ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION ("NUCLEAR-1") AND ASSOCIATED INFRASTRUCTURE

Geological Hazard Environmental Impact Report

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DECLARATION OF INDEPENDENCE

We, **Erna Hattingh** and **Johann Neveling**, as duly authorised representatives of the **Council for Geoscience**, hereby confirm our independence (as well as that of the **Council for Geoscience**) as specialists and declare that neither of us or the **Council for Geoscience** have any interest, be it business, financial, personal or other, in any proposed activity, application or appeal in respect of which Arcus GIBB was appointed as environmental assessment practitioner in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), other than fair remuneration for worked performed, specifically in connection with the Environmental Impact Assessment for the proposed conventional nuclear power station ('Nuclear 1'). We further declare that we are confident in the results of the studies undertaken and conclusions drawn as a result of it – as is described in our attached report.

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EXECUTIVE SUMMARY

In general the impact of a Nuclear Power Station on the geological environment is smaller compared to the potential impact that the geological environment may have on the proposed Nuclear Power Station. Geological investigations are guided by Nuclear Regulatory Codes, especially U.S. Nuclear Regulations, which are regarded as the leading international regulatory framework, and geoscientific investigations which are guided by the increasing resolution in consecutive regulatory radii of 1, 8, 40 and 320 km around each proposed site.

A number of different geological factors are considered here, including:

- Locally induced (by the steam turbines) vibratory ground motion at the site;
- Surface rupture;
- Subsurface stability; and
- Volcanic risk.

Available geological data on the three sites being considered for installation of a nuclear power plant, Thyspunt, Bantamsklip and Duynefontein, has been reviewed regarding the above-mentioned risk factors. This showed that the geological risk regarding the above-mentioned risk factors is low at all three proposed sites. However, additional neotectonic studies still need to be completed and the results submitted to the National Nuclear Regulator as part of the Site Safety Report submissions. These studies, which will be done separately from the EIA process, may impact and even change conclusions reached to date, and therefore no final conclusions can be made about site suitability.

Geologically, there are no sensitive areas that need to be avoided at the Bantamsklip and Duynefontein Sites. At the Thyspunt site the foundation of critical structures should not cross the contact between the Goudini and Skurweberg Formations.

A decision not to proceed with a Nuclear Power Station will have no impact on the geology at the Thyspunt, Bantamsklip or Duynefontein sites.

A minor risk to subsurface stability exists at the proposed Duynefontein site.

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GEOLOGICAL HAZARD

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APPENDICES

Appendix 1 International stratigraphic chart of the International Commission on Stratigraphy.

LIST OF ABBREVIATIONS

AEC	Atomic Energy Corporation
CFR	Code of Federal Regulations
CGS	Council for Geoscience
EIA	Environmental Impact Assessment
GIS	Geographic Information System
IAEA	International Atomic Energy ***Agency***
M	Magnitude
Ma	Million Years before present
NECSA	***South African*** Nuclear Energy Corporation
NSIP	Nuclear Siting Investigation Programme
SHA	Seismic Hazard Analysis
SSE	Safe Shutdown Earthquake
SSR	***Site Safety Report***
SRAFA	Safety Report And Final Assessment
SSEGM	Safe Shutdown Earthquake Ground Motion
USNRC	US Nuclear Regulatory Commission

GLOSSARY OF TERMS

Aeolian	Windblown origin.
Anticline	A convex-upward fold structure.
Brecciated	A rock structure characterized by angular rock fragments.
Calcarenite	Calcareous sediment in which a high percentage of the clasts can be of quartz within a calcareous matrix.
Décollement	A fault surface parallel to a mechanically weak horizon that detaches or separates deformed rocks above from undeformed or differently deformed rocks below.
Dyke	Intrusive, sheet like body of igneous rock.
Fault	A rock fracture which shows evidence of relative movement.
Fluvial	A term that refers to river deposits and processes.
Igneous	Rock type formed by the cooing and solidification of a magma.
Mafic	Silicate minerals, magmas, and rocks that are relatively high in the heavier elements, such as magnesium, iron, calcium and sodium.
Marine	A term that refers to geological process active in, and deposits formed in the ocean.
Neotectonic	The study of the post-Miocene structural history (i.e. the last 5 million years) of the earth.
Pluton	A body of igneous rock that formed through crystallization from molten magma below the earth's surface.

For Geological Ages see attached ICS international stratigraphic chart.

1 INTRODUCTION

1.1 Background

1.1.1 General

This report is a specialist assessment of geological, structural geology and tectonic data to be included in the Environmental Impact Assessment (EIA) report to be compiled by Arcus GIBB (Pty) Ltd. The report describes and assesses the scope of available data and investigations pertinent to the ***suitability*** of three sites for a new proposed Nuclear Power Station in South Africa.

The geological assessment forms part of the EIA and its primary purpose is to provide input for the seismic hazard analysis and geotechnical investigations. However, several other geological risk factors, such as the potential for surface or near-surface deformation, sub-surface and surface stability, are also assessed.

The regulatory guidance set out in the US Nuclear Regulatory Commission (USNRC) Standard Review Plan NUREG-800 is favoured, since it represents a well tested and credible international methodology. Hence, geoscientific information in this section is provided with specific reference to Chapters 2.5.1 to 2.5.5 of the NUREG-800 for Chapter 13 of a Site Safety Report (SSR). These requirements form the basis for the EIA report and entail on- and ***offshore*** geoscientific investigations in progressively greater detail closer to the site. Radii of 320 km (regional), 40 km (semi-regional), 8 km (site vicinity) and 1 km (site specific) constrain the envelopes that describe the required detail of the investigations (**Figure 1.1**).

1.1.2 Site Location and Physiography

Following a lengthy Nuclear Siting Investigation Programme (NSIP) and environmental scoping process, Eskom identified three localities along the South African south and west coast as preferred sites for Nuclear-1. They are: Duynefontein which is located about 25 km ***north*** of Cape Town in the ***Southwest*** Cape at latitude 33.675° S and longitude 18.433° E (WGS84); Bantamsklip located at latitude 34.707° S and longitude 19.553° E (WGS84), about 25 km ***southeast*** of Gansbaai along the ***Southwest*** Cape coastline; and Thyspunt, approximately 14 km west of Cape St. Francis along the Eastern Cape coastline, at latitude 34.192° S and longitude 24.715° E (WGS84) (**Figure 1.1**).

The coastline at Duynefontein (**Figure 1.2**) is dominated by sandy beaches with intermittent ragged outcrops and gullies in quartzitic greywacke of the Tygerberg Formation of the Malmesbury Group. About 20 m of sand belonging to the Cenozoic-age Sandveld Group covers the bedrock at the site terrace. Light grey calcified dune sand and calcarenite crop out amongst the generally white to light grey calcareous sand of the Witzand Formation.

Figure 1.1: **Location of the Proposed Nuclear Power Station Sites and regulatory radii that guide geological investigation, and most important towns.**

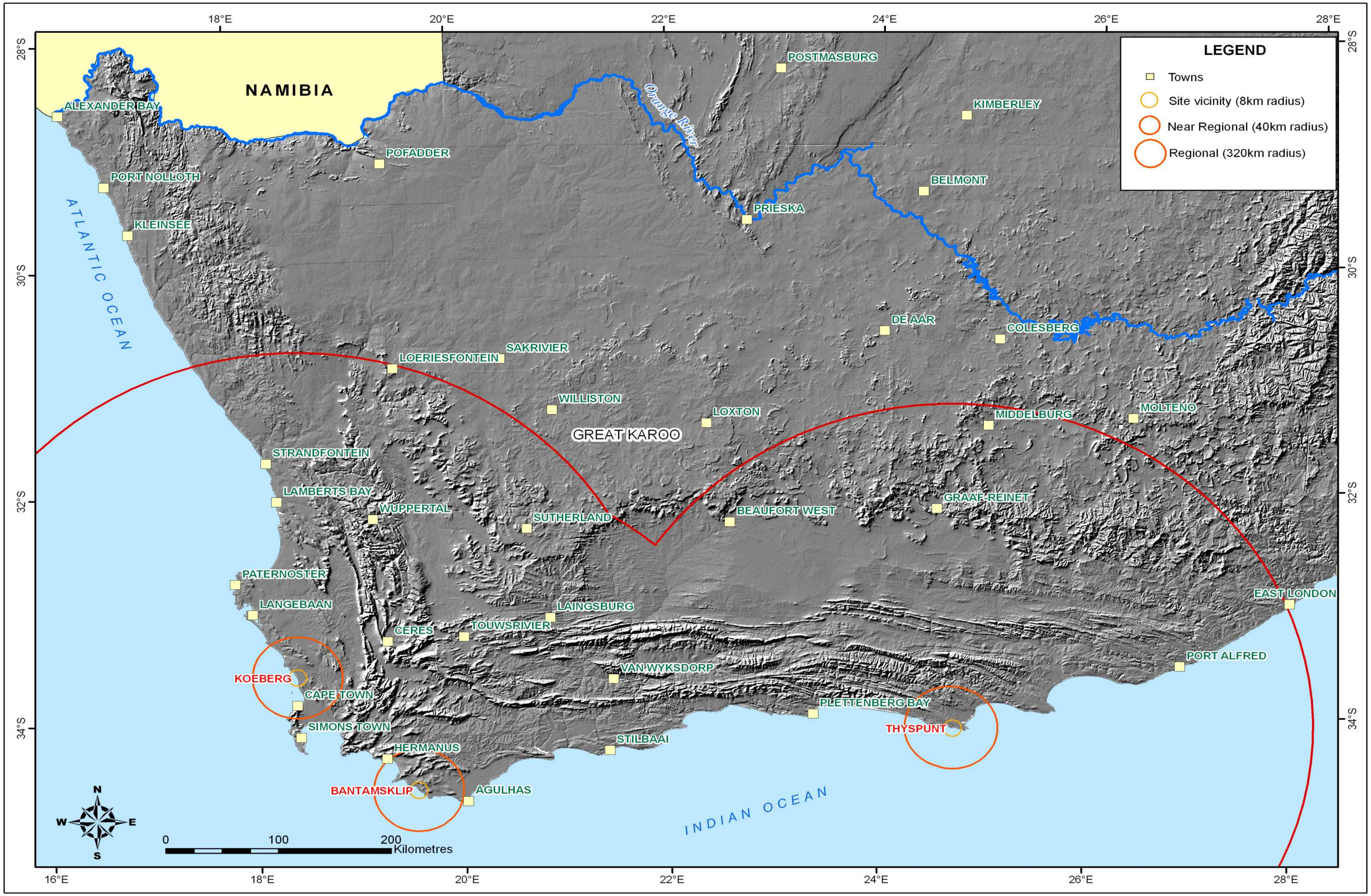


Figure 1.2: Topographic map of the Duynefontein Site area with the 8 km and 40 km radii that guide geological investigation

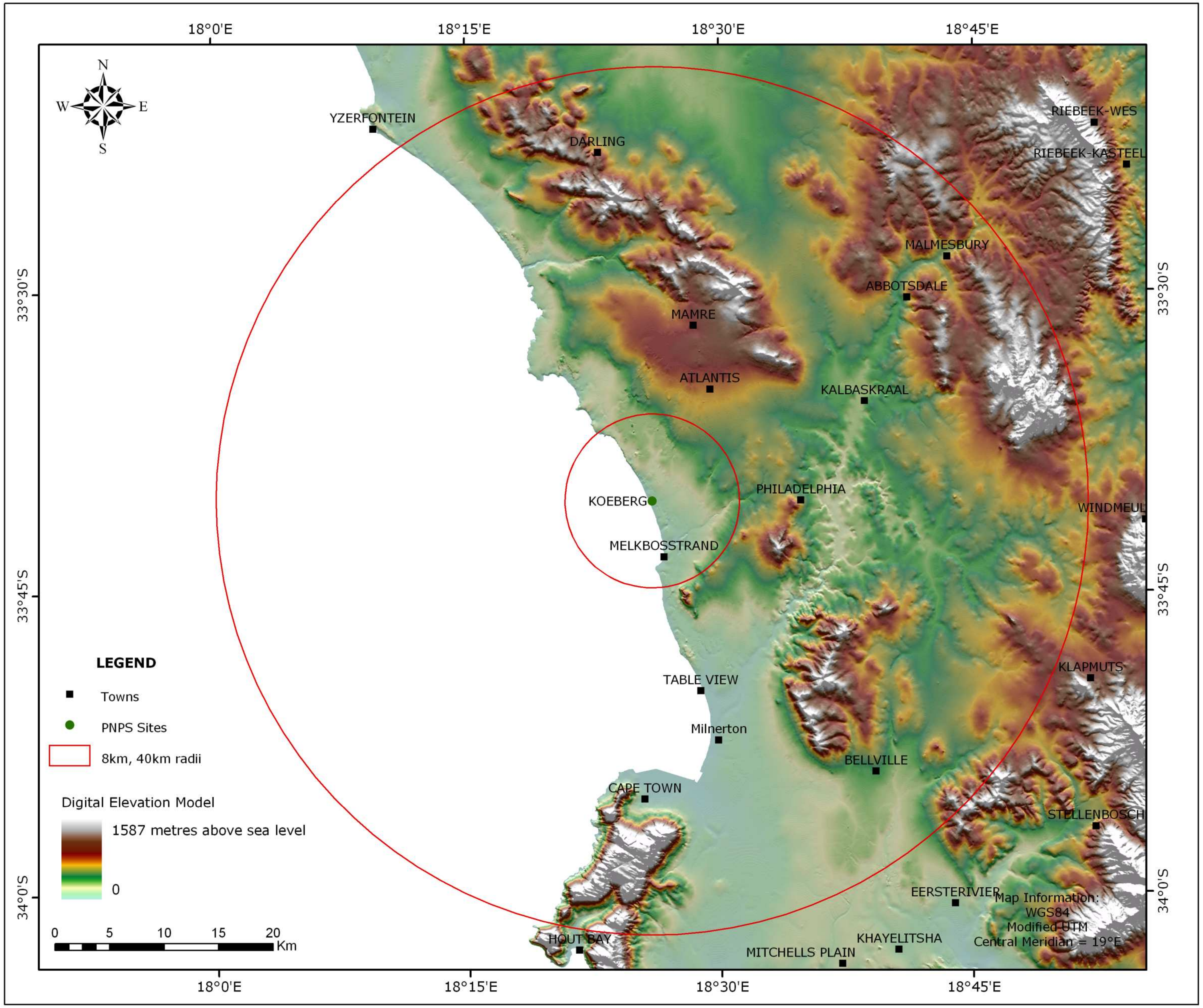
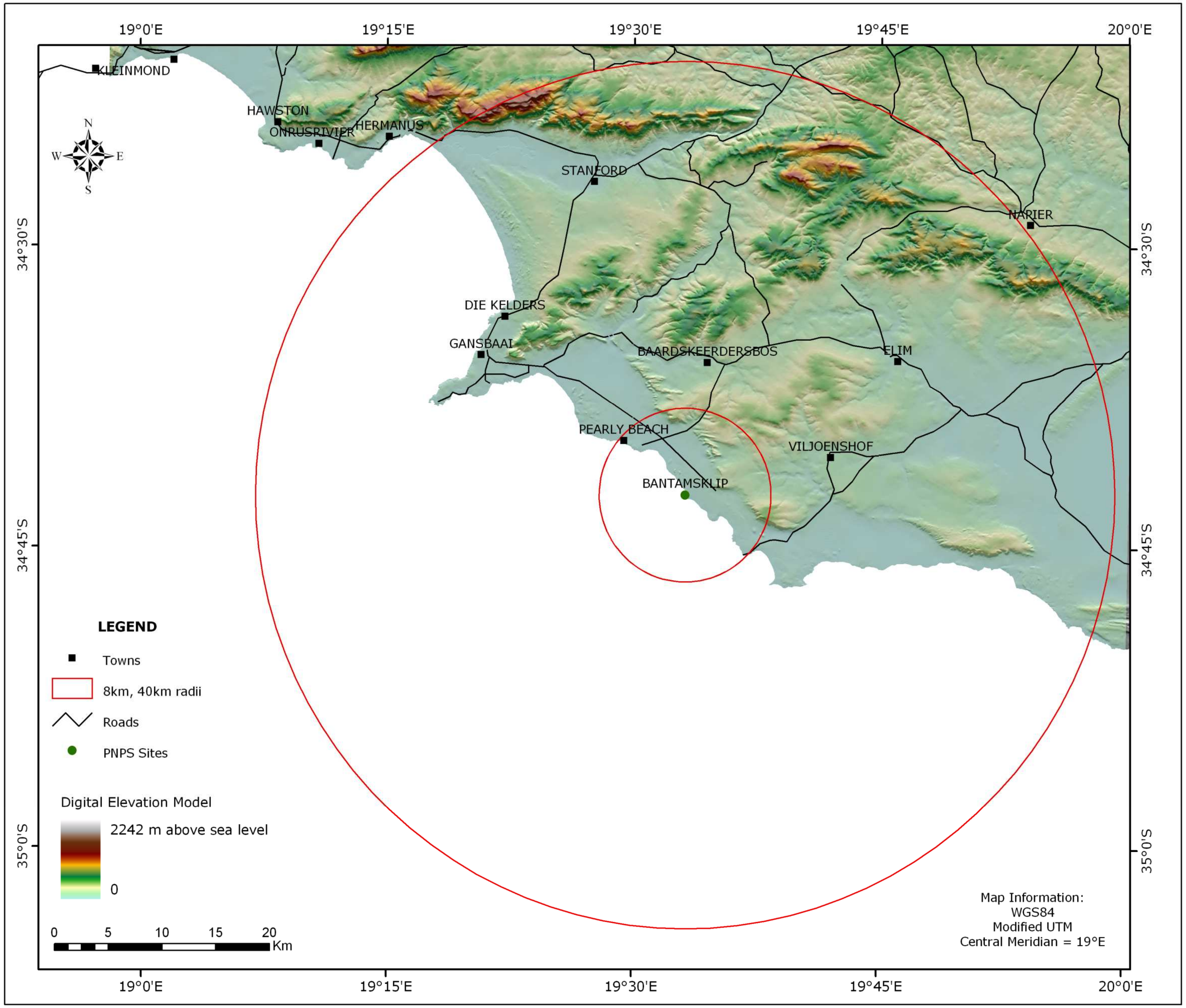


Figure 1.3: **Topographical map of the Bantamsklip Site area with the 8 km and 40 km radii that guide geological investigation**



A much more rugged coastline is found at Bantamsklip (**Figure 1.3**), dominated by ragged outcrops and gullies developed on fractured and faulted, well-bedded quartz arenites of the Peninsula Formation. A flat coastal terrace covered with white sand and grassy vegetation occurs between the rocky coastline and first dunes at Bantamsklip. Semi-consolidated, vegetated dunes persist to the road between Gansbaai and Buffeljags, north of which lies an extensive flat sandy plain with fynbos and local wetlands. The plain ends against a relatively straight 50 m Late Pliocene-age shoreline eroded into hills composed of calcarenite, and laterally against promontories of resistant rocks of the Table Mountain Group.

The Thyspunt area (**Figure 1.4**) is characterized by a relatively flat-lying to gently seaward-sloping coastal platform. Near the coastline, this platform is covered by a remnant thin veneer of weathered Cenozoic-age marine and aeolian (windblown dune) sediments, and buried by modern linear E-W dunes forming headland bypass dunefields. The landward extremity of the transgressive Miocene marine planation event that lead to the development of the platform is indicated by a palaeo-sea cliff developed along the southern foot of the fold-belt mountains.

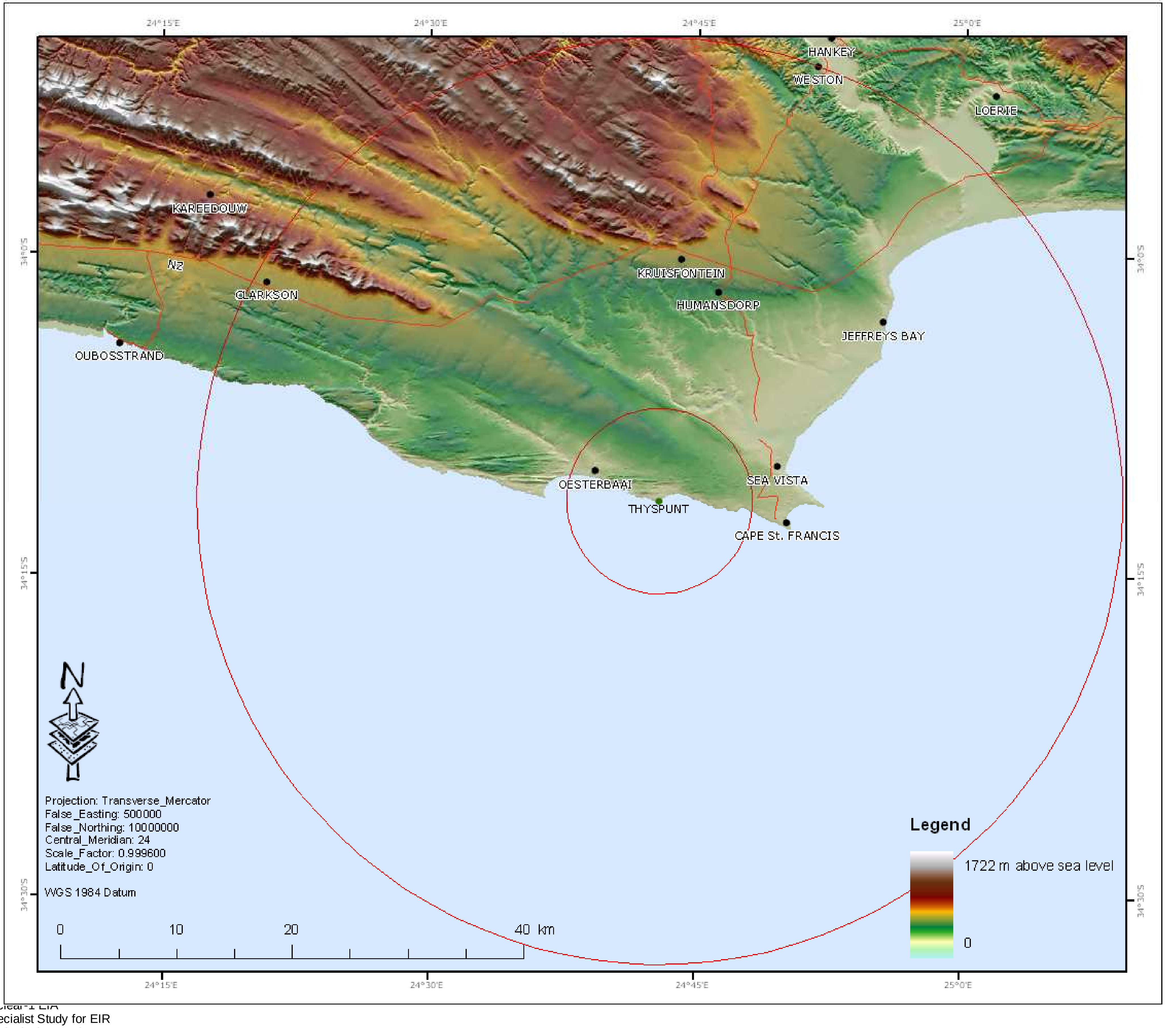
Several headlands and small embayments dominate the coastline at Thyspunt. This is due mainly to the underlying anticlinal and synclinal fold structures. Headlands are related to the more resistant lithological units in the Table Mountain Group (e.g. Peninsula and Skurweberg Formations) and the embayments correspond to softer, more easily eroded stratigraphy in this Group (e.g. Cedarberg, Goudini and Baviaanskloof Formations), or the overlying Bokkeveld Group (e.g. Gydo Formation at the base of the Ceres Subgroup).

1.1.3 Terms of Reference

General Terms of Reference as supplied by Arcus Gibb (Pty) Ltd are detailed below:

- Describe the baseline conditions that exist in the study area and identify any sensitive areas that would need special consideration;
- Ensure that all issues and concerns and potential environmental impacts relevant to the specific specialist study are addressed and recommend the inclusion of any additional issues required in the Terms of Reference, based on professional expertise and experience. Also consider comments on the previous specialist studies undertaken for the Nuclear Siting Investigation Programme (NSIP) undertaken during the 1980s-1990s;
- Provide a brief outline of the approach used in the study. Assumptions, sources of information and the difficulties with predictive models must also be clearly stated;
- Indicate the reliability of information used in the assessment, as well as any constraints/limitations applicable to the report (e.g. any areas of insufficient information or uncertainty);
- Identify the potential sources of risk to the affected environment during the construction, operational and decommissioning phases of the proposed project;
- Identify and list relevant legislative and permit requirements applicable to the potential impacts of the proposed project;
- Include an assessment of the “no go” alternative and identified feasible alternatives;
- Assess and evaluate potential direct and indirect impacts during construction operational and decommissioning phases of the proposed project;

Figure 1.4: Topographical map of the Thyspunt Site area with the 8 km and 40 km radii that guide geological investigation



- Identify and assess any cumulative effects arising from the proposed project;
- Undertake field surveys, as appropriate to the requirements of the particular specialist study;
- Identify areas where impacts could combine or interact with impacts likely to be covered by other specialists, resulting in aggravated or enhanced impacts and assess potential effects;
- Apply the precautionary principle in the assessment of impacts, in particular where there is major uncertainty, low levels of confidence in predictions and poor data or information;
- Determine the significance of assessed impacts according to a Convention for Assigning Significance Ratings to Impacts;
- Recommend practicable mitigation measures to minimise or eliminate negative impacts, enhance potential project benefits or to protect public and individual rights to compensation and indicate how these can be implemented in the final design, construction, operation and decommissioning of the proposed project;
- Provide a revised significance rating of assessed impacts after the implementation of mitigation measures;
- Identify ways to ensure that recommended mitigation measures would be implemented, as appropriate;
- Recommend an appropriate monitoring and review programme in order to track the effectiveness of proposed mitigation measures.

The Terms of Reference for the specialist Geology Assessments are:

- To provide a description of regional and site specific geology;
- Data collection – existing geology coverage (digital), topographic and topocadastral information (digital), air photos (colour digital, if available), satellite imagery, hydroclimatic coverage,;
- Geographic Information System (GIS) compilation of coverage and base plans containing above information. This is required for site reconnaissance, which is to identify land facets, site aspects, quarries and cuttings, and other relevant surface features to familiarise oneself with the expected ground conditions;
- Site reconnaissance: field inspection and documentation of relevant surface features, exposures (road cuttings, outcrops areas, accessibility, potential problem areas etc) as identified in RS & GIS-based desk-top surveys;
- GIS-based mapping of rock-type distributions around the (selected) sites;
- Field structural mapping of outcrop-scale bed-rock fracturing;
- GIS-compilation and interpretation of geological and structural data;
- GIS-compilation and interpretation of geophysical data;
- Identification of selected sites for pit sampling and trench-profiling;
- Logging of pits and trenches;
- GIS compilation and map integration of pit and trench data.

1.2 Study Approach

1.2.1 Regulatory Framework

The project concerns a range of proposed activities that have been identified in the schedule of activities listed in terms of section 24(4)(a) and (d) of the National Environmental Management Act, 1998 (Act No. 107, of 1998) in Government Notice No R 386 and R387 of 2006. Investigations required before environmental authorization of these activities can be considered must follow the procedure outlined in regulations 26 to 27 of the Environmental Impact Assessment Regulations.

The National Nuclear Regulator Act, 1999 (Act No. 47 of 1999) regulates the construction and running of nuclear power plants in South Africa. In addition geological and geophysical investigations done for the siting of a new Nuclear Power Station is subject to international regulatory requirements (IAEA, 2002). At present there are no specific South African regulations for seismic and geological issues related to the licensing of nuclear power plant sites, and thus Eskom decided to follow the US Regulations for Seismic Hazard Analysis (SHA) and associated geological work. This is because the US nuclear industry is well established and its regulations the most conservative as well as most readily understandable, tried and tested.

The Nuclear Regulatory Codes form the basis of all work conducted to date; therefore, compliance with these Codes and Regulations is essential. Geological and geophysical investigations are a requirement in all international regulations controlling the siting of new Nuclear Power Stations (see Regulatory Guide 1.208, USNRC, 2007). The necessity for such data arises in the first place from the need to identify seismic sources and to assess the potential for tectonic deformation at or near the surface, and secondly, to provide information that is necessary to calculate the local ground motions that can be expected at the site. It is a specific condition of the International Atomic Energy Agency (IAEA, 2002) that geological and geophysical studies for coastal sites should include offshore investigations of adequate size to decrease uncertainties with regard to potentially hazardous features.

The following US Nuclear Regulatory Commission codes provide regulatory guidelines for seismic and geological investigations:

- ***10 CFR (Code of Federal Regulations) Part 50, Appendix A, "General Design Criteria for Nuclear Power Formerly NUREG-75/087 Plants", General Design Criterion 2 – "Design Bases for Protection Against Natural Phenomena***
- ***10 CFR Part 100, "Reactor Site Criteria”***
- ***10 CFR100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Pants”.***
    - ***NUREG 0800 – Standard Review Plan (Revision 2 – July 1981). This Standard Review Plan is intended to guide the U.S. Office of Nuclear Reactor Regulation staff responsible for the review of applications to construct and operate nuclear power plants. "Standard Review Plans are not substitutes for regulatory guides or the U.S. NRC's (NRC) regulations and compliance with them are not required".***

The following regulatory guides provide information, recommendations and guidance and in general describe a basis acceptable for implementing the requirements General Design Criterion 2, Part 100, and Appendix A to Part 100:

- Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants";

- Regulatory Guide 4.7, "General Site Suitability Criteria for Nuclear Power Stations".
- Regulatory Guide 1.165 – Identification and characterization of seismic sources and determination of safe shutdown earthquake ground motion (1997); and
    - This guide has been developed to provide general guidance on procedures acceptable to the USNRC for (1) conducting geological, geophysical, seismological, and geotechnical investigations, (2) identifying and characterizing sources, (3) conducting probabilistic seismic hazard analyses, and (4) determining the SSE for satisfying the requirements of 10 CFR 100.23 (i.e. 10 CFR 100 paragraph 23). The information collections contained in this regulatory guide are covered by the requirements of 10 CFR Part 50.
- NUREG-1.208 A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion.
    - The purpose of this regulatory guide is to provide guidance on the development of the site-specific ground motion response spectrum. This represents the first part of the assessment of the Safe Shutdown Earthquake (SSE) for a site as a characterization of the regional and local seismic hazard. It provides an alternative for using the requirements of NUREG 1.165.

1.2.2 Prescribed Study Area

For the purpose of complying with U.S. Nuclear Regulations, the size of the area that has to be included in investigations for a Nuclear Power Station, is guided by consecutive regulatory radii of 320, 40 and 8 km around the proposed site (**Figure 1.1**). The following acceptance criteria and compliance was applicable to the studies (**Figure 1.1**):

- **Acceptance and compliance of Site Region (320 km radius).** Regional and geological and seismological investigations are not expected to be extensive or in great detail, but should include literature reviews, the study of maps and remote sensing data, and if, necessary, ground truth reconnaissances conducted within a radius of 320 km of the site to identify seismic sources (seismogenic and capable tectonic sources).
- **Acceptance criteria and compliance of for Site Vicinity (40 km radius).** Geological, seismological and geophysical investigations should be carried out within a radius of 40 km in greater detail than the regional investigations to identify and characterize the seismic and surface deformation potential of any capable tectonic sources and the seismic potential of seismogenic sources, or to demonstrate that such structures are not present. Sites with capable tectonic or seismogenic sources within a radius of 40 km may require more extensive geological and seismological investigations and analysis.
- **Acceptance criteria and compliance for Site Area (8 km radius).** Detailed geological, seismological, geophysical and geotechnical investigations should be conducted within a radius of 8 km of the site, as appropriate, to evaluate the potential for tectonic deformation at or near the ground surface and to assess the ground motion transmission characteristics of soils and rocks in the Site ***Area***.
- **Acceptance criteria and compliance for Site Location (1 km radius).** Very detailed geological, geophysical and geotechnical engineering investigations should be conducted within a radius of 1 km of the site, as appropriate, to evaluate specific rock and soil characteristics. This phase is only done just before construction and is not applicable to this report.

1.2.3 Investigation Background

All three sites under review were the subject of various geoscientific investigations during the Nuclear Site Investigation Programme (NSIP) performed by the AEC (now NECSA) team and its consultants for Eskom in the 1980s. During this time the AEC team produced a number of 1:50,000 scale geological maps which, together with several published (and digitally available) 1:250,000 scale CGS geological maps form the basis of the existing geological database. The CGS has been involved in seismic monitoring for Eskom at the Duynefontein, Thyspunt, Bantamsklip (and Brazil and Schulpfontein) sites since 1994. A summary of the work done up to 2002, including outcomes of audits, quality assurance, international reviews etc. is given in the Summary Report and Final Assessment (SRAFA, 2004).

Palaeoseismic investigations were carried out by the CGS between November 2003 and June 2006. Three projects were undertaken, namely a study of coastal warping (Roberts, 2006) a palaeoseismic trenching study of Quaternary-age reactivation along the Ceres-Kango-Baviaanskloof-Coega fault system (Goedhart, 2006), and an investigation into the potential for neotectonic reactivation along known and any new faults identified in the intervening coastal region (De Beer, 2006). This formed the basis for the assessment of potential geological hazards for the Thyspunt, Bantamsklip and Duynefontein sites.

Following this work onshore and offshore geophysical surveys were conducted within the 40 km radii from the sites. The necessity of such work arises from the fact that these coastal sites are bordered on the one side by the ocean and on the other side by extensive sand cover, with sparse rock outcrops. Geophysical investigations have proven to be powerful methods for mapping geological features important to hazard determination that may be obscured by water or loose sediment. Geophysical investigations at Thyspunt, Bantamsklip, and Duynefontein comprised of airborne magnetic surveys aided by ground follow-up methods where required and offshore geophysical surveys. The results of the airborne and ground geophysical surveys, as well as ground follow-up work and marine investigations were incorporated into reports by Goedhart (2007) and De Beer (2007a, b).

During the course of 2008 detailed geological investigations (De Beer *et al*., 2008; Goedhart *et al*., 2008; Siegfried *et al*., 2008) were undertaken by the CGS in the 8 km site area and 40 km site vicinity areas of all three proposed sites. This work produced maps at 1:5,000 scale in the Site Area and 1:50,000 scale in 40 km Site Vicinity, that provide a concise and definitive geological baseline for any further modelling or development at the site.

1.2.4 Assumptions and Limitations

The descriptions and facts given here stem from published data and work undertaken by the CGS and others. In terms of the identification of faults and seismic risk the information represents the current knowledge and understanding based on a regional picture. New evidence of neotectonic movements may be discovered in the more detailed investigations that still have to be undertaken to look for evidence of palaeo-seismicity and can alter the understanding of the tectonics and geology of the respective study areas. The assumptions and limitations applicable are:

- The EIA is based on the current state of knowledge without incorporating the regulatory required detailed investigations.

2 DESCRIPTION OF SITES AND SURROUNDING ENVIRONMENT

The descriptions provided below are not intended to be exhaustive or replace any previous work, but rather to summarise the basic geology and then focus on relevant geological hazards. The geological and tectonic setting of the sites and presence of faults or other potentially seismogenic sources in the 320 km radii from the sites are covered in De Beer (2006). The geology broadly represent four periods of geological activity (see **Appendix 1**):

(1) the Late Precambrian Pan-African orogeny, “Saldania Event”;
(2) the Permo-Triassic Cape Orogeny;
(3) the Mesozoic break up of Gondwana; and
(4) Late Neogene to Quaternary-age coastal uplift and sea-level fluctuations.

Regional map compilations are available for all the sites under investigation.

2.1 Thyspunt

The baseline description of the geology and tectonics (both regionally and locally) relating to the Thyspunt site incorporates available information from previous reports as summarised by De Beer (2006), Goedhart (2007) and Goedhart *et al*. (2008).

2.1.1 Geology

The geology and tectonics of the Thyspunt Site Regional area (320 km) and Site Vicinity area (40 km) have been reviewed briefly during the palaeoseismic project (De Beer, 2006), and subsequently updated following more detailed geological investigations (Goedhart *et al*., 2008) within the 40 km Site Vicinity and 8 km Site Area. The simplified geology of the Site Vicinity is depicted in **Figure 2.1** with the legend depicted in **Figure 2.2**.

The Thyspunt site is typical of most south-eastern Cape coastal regions with a broad, raised marine platform of Miocene and Pliocene age (Partridge and Maud, 1987; Partridge, 1998), cut into older rocks of variable resistance.

None of the Precambrian rocks (i.e. Gamtoos Group and Cape Granites) outcrop in the Thyspunt Site Vicinity, but form the floor, or basement, to the mapped formations. The Gamtoos Group is unconformably overlain by the Table Mountain Group, which comprises the basal unit of the Cape Supergroup. It is predominantly composed of supermature quartzose sandstone and accumulated through marine, glacial and fluvial depositional process during the Ordovician and Silurian Periods. It is conformably superseded by the argillaceous Bokkeveld Group with the basal Ceres Subgroup unit found north of St. Francis Bay.

The Cape Supergroup was intensely distorted by the Permo-Triassic Cape Orogeny, a compressional deformation event which produced the Cape Fold Belt mountain chain along the southern coast of South Africa. The northerly-directed compression

Figure 2.1: **Geological map of the Thyspunt Nuclear Site area with the 8 km and 40 km radii that guide geological investigation**

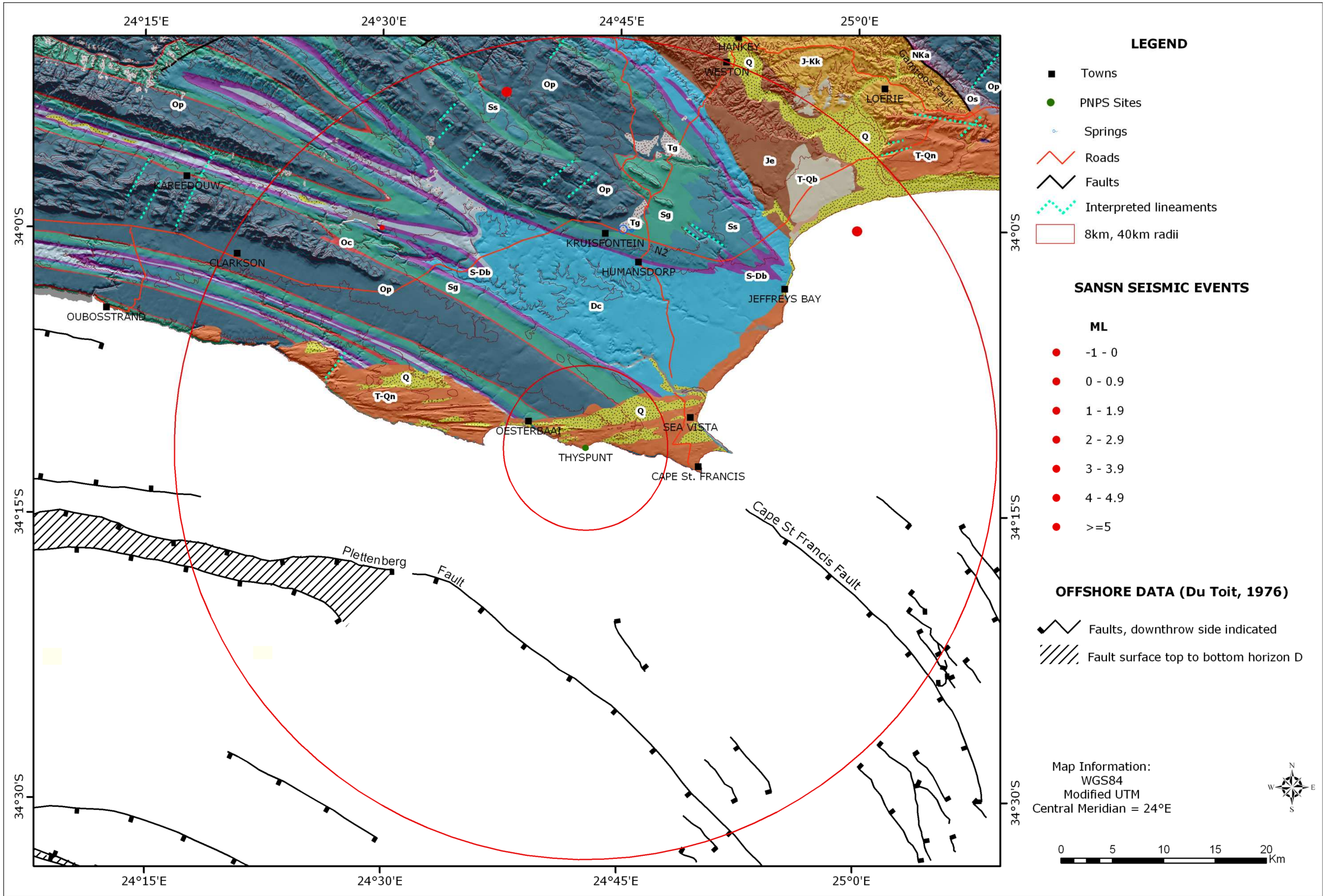
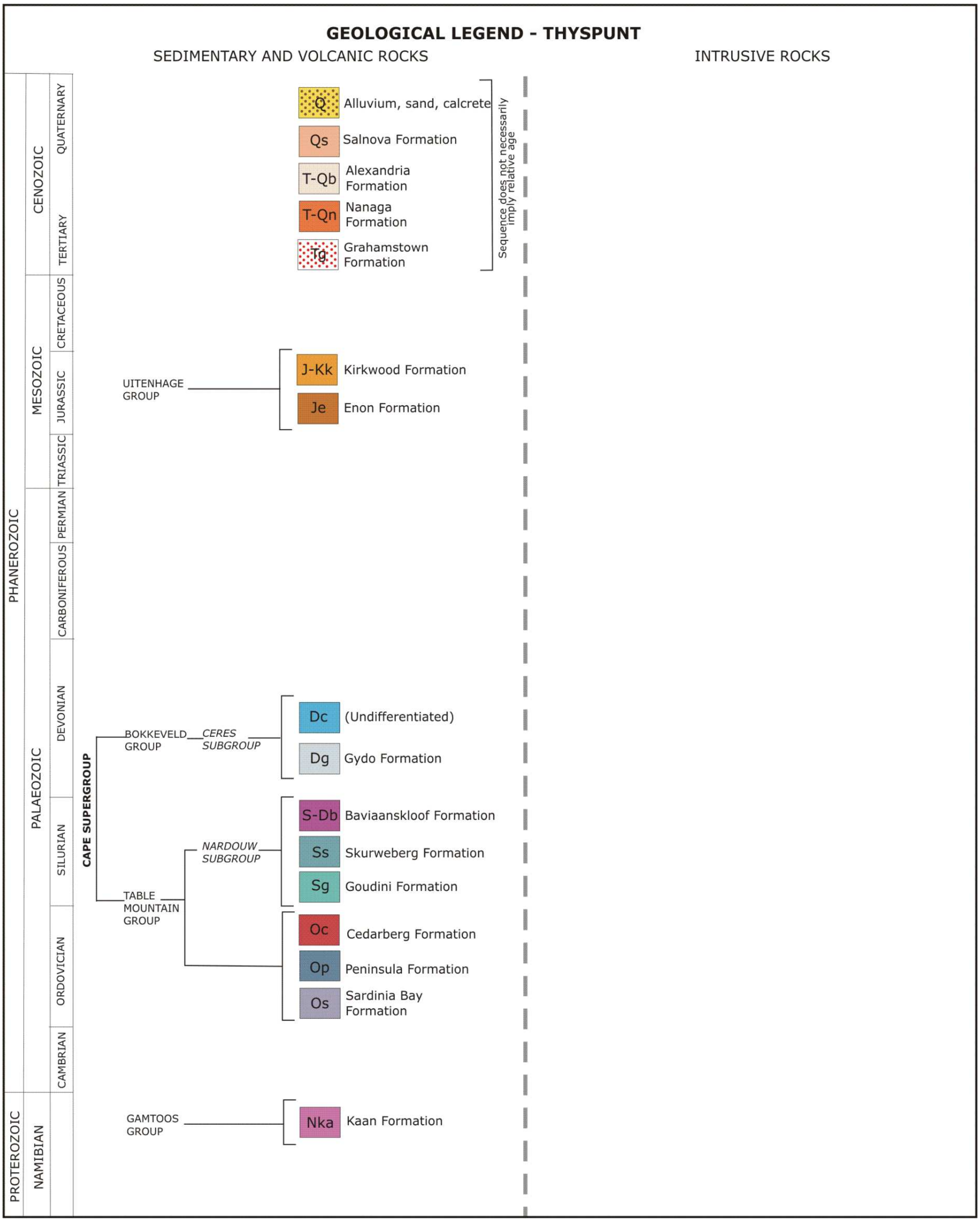


Figure 2.2: Legend for the Thyspunt geological map in Figure 2.1



resulted in widespread flexural-slip folding, commonly with fold asymmetry and décollement occurring in the upper stratigraphic units.

A schematic map (**Figure 2.3**) and cross-section (**Figure 2.4**) prepared by De Beer (2000), illustrates the folding of the Table Mountain Group at Thyspunt, which is located on the southern limb of a large anticlinal structure, with asymmetric north-verging synclinal and anticlinal folds that extend south-eastward.

Outcrops of the Late Jurassic to Early Cretaceous-age Uitenhage Group are found about 41 km from, and to the northeast of, the proposed site, in the Gamtoos Basin (Goedhart *et al*., 2008). Scattered remnants of hard, siliceous and subhorizontal fossil soils (Roberts, 2003) assigned to the Tertiary-age Grahamstown Formation, are preserved on flat tops of high lying areas in the vicinity northwest of Jeffreys Bay and north to northeast of the Kareedouw Mountains.

Most Late Cenozoic-age coastal deposits in the Site Vicinity area are assigned to the Algoa Group. The latter consists of nearshore-marine and coastal-aeolian formations of different ages and at different terrace elevation around the present-day shoreline (Goedhart *et al*., 2008). Where possible the Algoa Group is separated into its component formations, but where large tracts of coastal forest or extensive agricultural lands do not allow for this, it is mapped as undifferentiated Algoa Group (Goedhart *et al*., 2008). Three large, modern coastal dunefields (Oyster Bay, Thysbaai and Santareme dunefields) are present in the site vicinity.

2.1.2 Tectonics

The 1:250,000 geological maps Oudtshoorn and Port Elizabeth depict the Humansdorp-Thyspunt area as relatively fault-free compared with other sectors of the Cape Fold Belt. The structural geology at the Thyspunt site is typical of most south-eastern Cape coastal regions and has been reviewed in De Beer (2000), Goedhart (2007) and Goedhart *et al*. (2008).

Potential hazards within the Site Region

Potential hazards within the Site Region include the offshore faults in Bredasdorp, Pletmos and Algoa Basins, as well as the Ceres-Kango-Baviaanskloof-Coega-St Croix fault system (De Beer, 2004; Goedhart, 2007). The closest major on-land faults are the Gamtoos and Kouga faults, which are situated respectively 39-45 km and 42 km from the site. They are structurally linked to the 715 km long Ceres-Kango-Baviaanskloof-Coega-St Croix fault system extending along the southern Cape Fold Belt.

Faults with demonstrable neotectonic reactivation (Hattingh and Goedhart, 1997) include the Coega and the Zuurberg faults north of Port Elizabeth, the latter being located some 100 km northeast of Thyspunt.

Potential hazards within the Site Vicinity

Offshore geological coverage indicates two potentially hazardous offshore faults within the 40 km radius from the site. The Plettenberg Fault, a 100 km long, steeply ***southwest*** dipping normal fault with a throw of some 5 600 m (McMillan *et al*., 1997) extends to within 18 km of the site.

A smaller offshore fault with a **southwest** downthrow, the Cape St. Francis Fault (De Beer, 2006), is known to extend to about 16 km from the site. More work was devoted ***to determine whether this fault extend in to the Thyspunt Site Area. However, neither the AEC or existing CGS maps, nor subsequent geophysical and geological work could establish the presence of this structure onshore (Stettler et al., 2008, Stettler, 2008; Goedhart et al., 2008).***

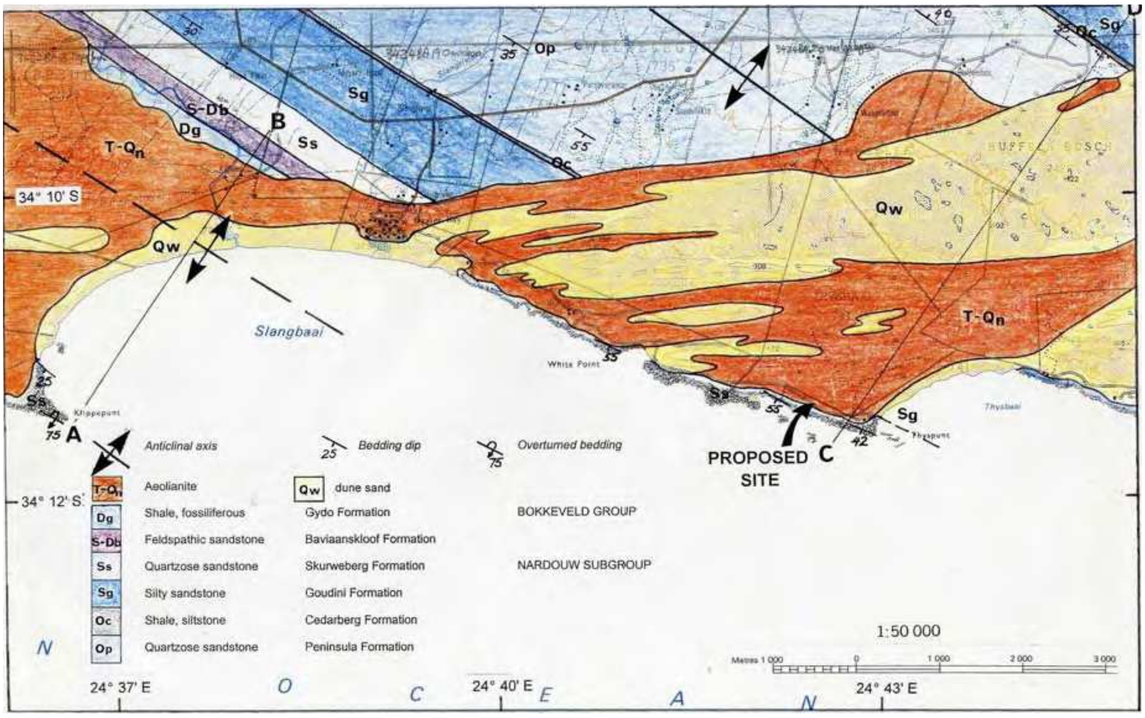


Figure 2.3: Sketch map depicting the onshore geology of the Site location area between Thyspunt and Klippepunt compiled from the 1:50 000 scale geological filed sheets and updated from reconnaissance fieldwork (from De Beer, 2000)

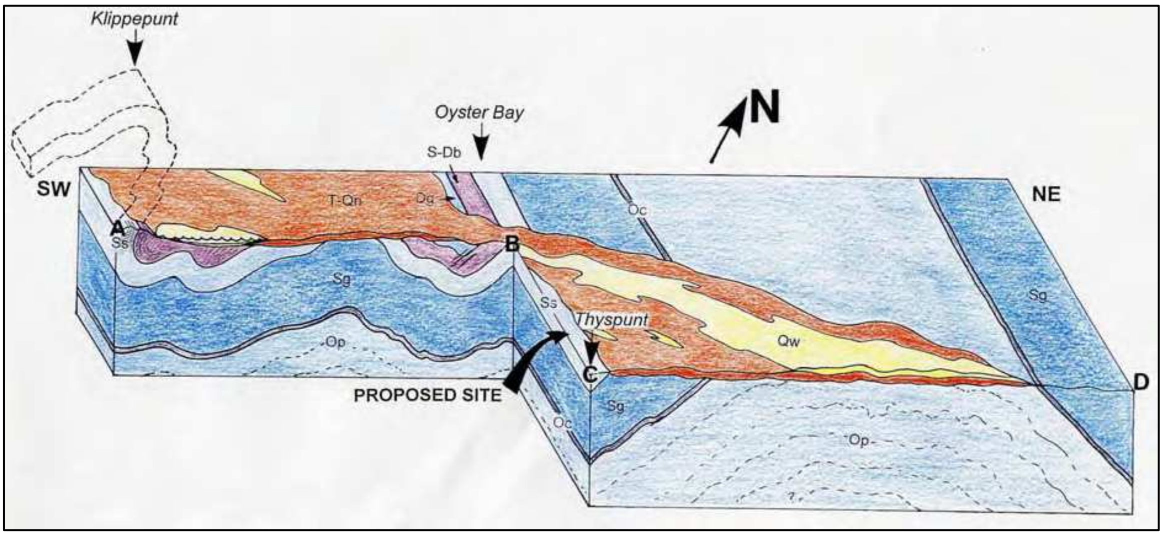


Figure 2.4: Schematic block diagram with cross-section A-B and C-D from Figure 2.3, showing the local geological structures between Thyspunt and Klippepunt in relation to the proposed Thyspunt site (from De Beer, 2000)

Potential hazards within the Site Area

The AEC described the so-called Klippepunt fault, with a closest offshore approach of 2.5 km. It was not regarded as "capable" by Faurie et al. (1993). Subsequent geological and geophysical investigations could find no evidence to support the presence of this fault (De Beer, 2000; Goedhart, 2007; Goedhart et al., 2008). Instead, the fracturing at Klippepunt has been shown to represent fracture cleavage formed during the Cape Orogeny in the overturned limb of a large northeast trending anticline.

Hill (1988) could not find any evidence for recent reactivation along the ***northeast – southwest*** trending Paul Sauer Fault ***northwest*** of the site. The fracture pattern at the Thyspunt site became established primarily during the Permo-Triassic-age Cape Orogeny and was amplified during the Mesozoic.

The table, included ***as Appendix A*** in Goedhart, 2007 is an up-to-date list of all known geological hazards for the Thyspunt nuclear site, with some updated information provided in Goedhart *et al*. (2008). It contains a summary of each feature and the evidence for it, or against it. Goedhart, 2007 also contains a record of decisions and conclusions regarding the evidence for each feature, made at the final NSIP pre-integration workshop, and recommendations for its use in the SHA for the site. Finally, Goedhart *et al*. (2008) noted that deep excavations during construction may produce local, unstable slopes of consisting of unconsolidated sand.

2.1.3 Impact of Climate Change

Climate change is not expected to have much direct impact on the Thyspunt geological environment. Changes in climatic patterns, especially precipitation, will influence landscape weathering rates, although this should be minor for exposed bedrock during the operating life time of a Nuclear Power Station. Soft or unconsolidated sediments will be much more susceptible to changed weathering rates, although the low gradient of the marine platform on which Thypsunt is located, means that the direct impact at the site is likely to be small. Relative changes in sea-level will impact local erosion and deposition at and directly adjacent to the sea-land interface and the marine flood line.

2.2 Bantamsklip

In addition to the regional description set out in De Beer (2006, 2007a) and regional map compilations, more detailed geology maps at 1:50,000 scale have also been compiled for Bantamsklip by the AEC. Regional data exists in the form of the 1:250,000 scale sheet 3319 Worcester compiled from base maps on 1:50,000 scale. The AEC (now NECSA) produced detailed mapping at 1:50,000 scale and site specific mapping at 1:5,000 scale, which were reviewed and updated in 2008 (Siegfried *et al*., 2008).

2.2.1 Geology

The Bantamsklip site is situated in a fractured part of the Cape Fold Belt, called the syntaxis where ***northeast – southwest*** trending faults dominate. The geology and tectonics of the Bantamsklip Site Regional area (320 km) and Site Vicinity area (40 km) has been reviewed briefly by De Beer (2006). The geology of the Site Vicinity Area geology is depicted in **Figure 2.5** with legend depicted in **Figure 2.6**.

The geology at Bantamsklip is typical of the Cape Peninsula and the southern West Coast. Resistant Palaeozoic quartz arenites of the Table Mountain Group build the mountainous topography to the north of the site, whereas the low-lying areas are underlain by poorly exposed, low-grade metasedimentary (locally metavolcanic) rocks of the Malmesbury Group that are extensively covered by sand along the coast (Siegfried *et al*., 2008). There are apparently no dolerite dykes in the area, but a suite of Late Cretaceous-age alkaline rock types occurs offshore to the southeast of the site. Evidence for neotectonics in the area was summarised in De Beer (2006).

There are five main geological sequences exposed in the Site Vicinity Area, namely the:

(1) Poorly exposed, late Precambrian-age Malmesbury Group;
(2) Intrusive Cambrian-age Cape Granite Suite, which is associated with the Malmesbury sediments and crop out in the deeply incised valleys and plains;
(3) Early Palaeozoic-age Cape Supergroup which extends over the largest part of the map area;
(4) Mesozoic-age Enon Formation in the Elim area;
(5) Late Cenozoic-age Bredasdorp Group along the coast and vicinity.

The Neoproterozoic Malmesbury Group is the oldest rock unit within the Site Vicinity with outcrops restricted to inliers in the area, but Andreoli *et al*. (1989a) recorded phyllite intersections in percussion drillholes indicating suboutcrop of this unit near the coast. The Cape Granite Suite, which intruded with the formation of the Pan-African Saldania Belt, during the Late Neoproterozoic and Early Palaeozoic, are only exposed in the study area as fault-bounded inliers in eroded anticlinal crests of Table Mountain Group rocks (Gresse and Theron 1992).

The larger part of the Site Vicinity is underlain by the Cape Supergroup, which is represented in the Site Vicinity by the quartzite-dominated Table Mountain Group and the lower parts of argillaceous Bokkeveld Group (Siegfried *et al*., 2008). The sandstone-dominated Table Mountain Group (TMG), lower unit of the Cape Supergroup, dominates the surface geology towards the west of the Site Vicinity and comprises all the basement occurrences along the coast except for the Groot Haelkraal Granite situated southeast of Pearly Beach.

The relatively subdued topography of the Bokkeveld Group, compared to the over- and underlying units, reflects its predominantly fine-grained nature, which comprises cyclic alternating fine-grained sandstone and mud-rock units. Restricted outcrop of the Enon Formation in the eastern-most part of the Site Vicinity and east of Elim, represents the only remnant of Cretaceous rocks in the Site Vicinity (Andreoli *et al*., 1989a). These red-coloured deposits consist of fine-grained to gritty, cross-bedded sandstone and grey shale, which are commonly carbonaceous and pyritic, and appear to be of lagoonal origin (Gresse and Theron 1992).

Both ferricrete and silcrete fossil soil remnants of the Grahamstown Formation are known from the Bantamsklip Site Vicinity area (Roberts, 2003; Siegfried *et al*., 2008). In general Cenozoic deposits along the southern African coastline can be closely linked to marine transgressions and regressions and consist of various aeolian and marine deposits. The stratigraphy of these coastal deposits between Plettenberg Bay and Hermanus, was described and defined by Malan (1989). In the study area the Cenozoic-age Bredasdorp Group is represented by the De Hoopvlei, Wankoe, Klein Brak, Waenhuiskrans and Strandveld Formations and is distinguished from the underlying rocks by their predominantly calcareous nature.

The discovery of several northeast to east striking mafic dykes at Bantamsklip and Buffeljagt, inferred to belong to this suite of Early Cretaceous-age, rift-related, tholeiitic dykes of the False Bay dyke swarm, for the first time now reveal that such dykes were in fact intruded far beyond their type area. The general agreement in strike of the dykes with the trends of Mesozoic faulting in the area confirms their contemporaneous formation.

2.2.2 Tectonics

The current understanding of the stratigraphy and structure within the area addressed by the geophysical investigations largely depends upon the 1:50,000 scale mapping of J.A. Malan for 1:250,000 scale Sheet 3319 Worcester, the four 1:50,000 scale maps produced by Andreoli et al. (1989a) and mapping by Siegfried et al. (2008).

Bantamsklip is situated towards the southeast boundary of the Cape syntaxis, where northeast trending folds that are characteristic of the Cape Fold Belt syntaxis, curve asymptotically into an easterly orientation. The 40 km radius around the site is characterised by east-northeast to northeast striking, Permo-Triassic-age thrust faults with displacements ranging between tens of metres to hundreds of metres, which are in turn cut by northeast, west-northwest and east striking, Mesozoic normal faults. The northwest - southeast to west-northwest – east-southeast trending faults are generally less common and occur near the northern boundary of the 40 km regulatory radius, as well as northeast of the site.

Very little of the evidence for neotectonic activity cited by Andreoli et al. (1994), was verified by subsequent investigation (De Beer, 2006). The extensive sand cover and lack of good outcrops over known faults of Mesozoic-age within 8 km radius inhibits surficial palaeoseismic investigations.

The airborne, ground, and marine geophysical surveys conducted by the Council for Geoscience and Fugro within the Site Area (8km radius) and part of the Site Vicinity area (40 km radius) to a large extent complimented the known onshore and offshore geology. The results of these surveys confirmed most of the positions of the major faults and improved the understanding of the exact position of some, e.g. the Groenkloof Fault (Figure 2.5).

The results of the multibeam and side-scan sonar surveys were very efficient in pointing out underwater fractures in the basement and Table Mountain Group rocks on the Bantamsklip promontory. On-land palaeoseismic investigations will need to be done on these fractures to determine if there exists any prehistoric evidence of strong ground motions in this area of presently very subdued

seismicity (De Beer, 2007a).

The geological hazards referred to in this report are derived from the preceding regional palaeoseismic and neotectonic investigations, and those newly identified in the latest onshore and offshore geophysical surveys. Geological hazards summarised below are discussed in greater detail in De Beer (2007a) and Siegfried et al. (2008) where they occur within the Site Region, Site Vicinity or the Site Area.

Potential hazards within the Site Region

Potential hazards within the Site Region include the offshore faults in the Bredasdorp Basin, the Ceres-Kango-Baviaanskloof-Coega fault system and major faults in the syntaxis area (De Beer, 2004). Additional geophysical information did not provide any new data with regard to potential hazards located between the 320 km regulatory radius around the site and the investigated area (De Beer, 2007a).

Figure 2.5: **Geological map of the Batamsklip Nuclear Site area with the 8 km and 40 km radii that guide geological investigation**

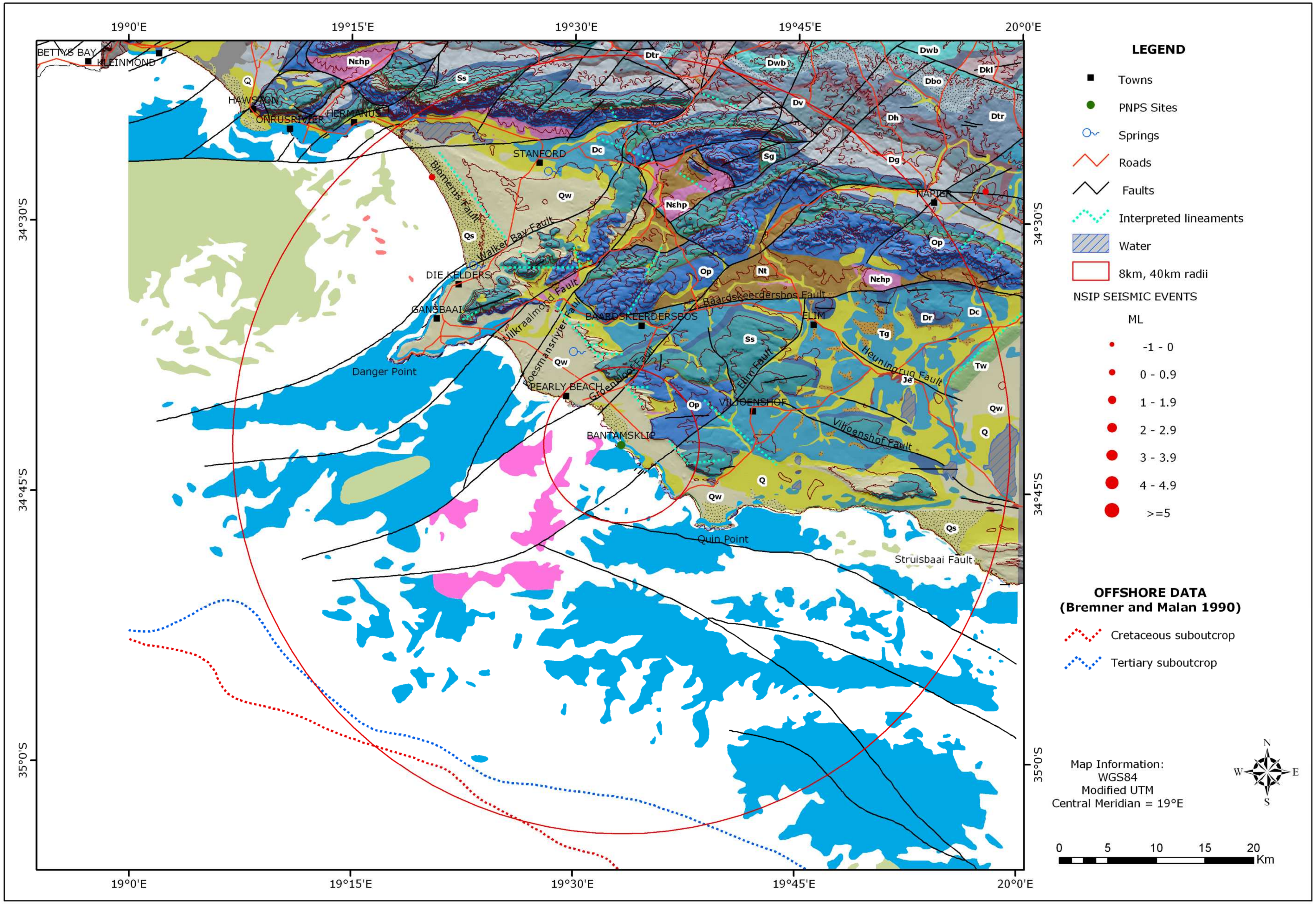
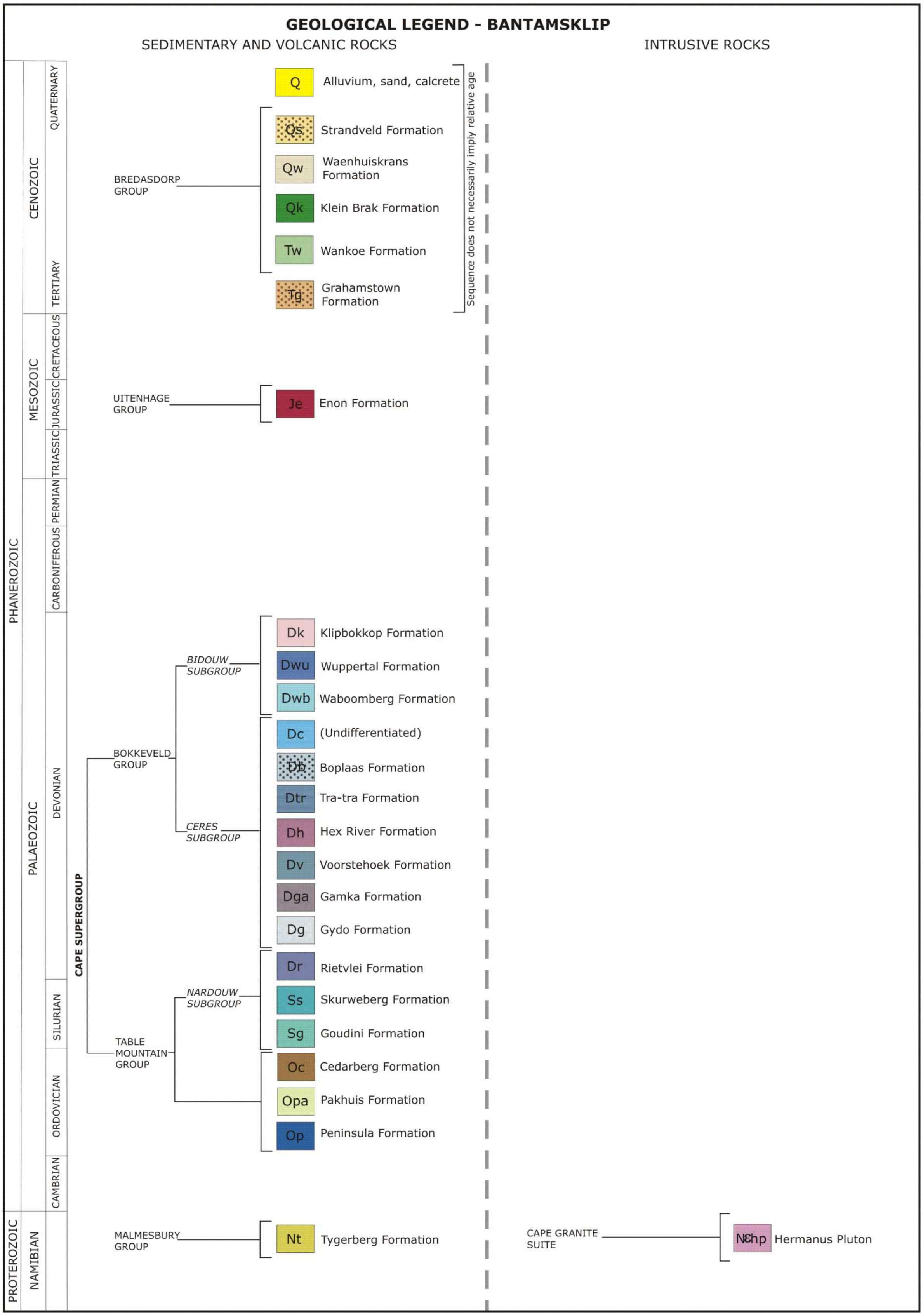


Figure 2.6: Legend for the Bantamsklip geological map in Figure 2.5



Potential hazards within the Site Vicinity

The position of most major faults previously identified on existing maps was confirmed by recent geological investigations (including geophysical surveys). Several large, ***northeast – southwest*** trending faults have been described from the Bantamsklip Site Vicinity, such as the Walker Bay, Uilkraalmond, Boesmansrivier, Groenkloof and Elim faults. The Viljoenshof and Heuningrug faults are E–W trending faults to the east of the site, while the Baardskeerdersbos Fault trends ***west-northwest – east-southeast,*** north of the site and intersects several ***northeast – southwest*** trending faults (Siegfried *et al*., 2008). The Groenkloof Fault has been accurately located at a distance of 7.5 km from the site, and the Elim Fault at a distance of 4 km southeast of the site, but neither of these are considered to be capable (De Beer, 2007a).

New ***lineaments were*** identified, mostly on the basis of apparent displacement of magnetic anomalies (Havenga and Raath, 2007), ***but*** after careful examination by a panel of experts, only the Breëvleikloof ***(a northwest trending structure 13 km northeast of the site) and the northwest striking Sandbaai (9 km southeast of Bantamsklip)*** lineaments were regarded to be of relevance. However, these lineaments cannot be considered evidence for the existence of faults until reviewed through geophysical profiles.

Potential hazards within the Site Area

Previously identified features include the Celt Bay and Blomerus faults. The east-west striking Celt Bay Fault was visually observed in the coastal strip to the east of Bantamsklip, but geophysical evidence for the ***northwest*** continuation of the Celt Bay Fault is tenuous and displacement across the fault appears limited. There is at present no evidence that the fault is capable and a conclusion as to the age of last movement on this Cretaceous-age fault may only be reached following detailed investigation of the relationships between bedrock and Cenozoic-age cover sediments in excavations within the Site Area.

Geophysical evidence for the existence of the postulated "Blomerus Fault" is poor and this feature is interpreted to represent a palaeo-shoreline located at +50 m (De Beer, 2007b; Siegfried *et al*., 2008).

A few, lineaments within the Site Area were interpreted as fault displacement of magnetic anomalies (Havenga and Raath,,2007). ***However, many of these may also be related to buried dykes and the*** majority of these cannot convincingly be interpreted as faults (De Beer, 2007b), but should be considered potential faults only.

A preliminary structural interpretation by De Beer (2007b) of the multibeam imagery delineated a number of fractures that may line up with inferred small faults shown in the 1:5,000 scale coastal strip map for Bantamsklip (Andreoli *et al*., 1989b). The fractures have been given the name of the "Bantamsklip fracture set", which recent investigations (Siegfried *at al*., 2008) interpreted as a fault called the Bantamsklip Fault. This fault consists of ***a northeast*** trending zone of intensely brecciated quartzite approximately 50 m wide and display no evidence of being capable.

A new feature labelled BM1, the "Bantamsklip south offshore feature" occurs as an ***east*** striking negative topographic lineament cutting bedrock near the ***southwest*** boundary of the Site Area. It is most probably a fault, but its relationship to sediment cover in the ***southeast*** part of the survey area is not currently clear.

2.2.3 Impact of Climate Change

Climate change is not expected to have much direct impact on the Bantamsklip geological environment. Changes in climate, especially more extreme oscillation in precipitation patterns, may result in increased landscape weathering rates, although this should be minor for exposed bedrock during the operating life time of a Nuclear Power Station. Soft or unconsolidated sediments will be much more susceptible to increased weathering rates. Relative changes in sea-level will impact local erosion and deposition at and directly adjacent to the sea-land interface and the marine flood line.

2.3 Duynefontein

The current understanding of the stratigraphy and structure relevant to the Duynefontein site and addressed by the geophysical investigations largely relies upon mapping performed by various geologists between 1970 and 2008 (see De Beer *et al*., 2008, for a review). The following description is not intended to describe the geology of the area in detail, but rather to summarise the basic geology and then focus on features that may have implications for seismic hazard and engineering.

2.3.1 Geology

The stratigraphy for Duynefontein is typical of the Cape Peninsula and the southern West Coast. The existing Nuclear Power Station at Duynefontein is underlain by the Neoproterozoic rocks of the Malmesbury Group, intruded by the late Neoproterozoic Cape Granite Suite and Cretaceous dolerite dykes (De Beer *et al*., 2008). Some 40 km to the south, the high topography of the Cape Peninsula is composed of the overlying Palaeozoic rocks of the Table Mountain Group. Most of the coastal plain around the site is covered with Cenozoic-age sand (**Figure 2.7** with legend depicted in **Figure 2.8**).

Only the Tygerberg, Moorreesburg and Franschhoek Formations of the Malmesbury Group crop out within the Duynefontein Site Vicinity (**Figure 2.7).** The Moorreesburg Formation consists of a succession of gritstone, limestone, quartz schist and some greywacke that are complexly deformed. The Tygerberg Formation constitutes a relatively monotonous succession of deepwater, turbiditic meta-sediments folded into simple folds, and is generally highly weathered. The Franschhoek Formation is confined to the south-eastern part of the Site Vicinity, between Malmesbury and ***Klipheuwel (De Beer et al., 2008).***

Exposures of the Cape Granite Suite can be found in the Mamre hills between Darling and Mamre, in the Paardeberg southeast of Malmesbury, in the Bottelary Hills east of Bellville, around Stellenbosch, and below the Table Mountain Group in the Cape Peninsula.

The Malmesbury Group and the Cape Granite Suite are overlain unconformably by the Klipheuwel Group, an assemblage of immature sedimentary rocks deposited in rift basins that preceded deposition of the Table Mountain Group. All of these rocks are easily distinguished by their pink to red-brown, to light purple colours (Theron et al., 1992) and are only present in the graben at Klipheuwel (De Beer et al., 2008)

Figure 2.7: **Geological map of the Duynefontein Nuclear Site area with the 8 km and 40 km radii that guide geological investigation**

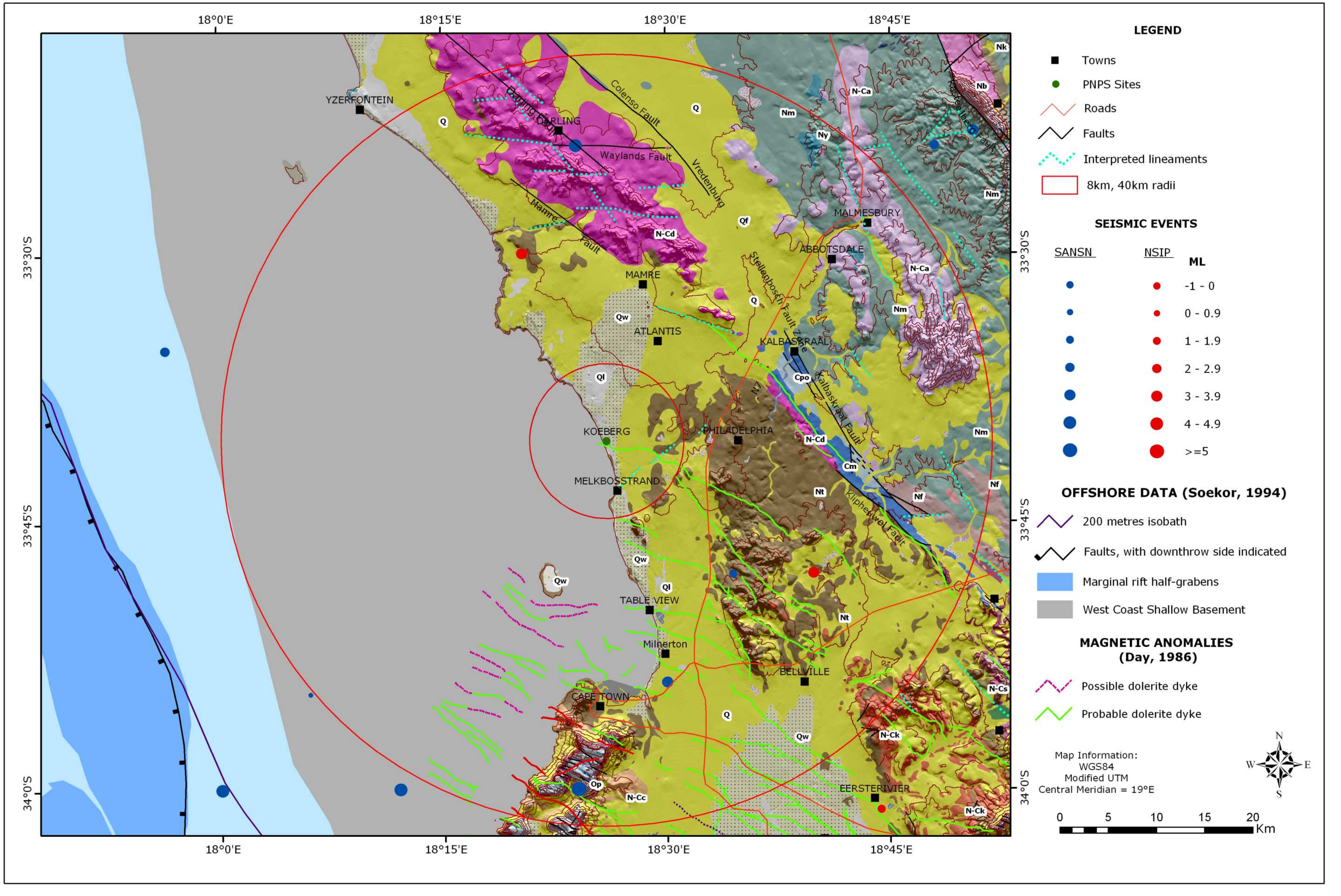
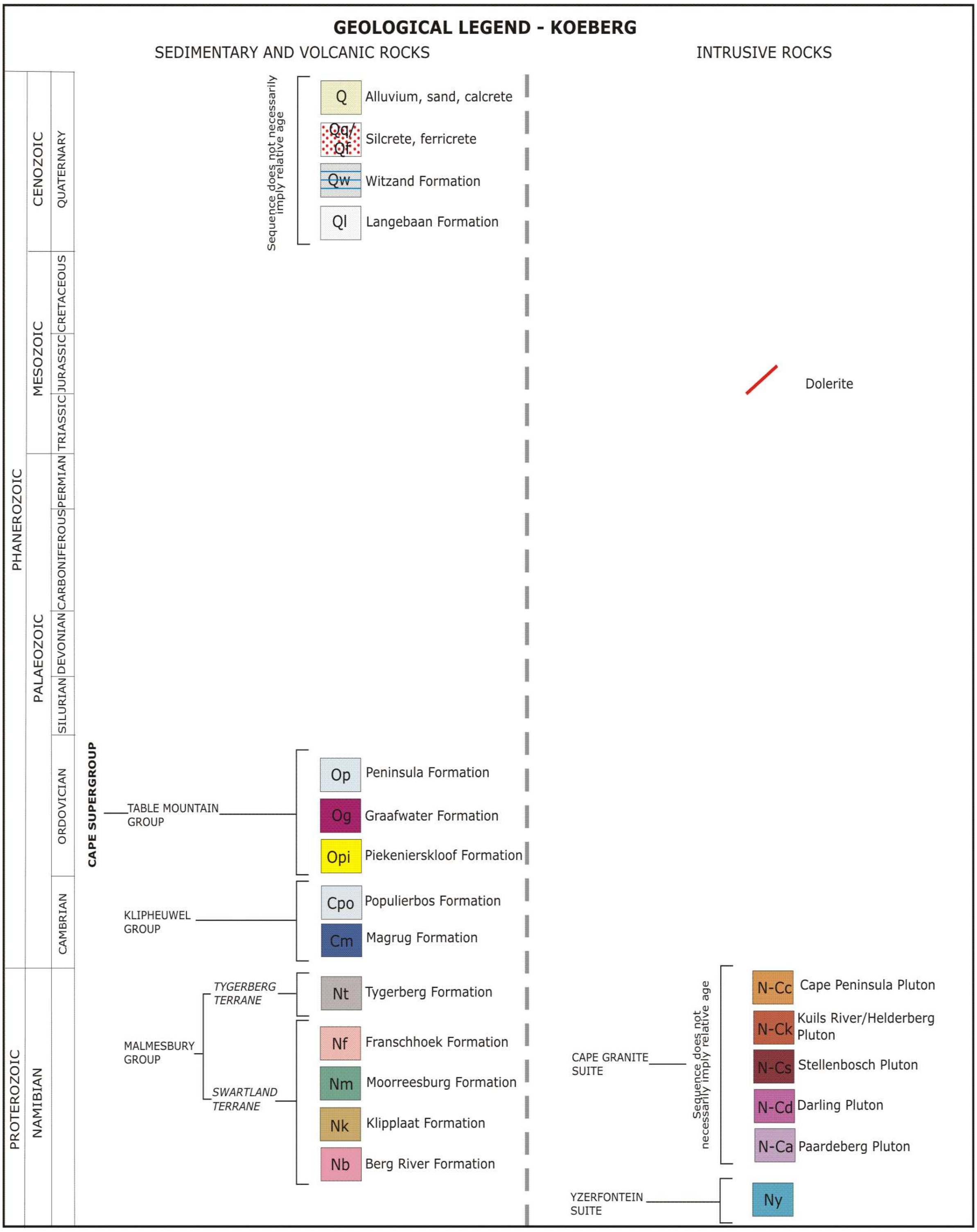


Figure 2.8: Legend for the Duynefontein geological map in Figure 2.7



In the immediate vicinity of Duynefontein, the Palaeozoic Table Mountain Group forms the mountains of the Cape Peninsula. Here the thin-bedded sandstone and shale of the Graafwater Formation is capped by the quartzitic sandstones of the Peninsula Formation. Limited exposures of the quartz pebble diamictite of the Pakhuis Formation are preserved at Maclear's Beacon, at the very summit of Table Mountain.

A swarm of dykes traverse the coastline between Milnerton and Bloubergstrand (Cole *et al*., 2007), and a dyke also occurs within the Site Area of Duynefontein (Dames and Moore, 1976). These form part of extensive suite of dolerite dykes that intruded throughout the southwestern Cape and along the Atlantic margin during the early Cretaceous.

Close to the coast, bedrock is overlain by a Cenozoic-age sequence of marine, estuarine and aeolian sedimentary rocks and sediments belonging to the Sandveld Group. The oldest preserved Cenozoic rocks in the Site Vicinity are the ferricretes and silcretes of the Bellville Formation (De Beer *et al*., 2008). They represent ancient palaeosols situated on deeply weathered bedrock and are probably Early Cenozoic to Quaternary in age (Roberts, 2003). The marine sedimentary rocks of the Cenozoic (Varswater and Velddrif Formations) are generally much thinner than the aeolianites, the latter being represented by the Langebaan Formation. Regionally, the Sandveld Group is overlain by the white dune sands of the Witzand Formation (De Beer *et al*., 2008).

2.3.2 Tectonics

The geological hazards discussed here are derived from the preceding regional palaeoseismic and neotectonic investigations, and those newly identified in the latest onshore and offshore geophysical surveys. Faults, in accordance with their importance for fault rupture and seismic hazard, are generally considered the most important structural feature and thus receive the most attention. Some distinction is made between faults and inferred faults, with the later defined through their stratigraphic necessity, strong geophysical evidence (displacement of magnetic anomalies), through interpolation between outcrops of fault rocks (mylonite or breccia), or a prominent linear negative topographic features. Thick sediment cover in the Duynefontein Site Vicinity impedes the detailed investigation and dating of most faults and other related structures.

The present disposition of geological formations within the Duynefontein Site Vicinity is the result of four major tectonic and geomorphic events:

1. the Late Precambrian, Pan-African, "Saldania Event";
2. the Permo-Triassic Cape Orogeny;
3. the Mesozoic break-up of Gondwana;
4. Late Neogene to Quaternary sea-level fluctuations

The structural imprint of the Permo-Triassic Cape Orogeny on the basement and cover rocks in the Duynefontein Site Vicinity is relatively low (De Beer, 1995). In contrast the rifting and eventual break-up of ***southwest*** Gondwana between c. 150 Ma and 100 Ma ago was accompanied by tensional, transtensional and strike-slip faulting, which comprise a complex assemblage of ***west-northwest – east-southeast, northwest – southeast, east – west*** and ***northeast –southwest*** striking faults. Unfortunately the absence of Table Mountain Group rocks over most of the Site Vicinity seriously inhibits quantification of Mesozoic reactivation along older faults (De Beer *et al*., 2008).

The Duynefontein 320 km regulatory radius contains some of the most faulted parts of the Cape Fold Belt, namely the western branch and the syntaxis, with current prominent seismicity in the Ceres–Tulbagh area. Additionally, it lies within 20 km of one of the most important ***northwest – southeast*** trending zones of faulting in the ***southwest*** Cape, namely the Vredenburg-Stellenbosch fault zone and its related faults, many of which are of appreciable displacement. These faults have been active from the Saldanian Orogeny (ca. 550 Ma – 500 Ma ago) to the Mesozoic break-up of Gondwana (150 Ma - 100 Ma).

Both the Colenso and Mamre faults put Cape Granite Suite against Malmesbury Group rocks, implying appreciable, but unknown vertical displacements, and suggesting that the Darling hills represent a horst block. The nearest proven faults to the ***southwest*** of Duynefontein are those displacing Table Mountain Group rocks in the Cape Peninsula some 30 km away from Duynefontein.

The aeromagnetic study of Day (1986) revealed the presence of many ***northwest – southeast*** striking magnetic anomalies in the area between Duynefontein and False Bay. Most of these are probably dolerite dykes of the False Bay Swarm as exposed in outcrops along the peninsula coastline, but as they trend in exactly the same direction as faults in the Cape Peninsula, some of them might have intruded along pre-existing faults.

Geological hazards are discussed in De Beer (2007a) and De Beer *et al*. (2008) where they occur within the Site Region area, Site Vicinity area or the Site Area and are summarized below.

Potential hazards within the Site Region

Potential hazards within the Site Region includes the offshore faults in the Bredasdorp Basin and reactivation of the Ceres-Kango-Baviaanskloof-Coega fault system. Additional geophysical information did not provide any new data with regard to potential hazards located between the 320 km regulatory radius around the site and the investigated area (De Beer, 2007b).

Potential hazards within the Site Vicinity

The surface investigations covered only part of the Site Vicinity and the ***aeromagnetic and offshore magnetic surveys and*** additional Duynefontein marine extension survey (Cole, 2007), added an immense amount of very important offshore data to the available information. In the case of Duynefontein, this is important as a large earthquake occurred nearby in historic times (1809 Milnerton event, see Von Buchenröder, 1830).

Of the previously identified features, the Mamre Fault is considered to extend further to the ***southwest*** than formerly considered, to a position near the Botterberg Pluton. The positions of the Darling Fault and of the faults comprising the Vredenburg-Stellenbosch fault zone (Colenso and Kalbaskraal faults) were confirmed.

Four new inferred faults should be considered. There is enough evidence to infer that the ***northeast*** facing Melkbos Ridge scarp (KM 1) is a fault. Its full extent remains unknown due to a lack of data northwest of the Duynefontein Site Area, but the clarity with which it is defined on the multibeam image suggests a fault that could be twice as long as the observed length of 6 km on the eastern boundary of the Melkbos Ridge. It is important to note that this structure extends into the Site Area of Duynefontien.

A lineament (KM7) identified by Fugro (2007) in their "Outcrop area TB" can be traced from the southern extremity of Table Bay for a distance of at least 10 km in a ***north-northwest to northwest*** direction before it is lost in the area between Robben Island and the shore. In Table Bay, ***inferred to be a fault called the Table Bay fault,*** the lineament takes the shape of a 200 m wide, shallow, sediment-filled channel, but is defined by intermittent elongate outcrops, similar to outcrops along the Melkbos Ridge, further north.

The intense short anomalies noted by Cole (2007) in the magnetics dataset near the western boundary of the extended marine area, was interpreted to be related to the penetrative ***northwest*** striking fabrics west of the inferred Table Bay Fault. Cole (2007) however, interpreted these anomalies as a set of dykes, but also surmised that enhanced fluid flow could have deposited magnetic materials in this part of the sequence. Both of these lines of evidence support the presence of a major line of ***northwest*** striking shearing (De Beer, 2007b).

Potential hazards within the Site Area

Surveys within the Site Area of Duynefontein mostly confirmed the position of dolerite dykes, and of a fault zone previously postulated by Stettler *et al*. (1999), which occurs about 4.8 km ***northeast*** of the site. The scarp identified by Dames and Moore (1976) correlates with the ***inferred*** Melkbos Ridge Fault, and was shown to extend into the Site Area of Duynefontein. It now appears that this feature continues to within 7.5 km of the site (De Beer, 2007b). The ***inferred*** 'Melkbos Ridge Fault' and 'Table Bay Fault' ***may be part of a northwest*** striking family of faults. ***To date none of these structures could be demonstrated as being capable.***

Offshore features KM2 to KM5 were identified as faults by S. Horwood in his detailed structural interpretation of the multibeam and side-scan sonar data in the Site Area (Horwood and Smith, 2007). Most of these have been accepted to be real features, although feature KM2 (De Beer, 2007b) is defined purely on grounds of discrepancies in the trend of structures on both sides of ***northwest*** striking elongated sediment covered area.

2.3.3 Impact of Climate Change

Climate change is not expected to have a direct impact on the Duynefontein geological environment. Changes in climatic patterns, especially precipitation, will influence landscape weathering rates, though this should be minor for exposed bedrock during the operating life time of a Nuclear Power Station. Soft or unconsolidated sediments, such those that drape the plain on which Duynefontein is located, will be much more susceptible to changes in weathering rates, although the low gradient of the plain should mute the direct impact at the site. Relative changes in sea-level will impact local erosion and deposition at, and directly adjacent to, the sea-land interface and the marine flood line.

2.4 Site Sensitivity

From a geological point of view there are no sensitive areas that need to be avoided at the Bantamsklip and Duynefontein Sites. At the Thyspunt site the foundation of critical structures should not cross the contact between the Goudini and Skurweberg formations (**Figure 2.9**) ***since they display different seismic shearwave velocity***

properties. Similar variation in shearwave velocity properties may be expected where the Goudini Formation grades into the increasing shale-rich Cedarberg Formation at the far northern end of Thysbaai, and should be considered for further investigation should any critical facilities span this transition. This can only be determined as the footprint position is being finalised.

2.5 No-Go Option

A decision not to proceed with a Nuclear Power Station will have no impact on the geology at the Thyspunt, Bantamsklip or Duynefontein sites.

Figure 2.9: Thyspunt Geology Site Sensitivity Mapping

3. IMPACT IDENTIFICATION AND ASSESSMENT

The assessment of potential impacts related to geology is significantly interrelated to other areas of impact assessment, particularly water quality. Geology and soils effects may differ from those of other disciplinary areas of assessment because many proposed projects or actions will not actually cause effects *on* the geology of soils of an area. Effects, rather, are normally associated *with* geology or soils as opposed to causing any physical or chemical changes in the characteristics of the actual geology or soils.

This section identifies and evaluates geologic conditions at the project site that could affect, or be affected by implementation of the proposed project and recommends mitigation measures to avoid or lessen potential impacts.

The impact assessment methodology used was according to the Terms of Reference Document distributed by Arcus Gibb (Pty) Ltd (**Table 3.1 – Table 3.3**). It is important to note that the presented results reflect current knowledge and does not preclude a change in the current understanding of the tectonics and geology of the respective study areas, following more detailed neotectonic investigations. Work to date suggests that there are no disqualifiers to the construction, operation and decommissioning of a Nuclear Power Station at any of the three sites.

The proposed project could have a significant environmental impact if it would:

- Expose people or structures to potential substantial adverse effects, involving:
  - Possible vibratory ground motion resulting from a ***Nuclear Power Station*** at the site;
  - Surface rupture;
  - Subsurface stability; and
  - Volcanic activity;

- Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse.

Table 3.1: Impact assessment criteria and rating scales.

Criteria	***Rating Scales***	***Notes***
Nature	***Positive***	***This is an evaluation of the type of effect the construction, operation and management of the proposed NPS development would have on the affected environment.***
	Negative	
	Neutral	
Extent	***Low***	***Site-specific, affects only the development footprint***
	Medium	***Local (limited to the site and its immediate surroundings, including the surrounding towns and settlements within a 10 km radius);***
	High	***Regional (beyond a 10 km radius) to national***

Criteria	Rating Scales	Notes
Duration	*Low*	*0-3 years*
	Medium	*4-8 years*
	High	*9 years to permanent*
Intensity	*Low*	*Where the impact affects the environment in such a way that natural, cultural and social functions and processes are minimally affected*
	Medium	*Where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way; and valued, important, sensitive or vulnerable systems or communities are negatively affected*
	High	*Where natural, cultural or social functions and processes are altered to the extent that the natural process will temporarily or permanently cease; and valued, important, sensitive or vulnerable systems or communities are substantially affected.*
Potential for impact on irreplaceable resources	*Low*	*No irreplaceable resources will be impacted.*
	Medium	*Resources that will be impacted can be replaced, with effort.*
	High	*There is a high potential that irreplaceable resources will be lost.*
Consequence (a combination of extent, duration, intensity and the potential for impact on irreplaceable resources).	*Low*	*A combination of any of the following* • *Intensity, duration, extent and impact on irreplaceable resources are all rated low* • *Intensity is low and up to two of the other criteria are rated medium* • *Intensity is medium and all three other criteria are rated low*
	Medium	• *Intensity is medium and at least two of the other criteria are rated medium*
	High	• *Intensity and impact on irreplaceable resources are rated high, with any combination of extent and duration* • *Intensity is rated high, with all of the other criteria being rated medium or higher.*
Probability (the likelihood of the impact	*Low*	*It is highly unlikely or less than 50 % likely that an impact will occur.*
	Medium	*It is between 50 and 74 % certain that the impact will occur.*

Criteria	Rating Scales	Notes
occurring)	***High***	***It is more than 75 % certain that the impact will occur or it is definite that the impact will occur.***
Significance (all impacts including potential cumulative impacts)	***Low***	• ***Low consequence and low probability*** • ***Low consequence and medium probability***
	Low to medium	• ***Low consequence and high probability*** • ***Medium consequence and low probability***
	Medium	• ***Medium consequence and medium probability*** • ***Medium consequence and high probability*** • ***High consequence and low probability***
	Medium to high	• ***High consequence and medium probability***
	High	• ***High consequence and high probability***

3.1 Impact 1: Possible Locally Induced Vibratory Ground Motion at the Site

The steam turbines may have a vibratory movement which could be transferred to the rock on which the plant is situated. ***Vibratory ground motion resulting from tectonic movement along geological faults will be discussed in the technical report on seismic hazard.***

3.2 Impact 2: Surface Rupture

This refers to the identification of any capable faults that may cause surface deformation as a result of tectonic faulting. According to the guidelines provided by the US Nuclear Regulatory Commission and specifically 10 CFR100, Appendix A, a capable fault is defined as a fault that exhibit on or more of the following:

(1) Movement at or near the ground surface at least once within the past 50,000 years or movement of a recurring nature within the past 500,000 years.
(2) Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.
(3) A structural relationship to a capable fault according to characteristics (1) or (2) of this paragraph such that movement on one could be reasonably expected to be accompanied by movement on the other.

3.2.1 Thyspunt

A number of faults are known to occur in the Site Vicinity (Goedhart, 2007), most of which formed during the Permo-Triassic Cape Orogeny and subsequently reactivated during the late Mesozoic. None of these can be shown to have been active during the Quaternary. Seismic data indicate that the Cape St. Francis Fault has not been active since the Tertiary (J. Roux, pers. comm., Petroleum Agency of South Africa, 2007), while evidence indicate no on-land continuation of this fault.

No evidence could be found to confirm the presence of the so-called Klippepunt fault (Faurie *et al*., 1993) to the west of Thyspunt. The so-called Jeffreys Bay faults have been interpreted based on sea floor scarps, but faults in this family are short and do not extend onto land. The offshore Plettenberg Fault may have been active in the late Tertiary (Goedhart, 2007), and possibly even the late-Quaternary to Holocene, but its closest approach to the site is 18km, and it runs sub-parallel to the coast line and does not extend onshore within the Site Vicinity area.

To date no capable geological fault could be identified within the Thyspunt Site Vicinity. Faults with demonstrable neotectonic reactivation including the Baviaanskloof, Coega and Zuurberg faults, lie outside the Thyspunt Site Vicinity. Hill (1988) could find no evidence for recent reactivation along the ***northeast – southwest*** striking Paul Sauer transfer faults, ***northwest*** of the site.

3.2.2 Bantamsklip

Since the Bantamsklip site is situated in a fractured part of the Cape Fold Belt, called the syntaxis, the basement rock of the Site Vicinity and part of the Site Region are intensely faulted. Andreoli *et al*., (1994) reported extensive evidence for neotectonic activity but only some of this evidence has been verified (De Beer 2006; Siegfried *et al*., 2008).

The AEC (Andreoli *et al*., 1989a,b) considered the ***west-northwest*** striking fault observed at Celt Bay a Grade IV fault, based on unproven ideas at the time that all ***west-northwest*** striking faults are candidates for Quaternary-age reactivation (De Beer, 2007a). As there is at present no evidence that the fault is capable, it is not regarded as a risk for surface faulting. Follow-up work removed the so-called "Blomerus Fault" (De Beer, 2007a).

At present there is no primary evidence to suggest post-Tertiary movement of any faults within the 40 km radius and it is therefore inferred that these faults are all faults with no Pleistocene movement history. Joints observed in exposures of the Wankoe and Waenhuiskrans Formations of the Bredasdorp Group, have alternatively been interpreted as of diagenetic origin, or rupture resulting form crustal uplift (Siegfried *et al*., 2008). Andreoli *et al*. (1994) suggested the reactivation of some faults ***that are*** related to the ***much earlier*** Cape Orogeny and Gondwana break-up. ***As*** evidence ***he sited*** the sudden truncation of a number of well consolidated aeolianite deposits close to known correspondence to faults in the Palaeozoic basement. However, this could not be confirmed during recent investigations (Siegfried *et al*., 2008). Nor is there any evidence of the faults in the offshore Bredasdorp Basin having been active after the 93 Ma old 15At1 unconformity (De Beer, 2006), but it should be noted that the offshore surveys were not tailored to the detection of fault displacement in the Tertiary cover.

3.2.3 Duynefontein

The Duynefontein regional area of investigation contains some of the most faulted parts of the Cape Fold Belt, with current prominent seismicity in the Ceres–Tulbagh area. No sign of Quaternary activation could be found for the better exposed faults such as Colenso, Mamre and Darling faults.

Several inferred faults have been proposed (De Beer, 2007b; De Beer *et al*., 2008) based on geophysical work. Very little detailed work has been done on these and in some cases the nature of these features is yet to be confirmed. The most important of these is the ***inferred*** Melkbos Ridge Fault identified from the multibeam imagery of the Duynefontein extended marine area. It is an offshore lineament previously called the Table Bay Fault, a magnetic low with apparent displacement of a dyke anomaly west of Milnerton. In addition, several geophysical lineaments and other features have been described in the Duynefontein Site Area (De Beer, 2007b), but the evidence for considering these as faults, are weak.

Evidence for any Cenozoic-age deformation is very rare, and is further compounded by the low preservation potential of surface deformation in this area, generally high rainfall and predominance of unconsolidated sedimentary cover. Micro-faulting described by Dr. J. Rogers in Pliocene and Pleistocene deposits at Koeberg (Rogers, 2006) can be attributed to a variety of processes including ground-shaking or local slumping in a marine environment. The faulted Pliocene to Middle Pleistocene sands are unconformably overlain by latest Middle Pleistocene-age deposits (ca. 125,000 year old) which are not affected by the faulting.

On the farm Wolwedans, just north of Klipheuwel and 24 km east of Koeberg, ***northwest-***striking fractures occur in silcrete of the Bellville Formation. This coincides with the Kalbaskraal fault, a member of the Vredenburg-Stelllenbosch fault zone (De Beer, *et al*., 2008). Some evidence for neotectonic activity was found in a sedimentary clay pit on the farm Zoutrivier 22 near Camphill Village, about 16 km northeast of the Duynefontein site. Marker horizons identified within the deposit are displaced by a ***northwest-***striking, ***northeast-***dipping normal fault by about 40 cm (De Beer *et al*., 2008). The clay deposit is inferred to be of Neogene age (24 to 1.8 Ma) but a younger age cannot at this stage be discounted. This faulting could be the result of reactivation of such a hitherto unknown fault that appears aligned with the Mamre Fault or extension of the Klipheuwel Fault De Beer *et al*. (2008). However, to date no evidence of surface rupture has been found within the Duynefontein Site Area.

3.3 Impact 3: Subsurface Stability

Subsurface stability refers to any potential surface or subsurface subsidence, solution activity, subsidence or uplift. The Thyspunt and Bantamsklip sites are underlain by quartzitic sandstones of the Table Mountain Group, which are stable and highly resistant to weathering.

No evidence of liquefaction-induced structures was observed at Duynefontein, but it is well-known that the 4 December 1809 M>6 events in Cape Town induced extensive liquefaction (primarily in the wetlands around Rietvlei), as far north as

Bloubergsvlei, a farm located only 11 km ***southeast*** of Koeberg (De Beer, 2006). In addition the sand of the Duynefontyn plume of the Witzand Formation is an important aquifer that serves as a source of potable water for municipal areas within the area served by the City of Cape Town. Water can therefore be expected to accumulate on the interface between Cenozoic-age deposits and the deeply weathered clays of the Malmesbury Group. Also, clay layers within successions such as the Springfontyn Formation could act as aquicludes, preventing effective drainage and inducing conditions in sands that are ideal for liquefaction by seismic shaking (De Beer *et al*., 2008).

3.4 Impact 4: Volcanic Activity

Any active or recently active volcanoes within the site vicinity of a Nuclear Power Station would constitute a risk to such a facility. However sedimentary rocks of various ages dominate the surface geology at all three sites. Intrusive rocks are primarily represented by the (Neoproterozoic) Cape Granite Suite at Bantamsklip and Duynefontein as well as Mesozoic dyke swarm between Milnerton and Bloubergstrand (Duynefontein). There is no evidence to suggest any Cenozoic-age ***(i.e. within the last 65 Ma)*** volcanic activity at any of the three sites that would pose a risk to a Nuclear Power Station.

3.5 Cumulative Impact

Geological impacts related to the proposed development involve hazards associated with site-specific soil conditions, erosion, slope stability, surface rupture and ground-shaking during earthquakes. Since hazardous events of this type, as well as seismological activity, occur infrequently in this region and display high return periods, the cumulative, incremental impact resulting from repeated events in the geological, tectonic and seismological environment is expected to be low. However, it should be remembered that a single initiating event, such as an earthquake, may manifest, sometimes simultaneously, as several geological hazards (for example ground-shaking, surface rupture, sediment movement on the continental slope, etc.),

When considering the three sites the impact of any geological event will be specific to any particular site and will not be common or shared with (in an additive sense) the other sites under investigation. This is because of the spatial separation of the three sites and also the unique geologic environment at each site. However, any such event may contribute to the background risk that has to be considered in geological risk analysis. Any potential cumulative impacts resulting from geological, seismic, and soil conditions can be reduced to insignificant on a site-by-site basis by construction methods and code requirements. In addition, development on the site would be subject to uniform site development and construction standards that are designed to protect public safety,

Given the size and nature of the geological and seismological environment, it is important to note that geological hazards impact an entire site. Thus where more than one nuclear facility is built and operated at a specific locality, there may be some variation in the impact of a geological hazard on individual facilities, but such a hazard will have an impact on all facilities present at the affected locality.

The three localities under review are considered suitable locations for Nuclear Power Stations following extensive investigations and to date no geological evidence has been found that would halt the development of a Nuclear Power Station at any of these sites.

4 ENVIRONMENTAL ASSESSMENT

The objective of the assessment of impacts is to identify and assess all the significant impacts that may arise as a result of a Nuclear Power Station at the proposed sites. The assessment of potential impacts related to geology is significantly interrelated to other areas of impact assessment. The geological environment differs from other disciplinary areas of assessment because many proposed projects will not actually cause effects *on* the geology of soils of an area. Instead the geological environment may pose a risk to a proposed development. The existing and potential future impacts of the geological environment on the proposed development for each of the three main project phases (construction, operation, decommissioning) is listed and described below. Given the long return periods employed in geological studies, the geological risk remains constant throughout the different project phases of construction, operation and decommissioning.

4.1 Impact 1: Possible Locally Induced Vibratory Ground Motion at the Site

(a) Nature of the impact

The steam turbines may have a vibratory movement which could be transferred to the rock on which the plant is situated ***and is considered a negative impact (Table 4.1).***

Table 4.1: Environmental Assessment Impact 1: Vibratory Ground Motion

Criteria	Rating Scales	After Mitigation
Nature	• Negative	• Neutral
Extent (spatial limit of the impact)	• ***Low***	• ***Low***
Duration (the predicted lifetime of the impact)	• ***High***	• ***Low***
Intensity / Severity	• ***Low***	• ***Low***
Impact on irreplaceable resources (is an irreplaceable resource impacted upon?)	• ***Low***	• ***Low***
Consequence	• ***Low***	• ***Low***
Probability (the likelihood of the impact occurring)	• ***Low***	• ***Low***
Significance	• ***Low***	• ***Low***
Confidence level (the specialist's degree of confidence in the predictions and/or the information on which it is based)	• ***High***	• ***High***
Cumulative impacts	• ***Medium***	• ***Low***

(b) Extent

As the name suggests, this impact has a very local extent, being restricted within the development footprint and is therefore given a low score (Table 4.1).

(c) Duration

The duration of this impact may range from the short term (less than 5 years) up to a maximum duration of the entire plant operation life time (40 years or more). Duration is therefore given a high rating.

(d) Intensity / Severity
Locally induced vibratory motion will only have a limited impact on the local geological environment and processes and are therefore given a low rating.

(e) Impact on Irreplaceable Resources
No irreplaceable resources will be impacted.

(f) Consequence
Based on the above information and the impact assessment methodology employed, the consequence of this impact is low and remains low after mitigation.

(g) Probability of Occurrence
It is unlikely that his impact will occur, resulting in a low rating for this impact.

(h) Significance
Based upon the above information and the impact assessment methodology employed, this impact is considered to have a low significance and remains low after mitigation.

(i) Degree of Confidence
The consultants have high a confidence in the predictions presented here.

(j) Cumulative Impact
The impact vibratory movement by the steam turbines may have a medium to low cumulative effect on the rock on which the plant is situated, which may in turn impact the structural integrity of the plant.

(k) Mitigation measures
- ***Foundations of the nuclear island to be to founded on competent bedrock or engineered foundation.***
- ***Vibration/shock absorbers between the turbines and the solid rock foundations if necessary.***

(l) Legal Requirements
The geological investigations that assess this risk factor should follow the regulations stipulated in the National Nuclear Regulator Act (Act No 47 of 1999) and the directives of the National Nuclear Regulator.

4.2 Impact 2: Surface Rupture

(a) Nature of the impact
Surface deformation as the result of tectonic faulting within the footprint area will have a negative impact on the facility. Surface deformation within footprint or within the site area will have a neutral to negative impact on the natural environment (Table 4.2). However it should be kept in mind that this does not refer to an impact that the proposed development will have on the environment, but the environment on the proposed facility.

Table 4.2: Environmental Assessment Impact 2: Surface Rupture

Criteria	*Rating Scales*	*After Mitigation*
Nature	• ***Negative***	• ***Neutral***
Extent (spatial limit of the impact)	• ***Medium***	• ***Mediuml***
Duration (the predicted lifetime of the impact)	• ***High***	• ***High***
Intensity / Severity	• ***Medium***	• ***Low***
Impact on irreplaceable resources (is an irreplaceable resource impacted upon?)	• ***Medium***	• ***Low***
Consequence	• ***Medium***	• ***Medium***
Probability (the likelihood of the impact occurring)	• ***Low***	• ***Low***
Significance	• ***Medium***	• ***Medium***
Confidence level (the specialist's degree of confidence in the predictions and/or the information on which it is based)	• ***High***	• ***High***
Cumulative impacts	• ***Low***	• ***Low***

(b) Extent

The most severe direct negative impact of surface deformation, resulting from tectonic faulting, will be restricted to the footprint area. However it may also have a negative impact on supporting infrastructure further away, while the presence of a capable, tectonic fault within the regulatory site area (i.e. within an 8 km radius) has important regulatory implications and hence the extent of this impact has been classified as medium.

(c) Duration

The visible trace of surface deformation will diminish over time as a result of erosion, or can be erased by human activities. However, once such deformation has taken place the underlying fault, irrespective of whether it was previously known or not considered to be capable, will have to be upgraded to a capable status. For all intents and purposes this will be considered a permanent condition and hence duration of this impact is considered to be high.

(d) Intensity ***/ Severity***

The impact intensity of surface rupture will vary depending on ***the degree and location of rupture,*** but in general the direct impact is expected to be low for the natural environment ***within the vicinity of the proposed Nuclear Power Station.*** Surface rupture ***within the footprint can potentially*** cause damage to ***infrastructure and the severity of the impact on the environment is therefore considered to be medium to high, although this can be reduced through the appropriate engineering mitigation.***

(e) Impact on Irreplaceable Resources

The impact that surface faulting will have on irreplaceable natural resources will vary depending on its location and amount of displacement, as that will determine any secondary impacts. This is outside the scope of this study. However surface deformation represents a natural process from which the environment normally recovers through natural processes, lthough some human intervention may also be required.

(f) Consequence

Based on the above information, and the impact assessment methodology employed, the consequence of surface deformation is high, but decreases to medium after mitigation.

(g) Probability of occurrence
Based on available information the probability of this impact occurring is very low.

(h) Significance
Based upon the above information, and the impact assessment methodology employed here, the significance of this impact is medium and remains unchanged after mitigation.

(i) Degree of confidence
The consultants have a high level of confidence in the predictions presented here.

(j) Cumulative impacts
Since this type of event is expected to occur very infrequently the cumulative impact at any one locality is expected be very low.

(k) Mitigation measures

- ***Knowledge of the potential for surface faulting to occur is important to mitigation, hence t***he area excavated for Nuclear Power Station footprint should be assessed for the presence of any capable faults.
- Results of the geological investigations to select an appropriate Nuclear Power Station design ***and inform general engineering mitigation.***

(l) Legal requirements
The geological investigations that assess this risk factor should follow the regulations stipulated in the National Nuclear Regulator Act (Act No 47 of 1999) and the directives of the National Nuclear Regulator.

4.3 Impact 3. Subsurface Stability

(a) Nature of the impact
Solution activity, subsidence or uplift within the footprint area may have a negative impact on the proposed facility (Table 4.3). However it should be kept in mind that this does not refer to an impact that the proposed development will have on the environment, but the environment on the proposed facility

Table 4.3: Environmental Assessment Impact 3: Subsurface Stability

Criteria	Rating Scale	After Mitigation
Nature	• Negative	• Negative
Extent (spatial limit of the impact)	• Local (Low)	• Local (Low)
Duration (the predicted lifetime of the impact)	• High	• High
Intensity / Severity	• Low	• Low
Impact on irreplaceable resources (is an irreplaceable resource impacted upon?)	• Low	• Low
Consequence	• Low	• Low
Probability (the likelihood of the impact occurring)	• Low	• Low
Significance	• Low	• Low
Confidence level	• High	• High

(the specialist's degree of confidence in the predictions and/or the information on which it is based)		
Cumulative impacts	• *Low*	• *Low*

(b) Extent
Surface or subsurface subsidence or uplift may occur over a large area, but will only have a negative impact within the footprint area, and is thus considered to be low.

(c) Duration
Any subsurface instability is likely to be the result of long term geological properties and activities, and should be given a high rating.

(d) Intensity / Severity
Subsurface instability may have an impact on the operation of the proposed Nuclear Power Station, but occurs at such a low rate or has such a localised distribution, that natural processes are minimally affected. A low intensity rating is therefore given to this impact.

(e) Impact on Irreplaceable Resources
The impact on irreplaceable natural resources will be low.

(f) Consequence
Based on the above information, and the impact assessment methodology employed, the consequence is rated as low.

(g) Probability of Occurrence
Based on available information the probability of this impact occurring is very low.

(h) Significance
Based upon the above information, and the impact assessment methodology employed here, the significance rating of this impact is low.

(i) Degree of Confidence
The consultants have a high level of confidence in the predictions presented here.

(j) Cumulative Impacts
Since this type of event is considered highly unlikely with very high return periods, the cumulative impact is expected be very low.

(k) Mitigation Measures
- Foundations ***of the nuclear island to be to founded on competent bedrock or engineered foundation***
- ***In the case of an open excavation for the Nuclear island, dewater the Atlantis aquifer locally around the excavation before construction to prevent slope instability.***

(l) Legal Requirements
Geological investigations should follow the regulations stipulated in the National Nuclear Regulator Act (Act No 47 of 1999) and the directives of the National Nuclear Regulator.

4.4 Impact 4. Volcanic Activity

(a) Nature of the impact

A Nuclear Power Station will not cause any volcanic activity, but the eruption of any active or recently active volcano within the site vicinity ***would have a negative impact on a Nuclear Power Station and the general environment*** (**Table 4.4**).

Table 4.4: Environmental Assessment Impact 4: Volcanic Activity

Criteria	*Rating Scales*	*After Mitigation*
Nature	• *Negative*	• *Negative*
Extent (spatial limit of the impact)	• ***Low***	• ***Low***
Duration (the predicted lifetime of the impact)	• ***High***	• ***High***
Intensity / Severity	• ***Medium***	• ***Medium***
Impact on irreplaceable resources (is an irreplaceable resource impacted upon?)	• ***Medium***	• ***Medium***
Consequence	• ***Medium***	• ***Medium***
Probability (the likelihood of the impact occurring)	• ***Low***	• ***Low***
Significance	• ***Medium***	• ***Medium***
Confidence level ***(the specialist's degree of confidence in the predictions and/or the information on which it is based)***	• ***High***	• ***High***
Cumulative impacts	• ***Low***	• ***Low***

(b) Extent

There is no record of recent (i.e. during the Holocene Epoch or within the last 11,700 years) volcanic activity at any of the three proposed sites, nor in the wider region. Any volcanic activity is therefore unlikely to occur or be of such a scale to impact an area larger than the footprint.

(c) Duration

The impact from any volcanic activity is unlikely to reversible and should therefore be given a high rating.

(d) Intensity / Severity

There is no record of recent volcanic activity at any of the three proposed sites, nor in the wider region. Any volcanic activity is therefore unlikely to be of such a scale that would prohibit the continuation of natural processes and a medium intensity rating is therefore assigned to this impact.

(e) Impact on Irreplaceable Resources

There is no record of recent volcanic activity at any of the three proposed sites, nor in the wider region. Any volcanic activity is therefore unlikely to be of such a scale that irreplaceable natural resources cannot be replaced. This impact is therefore given a medium impact.

(f) Consequence Impact on Irreplaceable Resources

Based on the above information, and the impact assessment methodology employed, the consequence is rated as medium.

(g) Probability of Occurrence

The probability of this impact occurring is extremely low.

(h) Significance

Based upon the above information, and the impact assessment methodology employed here, the significance rating of this impact is medium.

(i) Degree of Confidence

The consultants have a high level of confidence in the predictions presented here.

(j) Cumulative Impacts

Since this type of event is considered highly unlikely the cumulative impact is expected be very low.

(k) Mitigation Measures

None

(l) Legal Requirements

The geological investigations that assess this risk factor should follow the regulations stipulated in the National Nuclear Regulator Act (Act No 47 of 1999) and the directives of the National Nuclear Regulator.

5 MITIGATION MEASURES

5.1 Impact 1: Possible Locally Induced Vibratory Ground Motion at the Site

Mitigation measures that may be considered include:

- Foundations ***of the nuclear island to be to founded on competent bedrock or engineered foundation.***
- Vibration/shock absorbers between the turbines and the solid rock foundations.

Local vibration movement constitutes a minor and localised environment impact.

5.2 Impact 2: Surface Rupture

The most essential and critical mitigation measures include:

- A thorough assessment of the area excavated for Nuclear Power Station footprint to uncover the presence of any undetected capable faults.
- Incorporating the results of the geological investigations to aid in the selection of an appropriate Nuclear Power Station design
- The results of the geological and seismological studies should be used as design input for determining the Safe Shutdown Earthquake Ground Motion (SSEGM) during operation as well the regulatory period after its decommissioning.

In addition the following additional mitigation measures may be considered:

- The ***foundations of the nuclear island to be to founded on competent bedrock or engineered foundation.***

5.3 Impact 3. Subsurface Stability

Mitigation measures to be considered may include:

- Foundations ***of the nuclear island to be to founded on competent bedrock or engineered foundation.***

5.4 Impact 4. Volcanic Activity

No mitigation required.

All impacts and mitigation measures for the three sites are listed in **Table 5.1** – **Table 5.3.**

Table 5.1: Impact and Mitigation Table for all three alternative sites

Impact	Nature	Intensity	Extent	Duration	Impact on irreplaceable resources	Consequence	Probability	SIGNIFICANCE
Local Induced Ground Motion: Capable faults that may cause surface deformation as result of tectonic faulting.	Negative	Low	Low	High	Low	Low	Low	Low
Mitigated	Negative	Low	Low	Low	Low	Low	Low	Low
Surface Rupture: Capable faults that may cause surface deformation as result of tectonic faulting.	Negative	Medium	Medium	High	Medium	Medium	Medium	Medium
Mitigated	Negative	Low	Medium	High	Low	Medium	Low	Medium
Subsurface Stability: Potential subsurface subsidence or uplift.	Negative	Low	Low	High	Low	Low	Low	Low
Mitigated	Negative	Low	Low	High	Low	Low	Low	Low
Volcanic Activity: Any recently active volcanoes wiothin site vicinity.	Negative	Medium	Low	High	Medium	Medium	Low	Low - Medium
Mitigated	Negative	Medium	Low	High	Medium	Medium	Low	Low - Medium

6 CONCLUSIONS AND RECOMENDATIONS

This report presents specialist assessments of geological, structural and tectonic data to be included in the EIR to be compiled by Arcus Gibb (Pty) Ltd. The report describes and assesses the scope of published data and investigations and outlines the uncertainties related to available data.

6.1 Thyspunt

Several studies focused on the geological environment and the Thyspunt onshore regional pre-Quaternary-age geology and tectonics are well understood. The site is located in a tectonically dormant part of the subcontinent and no capable faults that may lead to surface rupture at the Site Area, have been found.

Several fault sources (or fault systems) were identified as being potentially capable of generating significant seismic events. Some of these are located offshore and are only inferred from geophysical data, which complicates their characterization. To date none of these structures display correlation with seismicity or show any evidence for reactivation. Information regarding offshore structures obtained from geophysical surveys may aid in the characterization of these structures, ***or alternatively can be modelled based on the data available from the large, parallel onshore faults within the Thyspunt Site Region.***

The coastal plain on which the site is located is underlain by the quartzitic sandstones of the Table Mountain Group, which are chemically stable and provide a stable platform for the proposed Nuclear Power Station. There is no evidence of any volcanic activity in the immediate Site Area to Site Region.

Based on the current state of knowledge there are no disqualifiers for this site. Implementation of the mitigation measures listed in **Section 5**, and compliance with applicable regulations would reduce the potential impact of any geological hazards on the site. This includes the completion of additional neotectonic studies.

6.2 Bantamsklip

Geological investigations at various scales have been undertaken in the vicinity of the proposed Bantamsklip site and at present the Bantamsklip onshore regional pre-Quaternary-***age*** geology and tectonics are well understood.

The airborne, ground, and marine geophysical surveys conducted by the Council for Geoscience and Fugro within the Site Area (8 km radius) and part of the Site Vicinity area (40 km radius) to a large extent complimented the known onshore and offshore geology at Bantamsklip. The results of the surveys confirmed most of the positions of the major faults and added a better understanding of the exact position of some, e.g. the Groenkloof Fault. Many faults have been identified in the region surrounding

Bantamsklip, with very few identified earthquakes. No evidence of any capable fault has so far been found in the site area or site vicinity. ***Nevertheless, Bantamsklip is situated in the most fractured part of the Cape Fold Belt, called the syntaxis, which is characterised by east-northeast to northeast striking, Permo-Triassic-age thrust faults that are cut by northeast, west-northwest and east striking, Mesozoic-age normal faults. The complex structural geology, together with extensive surface cover by soft sediments and vegetation, means that uncertainty remains regarding the appropriate seismic source model for Bantamsklip***

The site itself is underlain by the quartzitic sandstones of the Table Mountain Group, which are chemically stable and provide a stable platform for the proposed Nuclear Power Station. There is no evidence of any volcanic activity in the immediate Site Area to Site Region.

Based on the current state of knowledge there are no disqualifiers for this site. Implementation of the mitigation measures listed in **Section 5** and compliance with applicable regulations would reduce the potential impact of any geological hazards at the site to an acceptable level. This includes the completion of additional neotectonic studies.

6.3 Duynefontein

At Duynefontein the onshore regional pre-Quaternary-age geology and tectonics are well understood. The airborne, ground, and marine geophysical surveys conducted by the Council for Geoscience and Fugro within the Site Area (8 km radius) and part of the Site Vicinity area (40 km radius) to a large extent complimented the known onshore and offshore geology.

Paleoseismic information on ***geological*** structures ***within the Site Vicinity identified as having a relatively high seismic potential,*** is limited, with very little correlation with known seismicity. At present there appears to be little or no evidence for the reactivation of any of these faults, but further investigation ***will*** be required.

The thicker soft sediment cover and the presence of an aquifer near Duynefontein constitute a potential risk to subsurface stability. Implementation of the mitigation measures listed in Section 5 and compliance with applicable regulations would reduce the impact and uncertainty regarding the above-mentioned hazard.

Based on the current state of knowledge there are no disqualifiers for this site. In general all geological hazards at the site can be mitigated through the implementation of the mitigation measures listed in **Section 5**, and compliance with applicable regulations. This includes the completion of additional neotectonic studies.

6.4 Conclusions

The nature of the geological environment is different from most of the other disciplinary areas included in the environmental impact study, as the proposed Nuclear Power Stations will have very little effect on the geological environment. In contrast the potential impact of the geological environment on a Nuclear Power Station and associated infrastructure is much bigger and may pose a risk to the proposed development. This will be investigated in much greater detail as part of the SSR process. The only exception is vibratory movement, which could be transferred from the steam turbines to the underlying bedrock at Thyspunt and Dunyefontein, but this represents a very minor impact that is easily mitigated against.

Given the long return periods employed in geological studies the geological risk remains relatively constant throughout the different project phases of construction, operation and decommissioning.

The three proposed Nuclear Power Station sites reviewed here are exposed to very similar geological environments. Changes in the geological environment resulting from the mass movement of rock or soft sediment are considered improbable, especially as all three sites are situated on stable plains far away from potentially unstable slopes of higher gradient. Various mitigation measures such as the erection of rock fall barriers and sinking of foundations into bedrock, may be considered, but are not considered necessary. With the exception of the impact of the ***Atlantis*** Aquifer at the Duynefontein site, the risk of subsurface instability is low. Even in the case of the latter it can be mitigated against by monitoring the level of the said aquifer. Geologically there are no sensitive areas that need to be avoided at the Bantamsklip and Duynefontein sites. At the Thyspunt site the foundation of critical structures should not cross the contact between the Goudini and Skurweberg Formations. A decision not to proceed with a Nuclear Power Station will have no impact on the geology at the Thyspunt, Bantamsklip or Duynefontein sites.

Generally, fault rupture and volcanic activity represents more serious geological hazards to an Nuclear Power Station, as they have the potential to cause the failure of the facility's safety systems. The best mitigation measures against these impacts entail a thorough characterization of the geological environment prior to and during construction. There is no evidence of any recent volcanic activity within the site region of any of the three proposed sites. In summary, the existing body of work suggest that there is a low geological risk and no disqualifiers for any of the three proposed sites and surrounding natural environments. However, additional neotectonic studies still need to be completed, which may impact and even change conclusions reached to date, and therefore no final conclusions can be made about site suitability.

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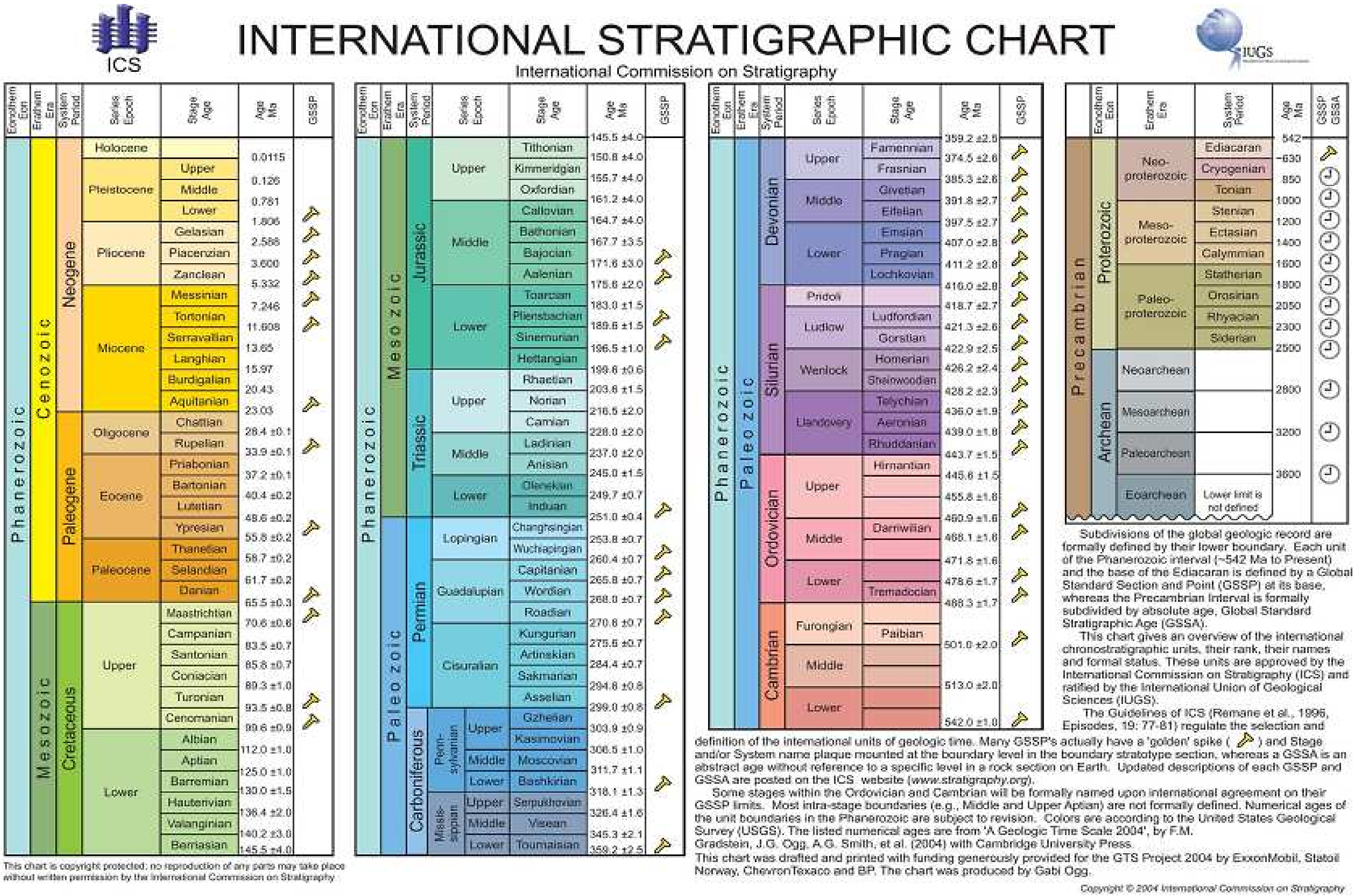
Appendix 1 International stratigraphic chart of the International Commission on Stratigraphy.



ICS
INTERNATIONAL STRATIGRAPHIC CHART
International Commission on Stratigraphy
IUGS
Eonothem Eon
Erathem Era
System Period
Series Epoch
Stage Age
Age Ma
GSSP
Phanerozoic
Cenozoic
Mesozoic
Neogene
Paleogene
Cretaceous
Holocene
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Upper
Middle
Lower
Gelasian
Piacenzian
Zanclean
Messinian
Tortonian
Serravallian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Thanetian
Selandian
Danian
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Paleozoic
Jurassic
Triassic
Permian
Carboniferous
Pennsylvanian
Mississippian
Tithonian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Bajocian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
Carnian
Ladinian
Anisian
Olenekian
Induan
Lopingian
Guadalupian
Cisuralian
Changhsingian
Wuchiapingian
Capitanian
Wordian
Roadian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Visean
Tournaisian
Devonian
Silurian
Ordovician
Cambrian
Famennian
Frasnian
Givetian
Eifelian
Emsian
Pragian
Lochkovian
Pridoli
Ludlow
Wenlock
Llandovery
Ludfordian
Gorstian
Homerian
Sheinwoodian
Telychian
Aeronian
Rhuddanian
Hirnantian
Darriwilian
Tremadocian
Furongian
Paibian
Precambrian
Proterozoic
Archean
Neoproterozoic
Mesoproterozoic
Paleoproterozoic
Neoarchean
Mesoarchean
Paleoarchean
Eoarchean
Ediacaran
Cryogenian
Tonian
Stenian
Ectasian
Calymmian
Statherian
Orosirian
Rhyacian
Siderian
Lower limit is not defined
GSSP GSSA
This chart is copyright protected; no reproduction of any parts may take place without written permission by the International Commission on Stratigraphy
Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic interval (~542 Ma to Present) and the base of the Ediacaran is defined by a Global Standard Section and Point (GSSP) at its base, whereas the Precambrian Interval is formally subdivided by absolute age, Global Standard Stratigraphic Age (GSSA).
This chart gives an overview of the international chronostratigraphic units, their rank, their names and formal status. These units are approved by the International Commission on Stratigraphy (ICS) and ratified by the International Union of Geological Sciences (IUGS).
The Guidelines of ICS (Remane et al., 1996, Episodes, 19: 77-81) regulate the selection and definition of the international units of geologic time. Many GSSP's actually have a 'golden' spike ( ) and Stage and/or System name plaque mounted at the boundary level in the boundary stratotype section, whereas a GSSA is an abstract age without reference to a specific level in a rock section on Earth. Updated descriptions of each GSSP and GSSA are posted on the ICS website (www.stratigraphy.org).
Some stages within the Ordovician and Cambrian will be formally named upon international agreement on their GSSP limits. Most intra-stage boundaries (e.g., Middle and Upper Aptian) are not formally defined. Numerical ages of the unit boundaries in the Phanerozoic are subject to revision. Colors are according to the United States Geological Survey (USGS). The listed numerical ages are from 'A Geologic Time Scale 2004', by F.M. Gradstein, J.G. Ogg, A.G. Smith, et al. (2004) with Cambridge University Press.
This chart was drafted and printed with funding generously provided for the GTS Project 2004 by ExxonMobil, Statoil Norway, ChevronTexaco and BP. The chart was produced by Gabi Ogg.
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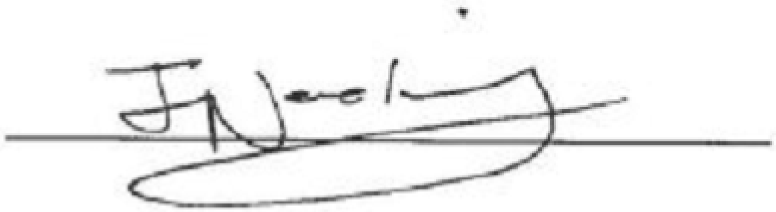
Company name	***Council for Geoscience***
Specialist signature	 ***Johann Neveling (Pr. Sci. Nat.)***  ***Erna Hattingh (Pr. Sci. Nat.)***
Date	***16 March 2011***