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CHAPTER 10 GEOLOGY AND SEISMOLOGY

10.1. REGIONAL AND SITE SPECIFIC GEOLOGY

10.1.1 Regional Geology

10.1.1.1 General

The regional geology describes an area within a radius of 15 km to 20 km of the Koeberg site.

The regional investigation has been conducted according to the requirements of Appendix A, 10 CFR 100 which require that investigations into surface faulting include the following:

- Determination of the lithologic, stratigraphic, hydrologic and structural geologic conditions at the site and in the area surrounding the site, including its geologic history;
- Evaluation of the tectonic structures underlying the site, whether buried or expressed at the surface with regard to their potential for causing surface displacement at or near the site;
- For faults greater than 1000 feet long, any part of which is within 5 miles of the site, determination of whether these faults are to be considered as capable faults;
- Listing of all historically reported earthquakes which can reasonably be associated with capable faults greater than 1000 feet long, any part of which is within five miles of the site.

Faults can be obscured by thick overburden at a particular site, but evidence may exist elsewhere upon which an evaluation of the characteristics of the faults in the site area can be based. Therefore, investigations into surface faulting require that the regional geologic and structural history be taken into account to determine whether a nuclear power plant need be designed for surface faulting.

10.1.1.2 Physiography

The Koeberg site lies within the coastal plain of the Western Cape Province which is covered for the most part by Tertiary and Recent deposits. Ancient dunes, stabilized by vegetation and Recent unconsolidated dunes occupy large areas. This 'Sandveld' rises gently towards the east and south east to an average elevation of between 100 and 200 metres some 20 km east of the Koeberg site. The south east margin is demarcated by the Tierberg, whilst the Darling range dissects the coastal plain in the north and the Blouberg hill forms a prominent feature some 10 km to the south of the site.

A few islands are present within a 20 km radius, the most notable being Robben Island, 3.0 km x 1.5 km in extent and situated some 8 km west of Bloubergstrand.

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The Western Cape coastal province is drained by two river systems, the Grootbergrivier draining the area to the north of the Darling Range and the Dieprivier draining the area between the Darling Range and Tierberg. Both are mature, incised river systems that meander across 1 to 6 km wide flood plains. Within 20 km of the site several short, perennial annual streams flow directly into the Atlantic, the Soutrivier north of Melkbosstrand being the most prominent. Most of the other small rivers disappear in the flat sandy areas near the sea or cannot maintain open river channels across the narrow raised dune along the coast.

10.1.1.3 Geologic History

The consolidated hard-rock geology of the region is dominated by Precambrian and Palaeozoic elements. The rocks present within the study area comprise the Malmesbury Group and Klipheuwel Formations, post Malmesbury intrusive Cape Granites and the lower parts of the Cape Supergroup. The Tygerberg Formation of the Malmesbury Group and granite which intrudes the Malmesbury rocks, comprise most of the bedrock on which the younger Quaternary sediments of the Western Cape were deposited. (***Drawing No 34***). The sandstones of the Table Mountain Formation of the Cape Supergroup comprise the highland areas east of the Coastal plains.

Meta sediments of the Precambrian Malmesbury Formation underlie most of the area, but its geological and structural history in the south western Cape Province is obscured by diverse lithology and complexity of structural deformation. In many places, lithologic units are bordered by fault zones of regional extent. Thus, correlation of lithologic or structural units across major zones of dislocation is frequently difficult, if not impossible.

A minimum age of 600 million years, indicated through isotopic age determinations (***Reference 10.1***), appears to be acceptable for the Malmesbury sediments.

The Malmesbury Formation is predominantly a marine sedimentary assemblage, showing great variation of litho-facies. The Malmesbury orogeny commenced with the folding of the Malmesbury sediments into synclines and anticlines around almost horizontal, NW striking fold axes. This first tectonic episode was followed by the main folding stage which was responsible for the tight isoclinal folding of the Malmesbury Formation. The folding was caused by near-horizontal compression acting along a SW-NE direction. Low grade regional metamorphism accompanied the Malmesbury diastrophism.

Intrusion of the Cape granite suite took place in two phases along NW-SE striking zones of crustal weakness. The first phase of granite intrusion covered the time span from 600 to 550 million years. The older, porphyritic biotite or two-mica granites were intruded into and frequently contaminated with Malmesbury rocks.

At some localities, the older granites show considerable foliation suggesting that the first granite intrusion was a synkinematic event during the Malmesbury orogeny. The second, more acid phase of granite intrusives have been dated 500 + 15 million years (***Reference 10.1***). These younger, generally more fine grained aplo-granites show a cross cutting relationship with the older granites and are found as vein filling in the dominant NW and NE fault and shear zones. The major ductile deformation of the Malmesbury Formation came to an end during the closing stage of the Cape magmatism.

The late Pre-Cambrian Malmesbury orogeny was followed by a period of erosion and planation, preceding the deposition of the Klipheuwel Formation. The Klipheuwel beds are mostly arenaceous in character consisting of red sandstones and conglomerates. The formation is unmetamorphosed and relatively little deformed. Inclusions of porphyritic granite pebbles suggest that the Klipheuwel beds are of post-Cape Granite, most likely of Cambrian, age.

There exists a large depositional gap in the geologic history of most of the south western Cape Province, lasting from Cambrian into Tertiary times. Whatever Palaeozoic and Mesozoic formations may have covered this area were eroded during a long period of uplift and planation. It is clear, however, that the Cape tectonism, Cretaceous rifting and final Tertiary uplift must have affected the pre-Cape formations in the south western Cape to some extent.

An extensive cover of Pleistocene and recent aeolian sands, interspersed with estuarine sediments, testifies to a period of uplift, erosion and planation with intermittent periods of sea incursion lasting into the Quaternary.

These Malmesbury Formation sediments, comprising greywackes, mudstones, shales, minor limestone layers and occasional volcanic rocks are part of the Tygerberg Formation. Pre-Cape granites and hybrid rocks of the Darling stock occur near Mamre, some 18 km from the site. The Klipheuwel Formation, a sequence of unmetamorphised sandstones and conglomerates, presumably of Cambrian age, occurs just outside the study area, some 20 km to the east of the site. No rocks of the Cape and Karoo Systems have been identified in the site area.

The following table summarises the geologic formations present in the South Western Cape Province in approximate chronological order.

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TABLE T-10.1
GEOLOGIC FORMATIONS

Late Tertiary and Recent		Sandy, clayey and calcareous soils. Alluvium and dune sand Silcrete, calcrete and ferricrete Terrace - gravel Beach and estuarine deposits
Ordovician to lower Carboniferous		CAPE SYSTEM Sandstones and Shales PRE-CAPE DOLERITE DYKES
Cambrian		KLIPHEUWEL FORMATION Sandstones and conglomerates
Late Precambrian		CAPE GRANITES INCLUDING DARLING GRANITES Granites with hybrid and porphyritic varieties; diorites; augengeisses MALMESBURY GROUP Greywacke, sandstone, mudstone and shale; metamorphosed equivalents.

10.1.1.4 Investigations

The objectives of undertaking an investigation programme which would generate essential geologic baseline data include:

- the identification of geologic structures and faulting in the site area
- the development of a model of geological history of the various phases of deformation and, where possible, to determine directly or by inference the age of last movement along faults of fault zones.

Due to the paucity of rock outcrops in the site area, various remote sensing and geophysical exploration techniques were employed and complimented by field mapping. These included:

- Satellite imagery to identify geologic linear structures of regional and sub regional extent which were neither man-made nor caused by bedding or foliation and which could be correlated with earthquake epicentres. The investigation was limited to the coastal zone between Milnerton and St. Helena Bay. The results of this investigation were combined with existing geological maps.

- Aerial photographs and oblique aerial colour photography to investigate possible faults occurring within the site area or trending towards the site.

- Offshore geophysical survey undertaken between Robben Island and the coastline between Bloubergstrand and Duynefontyn in order to collect lithological and structural information that would supplement geologic and geophysical investigations conducted in the vicinity of Koeberg site and to obtain geologic evidence that would verify the postulated existence of a major NW trending fault zone between Robben Island and the mainland. The geophysical techniques involved include magnetometer, side scan sonar and echo sounder.

- Aero Magnetic surveys aimed at delineating geological units and structural features in the area around Koeberg site which are covered by aeolian sands and alluvium and tracing those magnetic anomalies discovered during the previous offshore survey.

- Geophysical ground surveys including magnetic and seismic refraction surveys, employed to indicate the presence of faulting or fracturing which could explain the presence of linear features revealed by the above techniques. The techniques used provided limited success in this regard.

- Detailed field mapping of rock outcrops considered the various phases of folding and faulting in the site area within approximately 15 km of the site. The mapping also considered all geomorphic linear features and magnetic anomalies present within 8 km of the site. Geologic reconnaissance was carried further afield in the Darling and Klipheuwel areas to examine the tectonic relationship of geologic domains of particular relevance to the fault study.

10.1.1.5 Stratigraphy

10.1.1.5.1 Previous Work

The geology of the Precambrian bedrock and superficial deposits of the Koeberg Site area were the subject of comprehensive investigations prior to construction (***References 10.24, 10.5*** to ***10.16***, inclusive). Literature relevant to the local and regional geology was reviewed and subsurface drilling and laboratory investigations undertaken in the site area. (***References 10.9*** to ***10.16***, inclusive). The positions of certain boreholes used in the geological and geotechnical site investigations are shown on ***Drawing No 30*** and ***Figures 10.1 and 10.2***. ***Drawing No 34*** depicts the surficial geology north and east of the Koeberg site. (***Reference 10.16***).

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10.1.1.5.2 The Malmesbury Group

The Malmesbury Group comprises the oldest rocks in the region (± 6 million years.) Outcrops of this formation are intermittent and except for places along the coastline where the rocks protrude through the Cainozoic sands, exposure is poor and it is not possible from surface observation to establish the continuity of the formation over large areas.

The Malmesbury Group is divided into eleven formations (***Drawing No 31*** and ***Reference 10.24***). Of these the only formation of direct significance is the Tygerberg formation.

The Tygerberg formation is present to the west of the fault zone which trends northwards from Stellenbosch and Franschhoek through Klipheuwel and Darling as an echelon array of dislocations. The formation consists predominantly of pelitic and finely-bedded semi-pelitic rocks, but zones of greywacke and immature quartzite are extensively developed in the Tygerberg Formation near Bellville and at the Koeberg site (***References 10.13*** and ***10.14***). A few thin impure limestone and conglomeratic beds are also sporadically present, although some of these more distinctive lithological bodies are several metres in thickness and can be traced for considerable distances.

At Bloubergstrand, sheared and altered interbedded igneous rocks in which amygdaloidal textures are present in apparently autobrecciated rock flows are exposed on the beach and on an offshore island. These rocks are intercalated with fine-grained and laminated reddish-brown rocks. The rocks at Blouberg represent a metamorphised succession of andesitic, volcanic and interbedded pyroclastic derivations of this lava-type.

The Malmesbury Group in general and the Tygerberg Formation in particular have been extensively intruded by the Cape Granite Suite (***References 10.36*** and ***10.37***).

In the vicinity of the intrusive granitic bodies the Malmesbury rocks grade from re-mobilised and reconstructed metasediments into gradually less indurated rocks in which sedimentary structures can be clearly identified. In general, though the Tygerberg Formation is indurated attesting to the extensive metamorphic halo produced during intrusion of the granite (***Reference 10.24***). The exact age is uncertain but this may have occurred during the early phases of granite intrusion. It is impossible to measure the total thickness of the Tygerberg Formation, owing to the extensive sand cover, the disruptive effect of the granite intrusion and the subsequent tectonism.

10.1.1.5.3 The Cape Granite Suite

Like the Malmesbury Group the Cape Granites are only intermittently exposed in the Western Cape (***Drawing No 31***). The nearest granite exposure to the Koeberg site is that at Kanonkop, south-east of Mamre.

The granite is composed of a predominantly coarse-grained assemblage of quartz, feldspar and minor but ubiquitous concentrations of biotite and white mica (***Reference 10.36***). Detailed descriptions of the lithological variations of these rocks and their structural relationship with the Malmesbury Group in the Western Cape may be found in ***References 10.36*** and ***10.37***. The structural history and tectonic implications of this granite suite to the study of Koeberg were addressed in detail in ***References 10.10*** and ***10.11***.

10.1.1.5.4 The Klipheuwel Formation

This fault-bounded group of rocks of limited area extent (***Drawing No 31***) has no significance to the study of the safety of the Koeberg Power Station. Thus it is sufficient to note that they have been distinguished from the Malmesbury Group by their distinctive reddish/brown colour. Furthermore, the presence of gravels of granite and quartz porphyry of undoubted Cape-Granite origin supports the distinction and interpretation that these beds are post-Malmesbury and probably of Cambrian age (***Reference 10.24***).

10.1.1.5.5 The Cape Supergroup

Only the lowest group of this sequence, known as the Table Mountain Group, is relevant to this report. It is comprised predominantly of arenaceous sediments and has been divided into six formations (***Reference 10.26***).

TABLE 10.2
LITHOLOGICAL FEATURES OF THE TABLE MOUNTAIN GROUP
(After Rust, 1967)

Group	Formation	Dominant lithology and distinguishing features
Table Mountain	Nardouw (Sandstone)	Sandstone
	Cedarberg (Shale)	Shale
	Pakhuis (Shale)	Sandstone, conglomerate, diamictite
	Peninsula (Sandstone)	Sandstone (coarse, thick-bedded)
	Graafwater	Sandstone (thin-bedded), Shale, reddish / brown colours and trace fossils are characteristic
	Piekenier	Conglomerate, Sandstone. Consists of two laterally equivalent members: Rest Conglomerate Member / De Hock Sandstone Member

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10.1.1.5.6 Post Malmesbury/Cape Granite Intrusions

Numerous north-westerly trending dykes are present within the Malmesbury Group. The presence and orientation of these bodies are attested to by the strong north-westerly trending magnetic traces which have been recorded in the area. At least two and possibly three ages of dyke intrusion are present.

These include: intrusives of pre-Cape Supergroup age, younger less frequently occurring post-Cape (Karoo-age?) intrusives and occasional alkaline dykes, possibly of tertiary age.

The pre- and post-Cape but pre-Cretaceous dykes are largely of gabbroic composition and have been classified as dolorites. Studies by Bouman (***Reference 10.3***) did not produce conclusive evidence of the absolute age of these dykes. However, on the balance of evidence, the dykes are probably of both pre-Cape (Cambrian) and post-Karoo age (approximately 200 million years) and possibly even younger (***Reference 10.11***).

10.1.1.5.7 Cretaceous, Tertiary & Quaternary Sediments

The younger onshore deposits of the region consist essentially of Tertiary to Recent, partly consolidated sediments comprising the Duynefontyn, Springfontein, Bredasdorp and Witzand formations (***Reference 10.35***) present in the vicinity of Koeberg and a variety of recently named sedimentary sequences elsewhere in the region north, east and south of Koeberg (***References 10.22, 10.33, 10.40*** and ***10.41***).

The younger offshore sediments west of Koeberg comprise a sequence of deposits of Cretaceous, Tertiary and Quaternary age (***References 10.17 and 10.20***).

10.1.1.6 Structural Geology and Tectonics

10.1.1.6.1 Regional Faulting

The regional tectonic framework and the tectonic evolution of the Western Cape have been central issues in safety related studies of the Koeberg Nuclear Power Station (***References 10.5, 10.11*** and ***10.24***).

The Western Cape regional tectonic framework divides the occurrence of the Malmesbury Group in the region into three tectonic domains (***Table 10.3; Drawing No 32***) separated by the Saldanha-Darling-Franschhoek and Piketberg-Wellington fault zones.

There is also evidence to suggest the presence of a similar fault zone between Milnerton and Cape Hangklip.

TABLE 10.3
STRUCTURAL SUB-DIVISION OF THE MALMESBURY GROUP
(After Hartnady and Others, 1974)

TECTONIC DOMAINS	STRUCTURAL SUBDIVISION
South Western Domain	Tygerberg Formation
Central Domain	Moorreesberg Formation Porseleinberg Formation Franschhoek Klipplaat Bridgetown Formations Berg River Formation
North Eastern Domain	Brandwacht Formation Piketberg Formation

These faults comprise complex sub-parallel shear systems which resulted in en-echelon zones of ductile deformation, brittle failure with associated breccia zones, and en-echelon crack arrays, cataclasis and mylonitisation. The fact that these fault systems are originally of pre-Cape age is supported by evidence of intrusion of late-stage phases of the Cape granite suite through the fault systems which have been truncated by pre-Cape erosion prior to the deposition of the Table Mountain Group in Silurian times (***Reference 10.24***).

However, post-Table Mountain Group movement is apparent and rejuvenation along parts of the pre-existing fault zones no doubt occurred. The fault systems have also been taken as boundaries between formations (***Reference 10.24***). Thus the south-western Domain extends from the Saldanha-Franschhoek fault system west to the coast and probably beyond and includes the Tygerberg Formation and post-Malmesbury, Klipheuwel beds (***Drawing No 32*** and ***Reference 10.24***) as well as a minor portion of the western edge of the Moorreesburg Formation. The central and north-eastern tectonic domains are like the overlying Table Mountain Group, remote from the Koeberg Power Station and thus can be regarded as having little or no bearing on the safety of the site.

Along the Saldanha-Franschhoek fault line a particularly major zone of faulting appears to be present between Klipheuwel and Mamre while a 50 km long postulated fault continues from Mamre through Darling towards Langebaan.

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This Klipheuwel Darling fault zone, approaching to within 18 km of the site clearly represents a major discontinuity of regional extent along which large granite stocks were intruded. Broad mylonite zones testify to intense cataclastic deformation along this major fault during Precambrian and post Cambrian times.

10.1.1.6.2 Site Faulting

Within a 15 km radius of the site, a significant NNW trending zone of structural disturbance occurs between Philadelphia and Mamre. This zone of faulting is considered part of the Klipheuwel-Darling-Saldanha fault zone. No similar major NNW trending zone of disturbance was identified within 8 km of Koeberg site.

The southern part of Duynefontyn is traversed by a magnetic anomaly which may constitute a lithological boundary within the Malmesbury formation along which faulting could have occurred. A swarm of dolerite dykes was intruded along this postulated discontinuity.

No evidence was found that the postulated Milnerton -Cape Hangklip fault zone approaches closer than 8 km to the site.

10.1.1.6.3 Age of Faulting

On a regional scale faulting can be seen to have affected all the consolidated rocks in the region (***Drawing No 32***). The youngest consolidated rocks of the region are the Table Mountain Group of the Cape Supergroup and thus the youngest age of faulting which can be reliably established from such an analysis is of post-Ordovician age (approximately 500 x 10^6 years). This is of little value to an analysis which is primarily concerned with the last 10^6 years of geological history. Thus an analysis of the regional framework is necessary. The post-Cape and Karoo Supergroup tectonic history is of greatest importance to the site as is the Recent tectonic evolution of the region which must be understood in the evaluation of the safety of the Koeberg site with regard to seismicity. A review of the literature indicates that few published studies are available on the Recent tectonic history of the region. However, from general texts on the subject (***References 10.26, 10.30*** and ***10.39***) and the occurrence of historical and recent earthquakes in the regions south and east of Koeberg (***References 10.5*** and ***10.7*** and ***Figure 10.4***) there seems little doubt that the fault zones of Precambrian age have been the loci of repeated reactivation through time and that the predominant stress direction in the Western Cape region, north of Cape Town has been consistently orientated in a south-west to north-east direction. Hence the major regional fault trends are oriented in a north-westerly/south-easterly to north north-westerly and south south-easterly direction.

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Offshore surveys undertaken by Soekor north west of St. Helena Bay and on the Agulhas bank have established Cretaceous rifting on the continental shelf along NW trending fault zones that probably represent the seaward continuation of major fault zones identified onshore. In the offshore areas, lower Cretaceous sediments are displaced by NW and WNW trending faults. Hence, the last documented evidence of movement along these faults occurred approximately 110 x 10^6 years ago. On the Aguhlas bank the youngest known intrusives, for which an absolute age of 58 ± 2 million years has been established, do not penetrate Tertiary sediments. If Cretaceous faulting occurred in the site area, movement is likely to have taken place along old established lines of weakness such as the Klipheuwel - Darling - Saldanha fault zone and along NE or ENE trending transform faults. The many NNW and NE trending open fissures and tension gashes, found in the site area, may well date back to this last significant phase of brittle deformation affecting the western Cape Province.

10.1.1.7 Conclusion regarding Surface Faulting

Based on seismic studies in the region three and possibly four regions of potentially seismically active faults or fault zones have been defined.

These zones include the major dislocations in the region and maintain a north-westerly to north-north-westerly trend. None of these zones appear to come closer than 8 km from the Koeberg site. Therefore, unless specific evidence to the contrary can be shown in the future, it can be reconfirmed that as concluded in earlier site safety and related studies (***References 10.9, 10.10, 10.13*** and ***10.14***) and in terms of the presently accepted definitions (***Reference 10.14***) no seismically active faults are present beneath or within 8 km of the Koeberg site.

10.1.2 GEOLOGY OF THE KOEBERG SITE & SITE AREA

10.1.2.1 General

This section deals with the geology of the area considered for location of the reactor sites number I and 2, referred to as the 'site' and the area comprising the farm Duynefontyn-34 and portions of adjoining farms, referred to as the 'site area'.

The geology of this area is evaluated in terms of its broader relationship to the regional geology in order to better understand the probable structural and lithological conditions in the site area.

An investigation is also required at the site and its close vicinity in order to detect surface faults which may then, in turn, be examined to determine whether they have significant potential for relative displacement at or near the ground surface. The investigation for the above should include:

- Examination for faulting at the site and fault trends towards the site

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- Thorough examination of the activity of faults detected and the history of their displacement

- Evaluation of the size of the zone associated with the faults including possible secondary faulting

A site within a zone of surface faulting that has significant potential for relative displacement at or near the ground surface would be deemed unsuitable unless engineering solutions are applicable.

The main question to be answered is whether a fault at or near the site is capable. This can be based on the database incorporated in the seismotectonic model together with other specific information as required.

A fault is considered capable, if it shows evidence of past movement or movements of a recurring nature within such a period that it is reasonable to infer that further movement at or near the surface can occur; if a structural relationship has been demonstrated to a known capable fault such that movement of the one may cause movement of the other at or near the surface; and if the maximum potential earthquake associated with a seismogenic structure is sufficiently large and at such a depth that it is reasonable to infer that movement at or near the surface can occur.

10.1.2.2 Physiography

The farm Duynefontyn-34 is located on a sandy coastal plain some 8 km to the north of Melkbosstrand. Within the confines of the farm boundaries there is a gradual overall increase in elevation from sea level to about 40 m above sea level in the north east corner.

The surface drainage pattern in the site area is poorly defined due to the great thickness and high permeability of the surface sands and mobility of the dunes. The most prominent drainage feature in the site area is the seasonal Soutrivier which discharges into the sea just north of Melkbosstrand.

10.1.2.3 Geologic History

The site area appears to be underlain almost entirely by folded rocks of the Malmesbury Group. This statigraphic unit is typified by the Tygerberg Formation, with greywackes, mudstones and intermittent shale bands being the principal rock types in the site area. These rocks are overlain by unconsolidated sands of Tertiary to Recent age. The time gap between the folded Malmesbury and the Tertiary exceeds 500 million years. A swarm of Dolerite dykes occurs in the southern part of Duynefontyn.

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Prior to this study, the structural setting of the site was incompletely known. Boreholes, and a rock outcrop in the southern portion of Duynefontyn, showed steeply dipping, somewhat sheared, slightly indurated greywackes interbedded with alternating mudstone layers beneath the site area. However, the steep dip of the formations was such that correlations could not be made between the relatively shallow, widely spaced holes, and their regional relationships could not be determined from the limited information available.

Orientated core samples indicated that the site area is underlain by isoclinally folded Malmesbury rocks, which conform in both lithology and structural deformation with the Tygerberg Formation of the south western Cape.

10.1.2.4 Investigations

While the regional investigations established the geological and tectonic setting of the site area, a large area comprising the farm Duynefontyn and portions of adjacent farms remained geologically unknown due to the extensive cover of recent sediments. Hence, a detailed geophysical exploration programme was undertaken which comprised:

- Aero Magnetic survey:

  The most striking feature encountered is a magnetic linear crossing the southern part of Duynefontyn in a WNW direction consisting of a number of narrow, steeply dipping dolerite dykes. It is possible that this linear represents a contact between different lithologies of the Malmesbury Formation along which some faulting could have occurred. The area to the north of this linear is generally of low magnetic relief revealing little lithological and structural information. This survey gave no indication that the northern part of Duynefontyn is underlain by other than tightly folded NW trending Malmesbury greywackes and mudstones.

- Ground Magnetic survey:

  This survey was undertaken to further define the source of the magnetic anomalies discovered by the aero magnetic survey. No NE fault offset was noted along the magnetic linears in the southern part of Duynefontyn as inferred from the aero magnetic survey. En echelon intrusion of dolerite dykes along a WNW trending lithologic discontinuity is the likeliest interpretation. Five magnetometer traverses were conducted over reactor sites 1 and 2 but no magnetic anomalies were detected.

- Seismic refraction surveys:

  This survey indicated the possible existence of only minor fractures or shear zones in the vicinity of reactor sites 1 and 2.

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In the southern part of Duynefontyn a WNW trending low velocity zone bordered by dolerite dykes may represent a lithological or structural discontinuity associated with faulting or shearing. North of the reactor site a NE trending aero magnetic feature was not confirmed as a significant fault or fault zone.

- Core Drilling:

  The 600 series of boreholes was drilled to investigate magnetic linears identified to the north and south of the reactor site area, two low bedrock velocity zones within the reactor site area and a zone of shear previously identified. The northern magnetic linear could not be positively identified whereas in the south, one of the boreholes intersected a dolerite dyke. Low bedrock velocities were attributed to thick mudstone layers in the bedrock. The shear zone was intersected by one of the boreholes drilled.

- Field Mapping:

  This was initially limited to the rock outcrops of greywacke occurring at Ou Skip park some 1.3 km south of the reactor site. No evidence of major fault offset was found at the Ou Skip outcrop.

- Laboratory Investigations were conducted to establish the composition and texture of certain rock and soil types encountered in boreholes, to investigate fault mineralisation and age of last deformation along the faults and to determine the absolute age of the dolerite dykes intruded in the southern part of Duynefontyn.

- Investigation of the exposed bedrock at the reactor site included detailed mapping, sampling and photographic documentation of geological features and petrographic studies of rock samples.

- A detailed geological investigation of the exposed bed rock in the excavation for the power plant including mapping, sampling, photographic documentation of geologic features, petrologic studies and solicitation of expert opinion. The results of this investigation were integrated to identify the chronological and structural relationships found within the bedrock of the excavation.

10.1.2.5 Stratigraphy and Lithology

The stratigraphic succession at Koeberg comprises the following elements as revealed from drill cores and subsequent excavations (***References. 10.11, 10.13, 10.14*** and ***10.35***).

TABLE 10.4
LITHOLOGY AT KOEBERG

FORMATION	STRATIGRAPHIC SUCCESSION	
Witzand Dune Formation	(Members not identified)	TOP
Bredasdorp Formation	Atlantis Dune Member	
	Milnerton Beach Member	
Springfontyn Formation	Upper Arenaceous Member	
	Lower Gastropod Member	
Duynefontyn Formation	Peaty Sand Member	
	Upper Bioturbated Sand Member/ Shark Tooth Bed	
	Lower Arenaceous Member	
	Basal Gravel Member	
Tygerberg Formation	(Members not named)	BASE

The succession listed in ***Table 10.4*** will be described from the base upwards in following paragraphs.

10.1.2.5.1 Tygerberg Formation

The bedrock comprises a variety of predominantly arenaceous rock types of the Tygerberg Formation which has a minimum age of +600 million years. These rocks include steeply-dipping, interlaminated, variably weathered, jointed greywackes, siltstones and mudstones with a NNW-SSE strike. Gradational sequences and contacts are characteristic and the beds grade mainly from coarse to fine in grain size in upward-fining successions.

The arenaceous fraction of the succession is represented by extensively developed greywackes (or quartz-wackes). The greywacke horizons are often massively bedded to the exclusion of other rock types.

In some localities the greywacke contains distinct upward-fining sequences, crossbedding and slump structures. Discrete bedding planes and accurate assessments of the strike and dip of the formation can usually only be made where rapid variations in texture and composition occur.

The argillaceous horizons, interbedded-with the greywacke in the site area, are normally less massive and have a moderate hardness in the unweathered state. They are further distinguished from the greywacke by a fine-grained even texture, grey to grey/green colour and generally more noticeable bedding.

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Distinct lithological boundaries are not always present and gradational changes are common in borehole cores. Thus, the argillaceous rocks often contain significant proportions of arenaceous material and range from poorly sorted sandy mudstones to pure clay types.

The bedrock surface consists of a fluted, wave-cut terrace of pre-Tertiary age located 10.0 m below mean sea level.

10.1.2.5.2 Pre-Cape Intrusive Rocks

Although there is no evidence of Cape Granites underlying the farm Duynefontyn, the induration of the Malmesbury rocks and the occurrence of aplitic veining suggest the presence of granites at shallow depth.

10.1.2.5.3 Dolerite Dykes

During the initial drilling programmes, which were concentrated in the area of the proposed reactor sites, no dykes were intersected. However, subsequent aero magnetic and ground magnetic surveys indicated a distinct WNW-ESE trending magnetic anomaly in the southern portion of Duynefontyn. Follow up investigations revealed the presence of a swarm of narrow dolerite dykes.

10.1.2.5.4 Duynefontyn Formation

This formation rests unconformably on a marine platform cut into the Tygerberg Formation bedrock and consists of ubiquitous basal gravels (***References. 10.13*** and ***10.14***) overlain by a succession of fine sands. The gravel member, which overlies the pholad-bored (lamellibranch) marine bedrock platform is variable in thickness up to 0.4 m and comprises well rounded to angular pebbles of quartzite and vein quartz and sand; rich in phosphatised shell fragments.

The fine sandstones are characteristically composed of well-sorted fine grained sands and the presence of polished quartz grains accompanied by phosphatised shell fragments. Primary structures are weakly developed and consist mainly of sub-horizontal bedding planes. Bioturbation in the form of branching mud-lined burrows is weakly developed. Where the latter are present the mud content rises to approximately 2 %.

The Upper Bioturbated Sand Member characteristically contains numerous branching, mud-lined burrows up to 15 - 25 mm in diameter. These burrows completely obliterate the primary structures which may have been present in the sand. This member is comprised essentially of slightly clayey fine sand with scattered medium sized gravels.

In contrast to the rest of the member the lower part contains large concentrations of marine fauna. The most spectacular layer in the lower portion of the Upper Bioturbated Sand Member is that from which large numbers of sharks' teeth were recovered (***Reference 10.11***). Overlying the Upper Bioturbated Sand Member is the Peaty Sand Member. This horizon, which is present throughout the excavation areas at Koeberg, is characterized by the presence of gastropod casts in a matrix of slightly clayey fine sand with scattered medium sized gravels and abundant organic material. The organics in this member have been dated by carbon-14 methods and yielded an absolute age of approximately 50 000 years; which is at the limit of this method. The presence of Miocene age faunal remains (penguin bones) (***Reference 10.38***) indicated that this horizon could be much older than this figure.

10.1.2.5.5 Springfontein Formation

This Formation is continuous through the Koeberg excavation and has also been recognised to the north of Koeberg at Springfontein. The Formation is sub-divided into two members: a Lower Gastropod Member and an Upper Arenaceous Member.

The Lower Gastropod Member is composed of fossiliferous fine, medium and coarse sand with scattered fine gravels. The horizon is characterized by abundant internal casts of gastropods, fish and shells, concentrated in laminae. Phosphatised shell fragments and gastropod casts abundant in the succession to this level are not found in the Upper Member of the Formation or elsewhere in the succession above this level.

The Upper Arenaceous Member comprises mainly sand of fine to coarse, grain size. In contrast to the 'green sands' of the Duynefontyn Formation these sands are pale yellowish-brown to very pale orange in colour. Except for one greyish orange-coloured coarse sand which is cross bedded, the member shows no obvious internal bedding structures and is horizontally bedded.

10.1.2.5.6 Bredasdorp and Witzand Formations

Bredasdorp and Witzand Formations described in the excavations at Koeberg (***Reference 10.34***) have been discovered both at Duynefontyn (***Reference 10.32***) and elsewhere north and south along the coast (***Reference 10.33***). As these upper horizons are widespread and well documented but of lesser importance to the determination of the age of the marine-cut bedrock platform than the Duynefontyn Formation, their lithologies will not be described in this report.

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10.1.2.6 Structural Geology and Tectonics

Except for the south-western corner of the SEC Pumphouse excavation the bedding of the bedrock beneath the power station and the pumphouses dips steeply to the west-south-west at angles of about 75° with a strike varying between 320° and 330° true north (***Reference 10.13***). In the south-western corner of the pumphouse excavation a portion of a synclinal fold structure is present and this feature represents the only observed deviation from the general structural nonfigurative pattern present in the bedrock at Koeberg Nuclear Power Station. The synclinal fold predates all ages of faulting found to exist in the bedrock of the excavations (***Reference 10.14***).

10.1.2.6.1 Faulting

Syntectonic folding-related shear zones are present along bedding plans of the north-north-westerly striking of strata (***Reference 10.14***). Post-folding fault- related shearing on bedding plans is also present. Two ages of strike and slip faults and related joints were recorded. The oldest of these comprises a conjugate fault system with associated extension fractures trending north-east / south-west while the younger direction is represented by an approximately east-west trending right-lateral strike-slip fault (***References. 10.13*** and ***10.14***).

The principal structural elements mapped during the supplementary geologic investigation include:

- *Transcurrent Faults* - a conjugate system of vertical to subvertical strike / slip faults, trending NNE and WNW occurs throughout the excavation. These faults generally occur in a discontinuous en echelon pattern whereby individual faults rarely exceed 20 m in length. In width, they range from hair line fractures to 0.5 m wide shear zones, frequently infilled with quartz veining and/or brecciated greywacke and mudstone cemented with pyrite and carbonate.

- *Thrust Faults* - low angle thrust faults dipping from 10° to 60° occur where wedge shaped rock units have been thrust westwards over an essentially undisturbed, underlying rock sequence

- *Shear Zones* - of 0.1 m to 3.0 m in width, these zones are commonly located within the less competent mudstones, the result of fracturing and differential movement between the more competent greywacke units. Displacement occurs as fracturing throughout poorly defined zones.

- *Mineralised Extension Fractures* - E to ENE trending extension fractures with steep northerly dips occur throughout the excavation for the power plant. The fractures are frequently infilled with vein quartz and/or gangue of carbonate/pyrite mineralisation. The quartz veins range in width from 5 mm to 50 mm and can be found to traverse all other shears and discontinuities in the excavation.

The mapping of the bed rock in the excavation indicates that faulting is localised and no major continuous shear zone parallel to the axial plane of the formation nor transcurrent faults or fault zones traverse the width and length. None of the shear zones or fault offsets mapped in the reactor excavation exhibit the tectonic characteristics (intense mylonitization, brecciation, fault mineralization lateral extent and width) which would be expected of a seismic active type fault.

Geologic and geophysical investigations indicate that no major NNW trending fault, similar in character to the Klipheuwel-Darling-Saldanha fault zone, occurs within 8 km of the site. The possible presence of minor faults or fault zones on Duynefontyn has been inferred from an aero magnetic and offshore survey. The most prominent magnetic feature, an inferred lithologic boundary along which dolertie dykes had been intruded, crosses the southern part of Duynefontyn. It was considered that this magnetic linear constitutes a potential zone of weakness along which faulting may have occurred. In addition, two NE trending possible faults were inferred in the site area by an apparent offset of the magnetic linear.

10.1.2.6.2 Palaeontology and Age of Faulting

Palaeontology has played an important role in the establishment of the age of faulting in the excavation bedrock and the information on which the conclusion regarding age relationships of the faulting has been drawn is not widely publicised.

Lamillibranch (pholad) borings, concentrated mainly on the softer rock types and in highly weathered zones, are ubiquitously present on the bedrock surface of the excavations (***References. 10.13*** and ***10.14***; Fig 7 of ***Reference 10.14***). These tubular borings were made by a rock-boring lamellibranch of the genus pholas and the borings penetrate up to 20 cm into the soft, weathered zone of the bedrock.

Of special significance was the identification of these borings in all fault / bedrock intersections investigated on the surface of the excavations at Koeberg. No indication of any tectonic deformation of these borings, by faulting, was observed during studies (***References. 10.13*** and ***10.14***).

The upper age of the borings is thus of paramount importance in establishing the minimum age of faulting. Preliminary work was carried out by Dr C Vogel of the NPRL in Pretoria. This study indicated a minimum age of 50 000 years (***Reference 10.14***) for the peat layer in the sands overlying the bedrock at approximately mean sea level. However further work (***Reference 10.27, 10.28, 10.29*** and ***10.32***) indicated a possible. middle-Miocene age (5×10^6 years) of the uppermost sedimentary formations at Koeberg. Finally, a study of the fauna and flora in the overlying sands conducted by members of the Geological Survey of South Africa (***Reference 10.35***) concluded that the lower sand layers are greater than 5×10^6 years (***References. 10.35*** and ***10.38***).

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Mapping in the excavation has revealed that in many parts mineralised extension fractures crosscut and therefore, post date older generations of shear zones and fault offsets. Petrologic investigations of the vein quartz show no signs of post crystalline deformation other than microfractures. As rock borings of Pholididae have been found on undisturbed quartz veins, these veins must have formed prior to the existence of the wave cut platform of the Malmesbury rocks at the site.

10.1.2.6.3 Correlation of Regional Tectonics with the Excavation Investigations

Regional Tectonics	Observations from the Excavation
Folding of the Malmesbury Group prior to intrusion of the Cape-Granite suite	The rock formation present in the excavation represents the western limb of an anticline with a near horizontal NNW trending fold axis.
Intrusion of the Cape-Granite suite along major NNW trending zones of crustal weakness. The last phase of granite intrusions occurred approximately 500 million years ago.	No evidence has been found during the recent geologic investigations, that quartz veining observed in the bedrock of the excavation is related to hydrothermal activity of Cape Granite intrusives.
High level, cataclastic deformation along major NNW trending fault zones continued into the Mesozoic.	No major fault or shear zones spatially related to this phase of deformation occur in the Koeberg excavation. The pervasive fracture and shear pattern present in the bedrock of the excavation appears to have resulted from a tectonic episode having a principal stress in a east-west direction.
	Following the last phase of tectonic deformation, quartz mineralization was introduced into shear zones, faults and E to NE trending extension fractures. This mineralization must have precipitated under higher pressure/temperature conditions than now occur at the site, and hence prior to erosion and planation of the Malmesbury Formation.

10.1.2.7 Conclusion on Surface Faulting

In summary, the regional and site area investigations have concluded that zones of seismically active or capable faulting lie no closer to the site than 8 km.

The detailed geologic mapping and evaluation of bedrock exposed in the excavation for Units 1 and 2, Koeberg Nuclear Power Station have indicated that fault movement could not have occurred later than 500 000 years ago. No evidence has been found that faulting affected the wave cut platform of bedrock underlying the Koeberg site after deposition of unconsolidated sediments which have a minimum age of 500 000 years and a probable age of several million years.

It is concluded that the nature of the geologic features exposed in the excavation for Units 1 and 2 Koeberg Nuclear Power Station do not indicate any potential for surface rupture and no adverse geologic features or conditions exist which could effect location or construction of the Koeberg Power Station.

10.1.3 SEISMOTECTONIC MODEL FOR THE REGION

10.1.3.1 General

The bridge between the geological and seismological databases and any calculation model for deriving hazard levels is the regional seismotectonic model. It is possible that a number of such models will explain the observed seismological, geophysical and geological data equally well and the final hazard assessment should take account of all these models.

In the case of ground motion hazard, the concern is with seismogenic structures where the combination of location and earthquake potential would affect levels of motion at the site. In the case of surface faulting hazard, the concern is with those seismogenic structures which have the potential for relative displacement at or near the ground surface.

Within the limitations of the various elements of the database, a set of discrete seismogenic structures are identified from the regional and site geological and tectonic investigations.

To account for seismic activity which cannot be attributed to specific structures, diffuse seismicity is included in the model as seismotectonic provinces, assumed to encompass areas of equal seismic potential.

10.1.3.2 Seismic Occurrences in the Western Cape

The relationship of seismic occurrences with tectonic structures in the south-western Cape Province was documented and dealt with in the ***References 10.7, 10.10, 10.42***. The known seismic history of this region dates back some 350 years. Prior to 1809, several low intensity shocks of modified Mercalli scale (MM) III-IV were reported in the Cape Town area.

In 1809, a damaging earthquake occurred near Milnerton on 4 December. Damage in Cape Town itself was limited but mud boils, extensive cracks in superficial material and water spouts were reported from its epicentral area near Milnerton. Intensity may have reached VII-VIII (deduced Richter magnitude 6,0). Aftershocks continued until 12 December 1809.

Between the 1809 shock and the Ceres earthquake of 1969 a number of tremors were felt in the south western Cape Province, generally with intensifies MM III to V. A severe shock (MM VI) occurred near Cape Town on 2 June 1811, while smaller events were reported from Piketberg (1819) and Saldanha Bay (1926).

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An earthquake caused slight damage at Tulbagh on 9 October 1921 (assigned intensity MM VI). In the Darling area a series of tremors was felt between 11 and 13 August 1926 (intensity MM III-IV) and again on 19 August 1937 (intensity MM IV).

A sharp earthquake (MM VI) was felt all over the Western Cape Province, strongest in the Worcester - Ceres area, on 27 August 1963. This earthquake was followed by several lesser shocks on 18 September 1963.

A few minor shocks occurred in the Southern Cape during the next ten years and on 29 September 1969, a severe shock rocked the Ceres-Tulbach-Wolseley area, causing extensive damage and death. This shock had an epicentral intensity of MM VIII-IX (measured Richter magnitude 6,3) and was felt all over the Western Cape. This earthquake was followed by numerous after shocks, some of which were quite severe in themselves.

Several tremors occurred in the Ceres-Tulbagh area in the following year. Most severe of these was the 14 April 1970 shock with an epicentral intensity of MM VII (magnitude 5,7). Still another shock (MM IV) was felt in the same area on 19 September 1971.

A more detailed description of the seismic history is given in ***References 10.43, 10.31***.

10.1.3.3 Association of Earthquakes with Tectonic Structures

Recent geologic investigations (***Reference 10.11***) indicated that earthquakes are likely to be associated with major NNW trending fault zones in the south-western Cape Province. These discontinuities are of regional extent and characterised by intense ductile and brittle deformation that may have lasted into mid-Cretaceous times associated with the South Atlantic rifting. Two fault zones, the Saldanha-Darling-Franschhoek and the Piketberg-Wellington fault zones separate geotectonic domains. There is evidence that important north-westerly striking dislocations occur elsewhere particularly between Cape Hangklip and the Cape Flats area and further inland, in the Tulbagh-Wolseley area.

A plot of the earthquake epicentres of the south-western Cape Province shows the following close association of earthquakes with major tectonic structures (***Reference 10.11***).

- Postulated Cape Hangklip fault zone

  The MM VII-VIII Milnerton shock of 1809 occurred very close to this postulated fault zone. It is certainly possible that many smaller earthquakes recorded in the Cape Town area may have been located close to this postulated regional feature as well. In most cases historical accounts for the Cape Town events indicate motion and audible effects of the shocks passing from NW to SE. This is in general agreement with the NW strike direction of the Postulated Milnerton-Cape Hangklip fault zone.

- Saldanha-Darling-Franschhoek fault zone

  There have been several earthquakes which are remarkably well aligned with this fault zone, namely:

  A severe tremor "early 1826" at Saldanha Bay, MM IV.

  A series of earthquakes in the Darling area from 11 to 13 August 1926, MM III-IV.

  A further tremor was reported at Darling in 1937, MM III.

  Two noticeable earthquakes occurred in 1947 in the St. Helena Bay area near Cape Columbine and Paternoster, MM IV-V.

- Postulated Piketberg-Bridgetown-Worcester fault zone

  It is likely that a major abyssal structure continues from Piketberg through Bridgetown in a south-easterly direction towards the Tulbagh-Wolseley area linking up with the Worcester and associated faults.

  A MM III tremor was noted at Piketberg in 1819, adjacent to this postulated fault zone.

  In recent years the Tulbagh-Wolseley area has shown the most earthquake activity culminating- in the 1969 Ceres event (magnitude 6.3; MM VIII-IX). The focal mechanism of this shock indicates a NW-SE trending nodal plane with left lateral shear. The aftershock sequence including the MM VI 1970 event, further supports this trend.

There is good evidence that major discontinuities, namely the three above named fault zones are the loci for earthquake occurrences in the south-western Cape Province. While small earthquakes with epicentral intensifies of MM VI or less might be expected anywhere in the region, the occurrence of larger events would be expected to be confined to these zones of major faulting.

10.1.3.4 Seismotectonic Model

There is reasonable justification, from a tectonic standpoint, to assume that the earthquakes in the south-western Cape area are associated with major structural discontinuities. The methods by which this association can be made comprise spatial distribution and association, isoseismal alignments, focal mechanism solutions and the distribution of the aftershocks of the 1969 Ceres event.

Hence, the above named fault zones are considered 'seismically active' as defined in the IAEA 'Safety Guide on Earthquakes and Associated Topics for Nuclear Power Station Siting' and are located with respect to the Koeberg site as follows:

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- The postulated Piketberg-Bridgetown-Worcester fault zone occurs over 70km to the NE of the site.
- The Saldanha-Darling-Franschhoek fault zone at its closest approach is located approximately 18 km from the site.
- The postulated Milnerton - Cape Hangklip fault zone which is observed not to approach closer than 8 km to the site.

While small earthquakes with epicentral intensities of MM VI or less might be expected anywhere in the region, the occurrence of larger events would be expected to be confined to zones of major faulting.

The seismotectonic provinces are defined between these seismogenic structures as follows

- The Southwestern Province comprising the site, are characterised by a rather uniform regional style of deformation. The primary mode of deformation is isoclinal folding about WNW -ESE to NW-SE axes.
- The Central Province lying between the Saldanha-Darling-Franschhoek and Piketberg-Bridgetown-Worcester fault zones. There exists a major difference in the severity of deformation between the central block and those that flank it on either side.
- The Northeastern Province separated from the central province by the Piketberg-Bridgetown-Worcester fault zone has a much simpler structural style.

Recent geologic investigations have shown no evidence to suggest that Tertiary or recent sediments are faulted in the site area. The last fault movement as can reasonably be surmised, is likely to have occurred during Mid-Cretaceous rifting - some 110 million years ago.

Seismic active faults viz. the postulated Milnerton-Cape Hangklip and the Saldanha-Darling-Franshoek fault zones approach no closer to the site than 8 km and 18 km respectively. Faults and shear zones inferred or known to occur within 8 km of the site conform neither directionally, nor in mineralogic characteristics or tectonic style with 'seismic active fault zones' in the region.

In addition, no seismic events been recorded within 20 km of the site during historic times and hence, it is concluded that surface faulting does not present a risk to the Koeberg Nuclear Power Station.

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10.1.4 DETERMINATION OF DESIGN BASIS GROUND MOTION

10.1.4.1 General

Determination of the design basis ground motion is based on the seismotectonic model. The ground motion should be defined by appropriate response spectra, having a range of damping values, and time histories in free field conditions either at the surface of the ground, the level of the foundations or on bedrock, as input for the design process. Parameters such as amplitude, frequency content, attenuation and duration of ground motion should be given for the design basis.

- *Deterministic Technique:* involves reducing the seismotectonic model to seismotectonic provinces and seismogenic structures each having an associated maximum earthquake potential. The maximum potential earthquake is assumed to occur at a point closest to the site for each seismogenic structure, whereas in the case of a tectonic province, it is assumed to occur at an arbitrary agreed distance, generally at the boundary of the tectonic province closest to the site. The best estimate of the focal depth of such events as well as their physical dimensions are also considered. An appropriate attenuation relationship is used to calculate the ground motion level which each of the events could cause at the site, taking into account local site conditions.

- *Probabilistic Techniques:* are required when risk analyses will be conducted at a later date. They involve the idealisation of the seismotectonic model in terms of source type, geometry and depth. For each source type the magnitude frequency relationship, maximum magnitude and attenuation with their associated uncertainties are described. Evaluation of the best estimate hazard curve with appropriate confidence intervals using particular stochastic models (eg, Poisson, Markov, cluster, renewal).

10.1.4.2 Maximum Earthquake Potential

The limiting magnitude size is much more critical for the deterministic method where it is recommended that this event occurs at the closest point to the site from the fault or seismic source region. An estimate on the limiting magnitude was necessary for Koeberg because of its closeness to the postulated Milnerton - Cape Hangklip source zone.

Data from the seismic catalogue within a radius of 400 km was used to determine the Gutenberg - Richter recurrence curve having the equation $\log(N) = 5.88 - 0.93\,M$: where N is the number of events equal to or exceeding a magnitude M. The use of these recurrence rates using a Type III extreme value distribution of Gumbel, although often used in practice, was found not to be reliable in estimating the maximum magnitude of earthquake. An alternative method, developed by Nuttli, was employed which indicated a maximum magnitude of 6.5.

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In considering the geologic and tectonic data, it was concluded that the two largest events (1809 Milnerton, M=6.0 assumed ; and 1963 Ceres, M=6.3) which have occurred in the south western Cape region are consistent in magnitude with the maximum earthquakes in Cratonic environments of a similar setting, worldwide. It was also concluded that the large NW - SE trending fault zones, including the postulated Milnerton - Cape Hangklip zone, would be the sources of future earthquakes with epicentral intensities larger than MM VII (M = 5.5).

An earthquake of magnitude 6.5 consistently envelopes the worldwide data on maximum earthquakes in a stable tectonic setting where no surface fault rupture is evident. Therefore, it was concluded that from both seismological and geologic points of view that an event of Magnitude 6.5 is the most likely maximum magnitude for the region surrounding Koeberg site.

10.1.4.3 Ground Motion Attenuation

Very little data on attenuation is available in South Africa which is based on actual measurement. As part of this investigation, velocity measurements were recorded of a series of explosions in Cape Town harbour. Also, a set of 20 isoseismal maps was used in preparing a data set of distance, intensity and magnitude. Averaged worldwide data, relating ground motion levels to intensity levels, was then used to develop a relationship between acceleration and intensity.

A least squares approach was then applied to obtain an attenuation relationship having the parameters of acceleration, magnitude and distance. Where comparison was made with relationships using focal depth, it was assumed that the events are shallow having focal depths of 15 km. The similarity of the relationship developed for the site region using isoseismal data to others derived directly from strong motion records is readily apparent and confirms the assumption that the attenuation in South Africa is very similar to that which has been observed in western North America.

10.1.4.4 Seismic Hazard Assessment

10.1.4.4.1 Deterministic Approach

A decision was made after discussion with the relevant authorities, that the maximum event size and the associated Safe Shutdown Earthquake (SSE) should be considered as local magnitude 7.0, in conjunction with the attenuation relationship developed in this investigation. The postulated Cape Hangklip - Milnerton fault zone was not subjected to a detailed geologic and geophysical study to establish its potential activity but rather included as one of the three fault zones which could produce the maximum event.

Hence the SSE is defined as an event with a local magnitude of 7.0 at a distance of 8 kilometres from the site. Using the attenuation equation developed, a peak acceleration of 0.3g is obtained. A somewhat higher acceleration was obtained for the Damage Study Earthquake (DSE) by specifying a local magnitude 6.5 event occurring at the same distance from the site but having a peak acceleration assuming the attenuation equation is fixed at one standard deviation above the mean value. This is a value of 1.74 times the mean value or a peak acceleration of 0.36 g.

The vertical SSE accelerations were set at two-thirds of the horizontal values based on the two-thirds factor used by the United States NRC which is recognized as conservative (Hall, et al, 1976).

In addition, a 'distant' event on the fault zone inland from Koeberg was specified as a Magnitude 7 event occurring at 17 kilometres from the site. For this event, the peak horizontal acceleration value is 0.24g.

TABLE 10.5
HORIZONTAL ACCELERATION VALUES

	Estimated Magnitude	Distance (km)	Attenuation Equation Type	Peak Acceleration (g)
SSE	7.0	8	Mean	0.3
Damage Event	6.5	8	Mean + 1 Sigma	0.36

10.1.4.4.2 Probabilistic Approach

Generally, integration is incorporated across the attenuation relationship which allows direct inclusion of the uncertainty of such relationships. However, for Koeberg where accident risk probabilities are being assessed and calculated for all hazards, the annual probability of exceedence of the different ground motion levels were computed using the mean relationship only.

The activity rates assigned to the fault sources representing the fault zones assumed that the total activity would come from these zones and that this activity would be comparable to the activity during the 70 year period of record. The activity rate was 1.5 x 10^{-4} events/year/km^2 for events of magnitude 4 or larger. The recurrence curve b value used was 0.93. A small background activity rate was also applied to the remaining region.

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The activity rate used is based on the activity within 100 kilometres of the Koeberg site. The historic data lists 63 events with magnitude greater than 4 within this distance. Of these 25 were possible aftershocks of the 1969 Ceres earthquake. The assigned activity rates are therefore biased in a conservative way by the incorporation of the total data.

The results of the analyses are extrapolated to a probability of exceedance $1x10^{-6}$ per annum with the assumption that at this probability, the curves become asymptotic to the limiting value which is represented by the contribution of the point closest to the site on the nearest active source zone. In this way the values for the probabilistic study have approached asymptotically and become equal to those given in the previous section using deterministic procedures.

The vertical ground motion levels were not chosen on the basis of a probabilistic study_but set for the SSE at two-thirds of the horizontal SSE ground motion.

10.1.4.5 Design Response Spectra

The velocity to acceleration ratio used for the development of the free field ground surface response spectra for the existing soil conditions at the Koeberg site is 36 inches per second per unit of gravity.

The ratio of (acceleration x displacement)/(velocity)^2 was chosen as 6.

The spectral amplification parameters used have been taken from a reference prepared by Hall, et al, for the United States Nuclear Regulatory Commission and are listed below.

TABLE 10.6
SPECTRAL AMPLIFICATION PARAMETERS
(5 percent Critical Damping)

Event	Amplification Factors		
	Acceleration	Velocity	Displacement
Horizontal SSE	2.60	2.17	2.55
Vertical SSE	2.83	1.69	2.59
Horizontal DSE	1.92	1.46	1.84
Vertical DSE	1.99	1.17	2.00

Spectral amplification ratios equal to values one standard deviation greater than the mean value were used in developing the SSE spectra. As the damage level event acceleration value of 0.36 g has been taken as one standard deviation larger than the mean value of acceleration, the response spectra constructed from this acceleration value is based on the mean amplification ratios.

The approach, at the time, within the USNRC for vertical response spectra is to take the same spectral amplification factors as are used for horizontal motion and scale the entire spectrum by a factor of two-thirds. An analysis of seismic data corresponding to strike / slip fault motion was undertaken and a vertical to horizontal acceleration ratio of 0.6 was determined. The spectral amplification factors as determined in ***Table 10.6*** were however, used.

10.1.4.6 Duration

An estimate of the duration of shaking is required prior to developing time histories for design purposes. Published duration relationships were referenced and a duration of 30 s was selected for both the SSE and distant events.

10.1.4.7 Acceleration Time Histories

Acceleration time histories were generated such that the computed response spectra would approximate the recommended design spectra. The procedure used, superimposes sinusoids with random phase angles and an amplitudes given by a power spectral density function compatible with the desired response shape. The generation procedure incorporates a rise time of increasing intensity (5 s duration), a central portion of approximate uniform intensity (15 s duration) and a decay period (10 s duration).

The generated motions are more broad banded than recorded seismic events, resulting in higher response over a wider range of periods.

Response spectra contain no information regarding phase relationships between different frequency components and hence, considerable variation can occur between analyses using different acceleration time histories having similar spectra. It is necessary to use a number of time histories and then to utilise the average (rather than maximum) of the results to produce a design similar to that which would be obtained by direct use of the response spectrum.

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Figure 10.1
PUMPING TEST IN ROCK UNDER FOUNDATION AREA
BOREHOLE LAYOUT - BEDROCK PERMEABILITY TEST PROGRAMME

BOREHOLE NO.	SERIAL NO.
N 02	801
N 01	802
PW	803
E 01	804
E 02	805

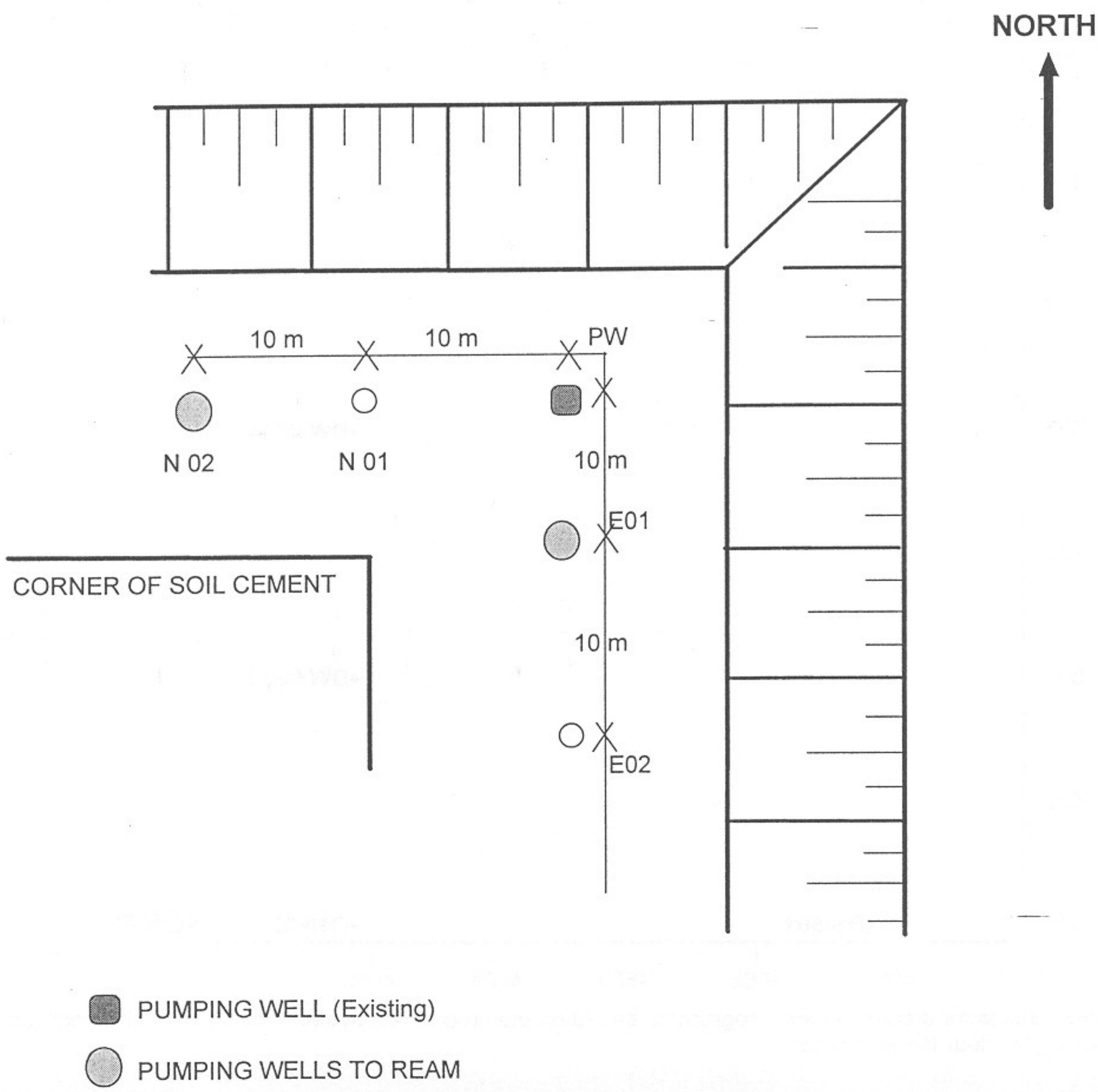

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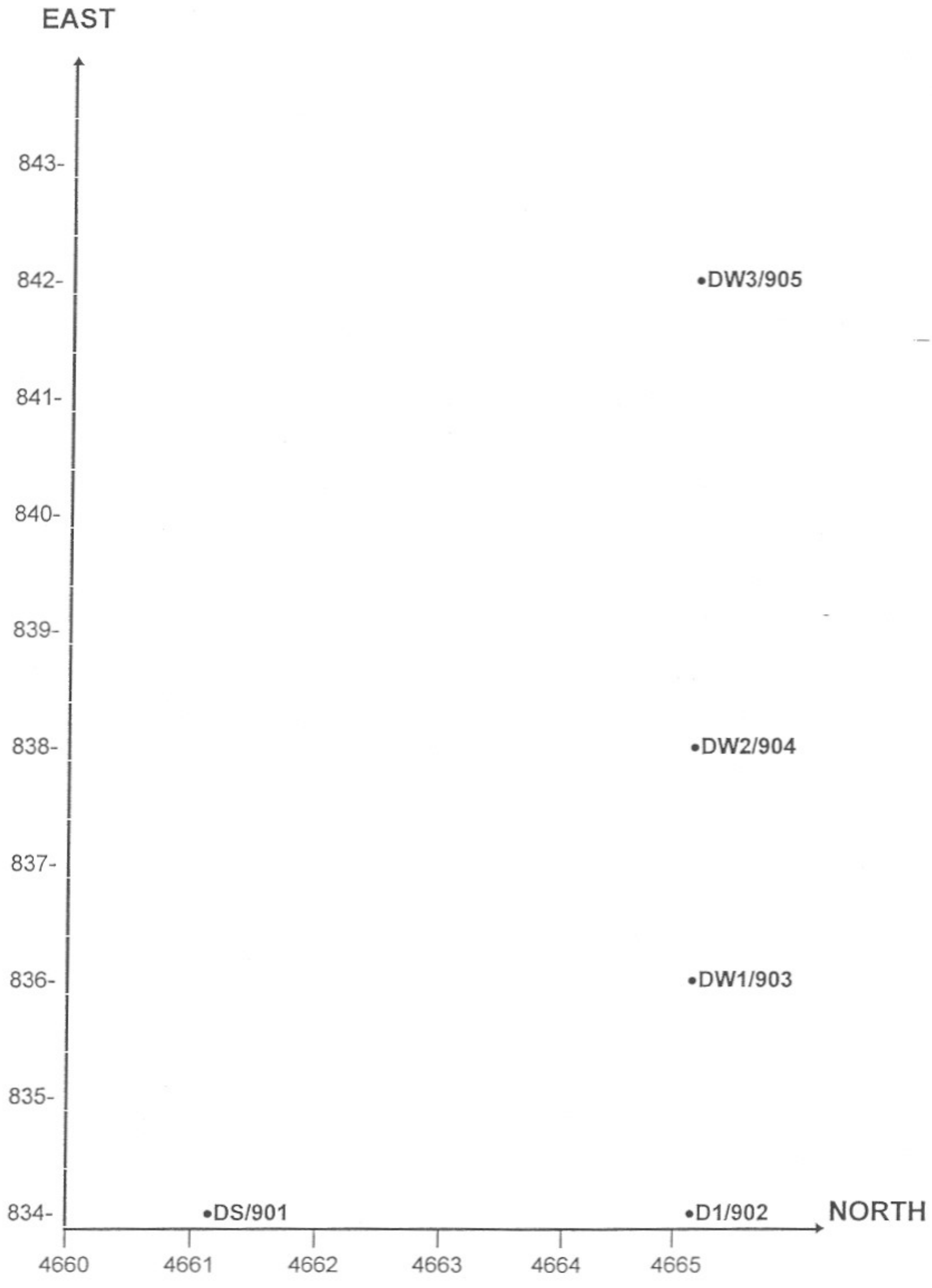
Figure 10.2
BOREHOLE LAYOUT - SOIL DISPERSION TEST PROGRAMME
FOR GROUND WATER SIMULATION



Position of holes for dispersion test programme based on the co-ordinate system used by the civil contractors at Koeberg Nuclear Power Station.