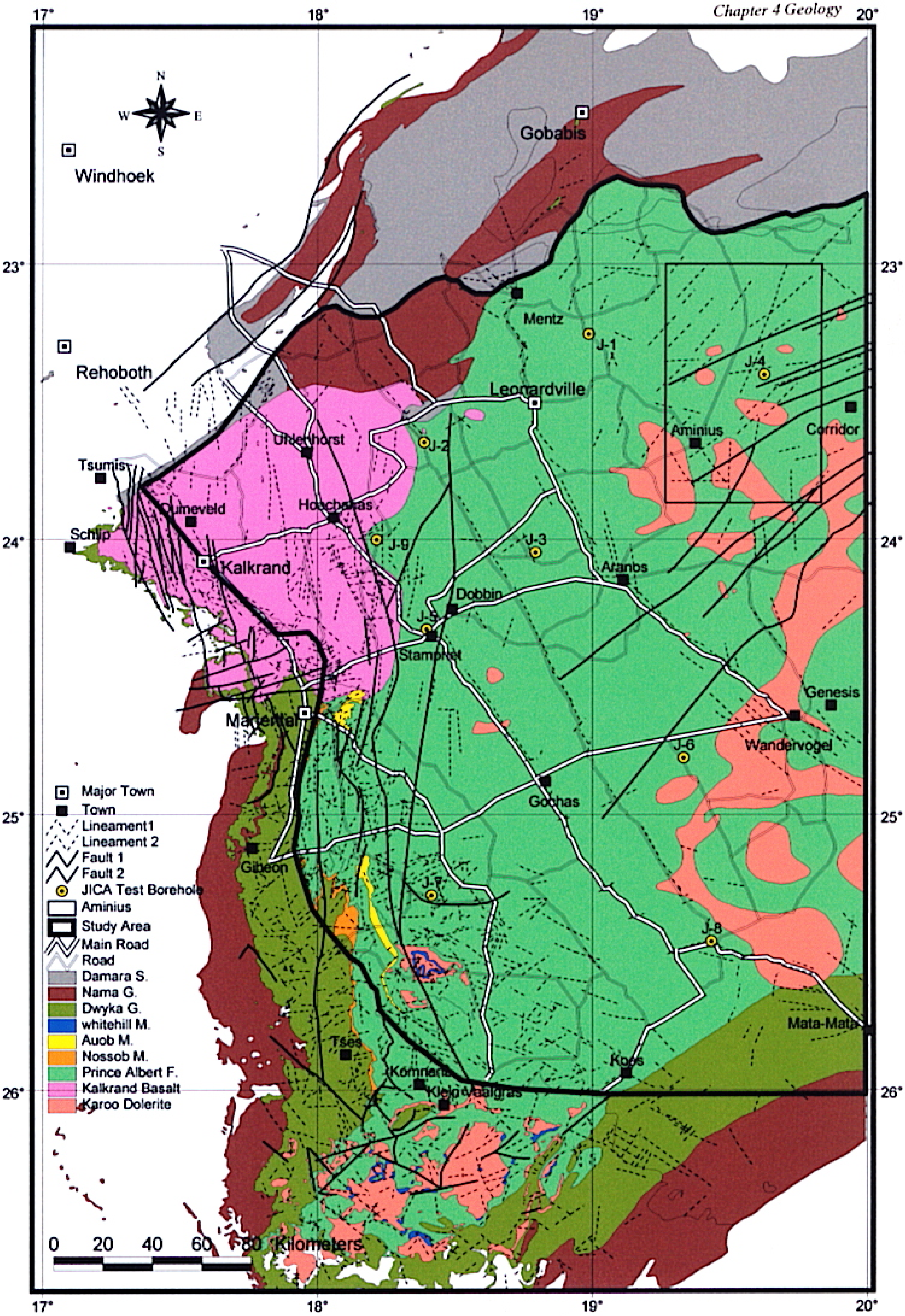

Fig.4 2-1 Geological Map of the Southeast Kalahari Artesian Basin

## 4.3 Geological Structure

### 4.3.1 Cross Section

Geological cross sections are illustrated as Fig.4.3-2 to Fig.4.3–9 and their locations are shown in Fig. 4.3-1. These cross sections and the following isopach maps were drawn on the basis of the geological database of existing boreholes, which have geological information, and investigation boreholes for the coal development project in 1980's. The former includes JICA Test Boreholes, DWA's observation boreholes and Namwater's observation boreholes.

These cross sections indicate that major three aquifers, Kalahari, Auob and Nossob aquifer do not simply overlie each other but they are cut by faults, intruded by dolerite or eroded somewhere. Their structure is considerably more complicated than our previous understandings of them.

### 4.3.2 Lineaments and Faults

A lineament is defined by "straight and/or semi-curve linear features on the surface, which seem to reflect subsurface geologic structures such as fractures." The lineaments were extracted from TM images as well as aerial photographs as mainly linear features on the surface and alignments of Pans distributed in the Kalahari calcretes area The former permits the larger scale of lineaments than the latter, depending upon their scale difference. They were divided into two categories; one was clear or certain lineaments and the other was unclear or inferred lineaments. Lineaments are shown in Fig.4.2-1 together with certain and inferred faults. Dykes were also included into the faults as a category.

A great number of lineaments were extracted from the western to southern parts of the study area, where they showed mainly N-S in direction almost parallel to the faults. Other directions of lineaments tended to be small in their scales. In the Kalahari calcrete area, NW-SE and N-S trending lineaments were developed. These directions are almost parallel to main drainages such as Auob and Nossob rivers as well as linear dune directions affected by winds. Their density in the Kalahari area is extremely lower than the one in the western to southern parts. These lineament characteristics provide only local geologic structures, apart from regional structures of the study area.

Although there are many NE-SW faults in the northeastern part of the study area, they are merely drawn as lineaments in the geological maps (Fig.4.2-1) because of the covering of the Kalahari Beds.

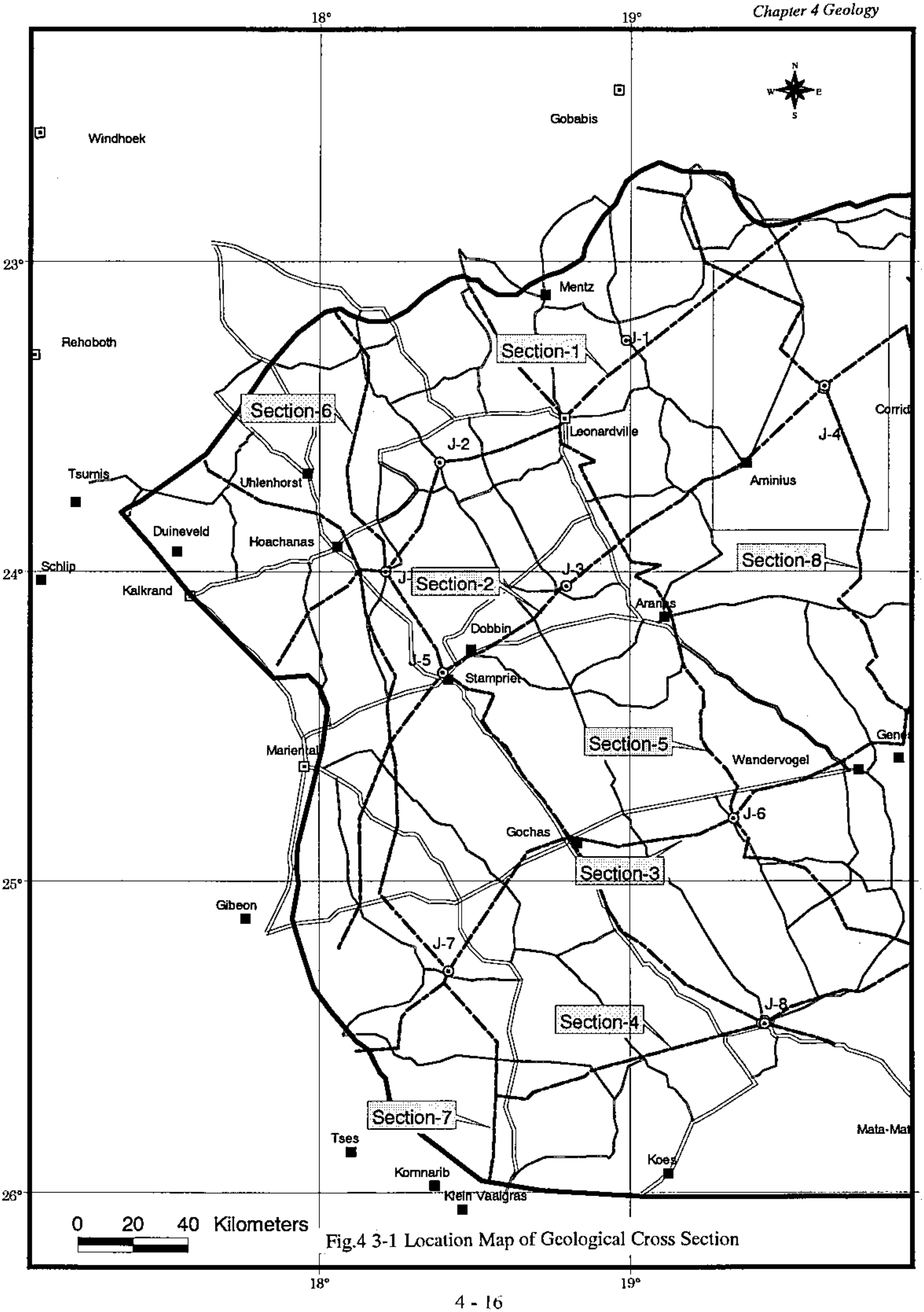

Fig.4 3-1 Location Map of Geological Cross Section

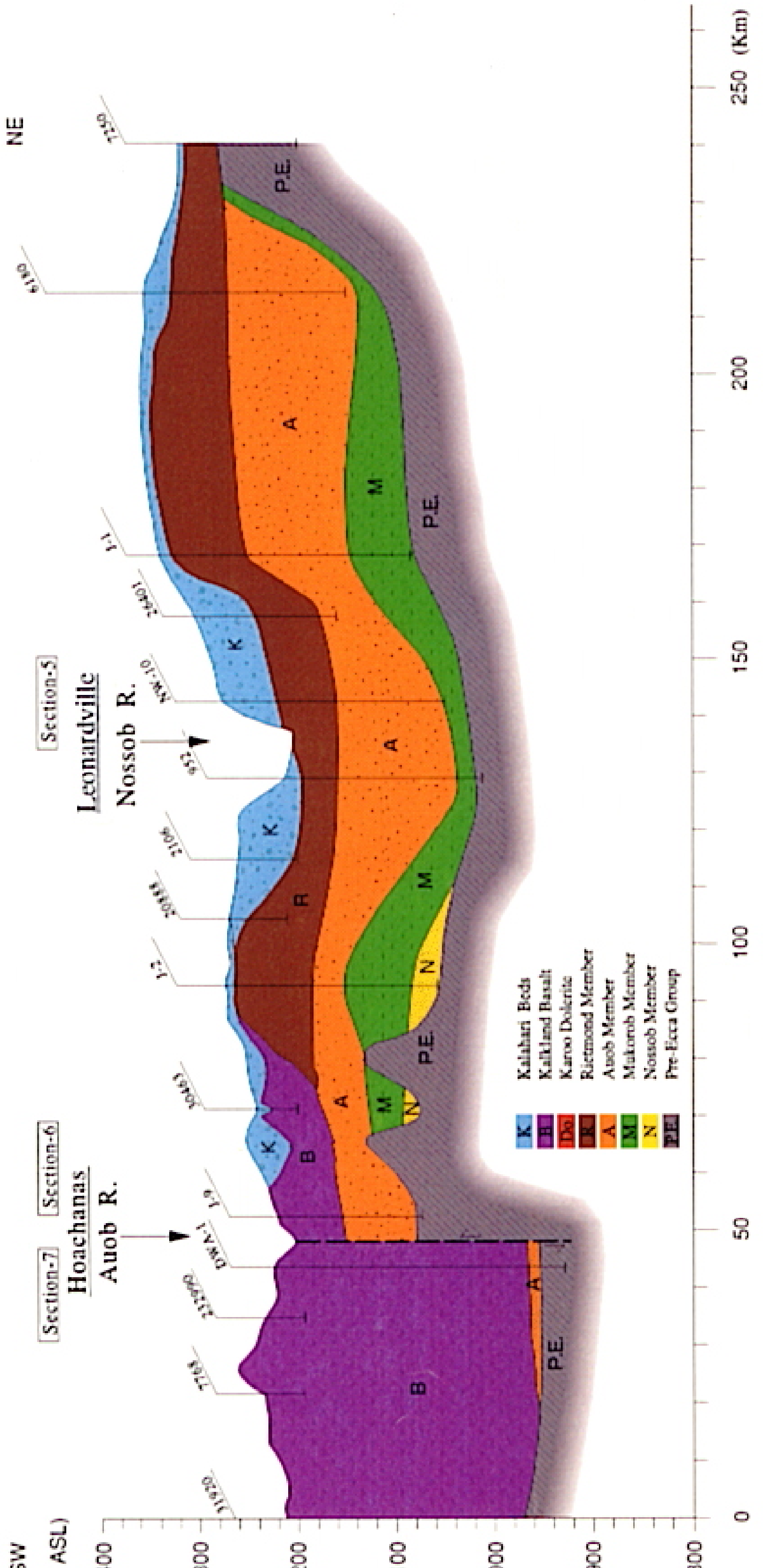

Fig.4.3-2 Geological Cross Section-1