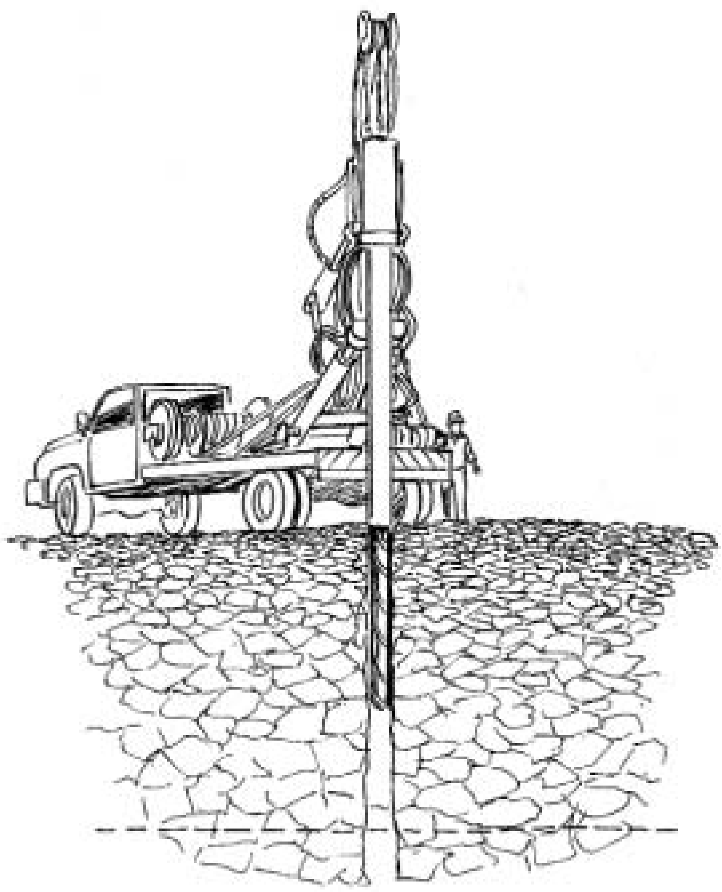
Standard Descriptors for Geosites



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NORWEGIAN AGENCY FOR DEVELOPMENT COOPERATION

TOOLKIT for WATER SERVICES: Number 2.1

The purpose of this document is to establish a nationally acceptable standard for the description of groundwater related data being generated in the execution of groundwater development projects funded by Government or government agencies

Standard Descriptors for Geosites

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Foreword

Toolkit for Water Services

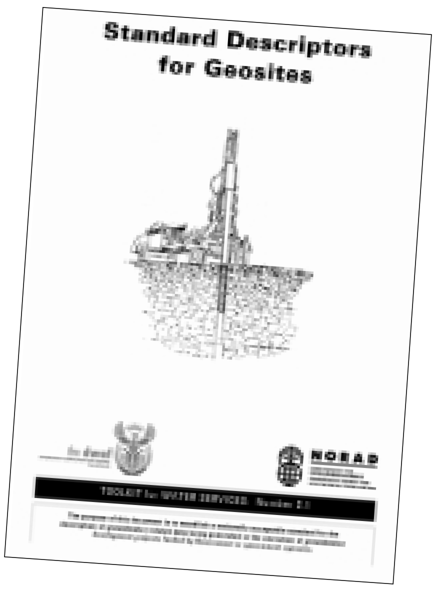
Groundwater has historically been given limited attention, and has not been perceived as an important water resource, in South Africa. This is reflected in general statistics showing that only 13 % of the nation's total water supply originate from groundwater. However, because of the highly distributed nature of the water demand in rural and informal peri-urban settlements, regional schemes are, in most instances, not economically feasible. And because of generally increasing water scarcity and decreasing available river and spring flows during low flow and drought periods, as well as wide-spread problems of surface water pollution in rural areas, groundwater will be the most feasible option for a large part of the new water demand. Already it is estimated that over sixty percent of community water supply is from groundwater, making it a strategically important resource.

The NORAD-Assisted Programme for the Sustainable Development of Groundwater Sources under the Community Water and Sanitation Programme in South Africa was managed by the Department of Water Affairs and Forestry (DWAF) between 2000 and 2004. The Programme undertook a series of inter-related projects aimed at enhancing capacity of water services authorities and DWAF to promote and implement sustainable rural water supply schemes based on groundwater resources and appropriate technologies.

The next page has a full list of the Programme outputs. The formats for these range from documents to software programmes and an internet portal, to reference sites where communities have implemented appropriate technologies. For more information on the "package" of Programme outputs contact your nearest DWAF Regional Office or Head Office in Pretoria.

It is our sincere hope that this Programme will contribute to the body of work that exists to enable more appropriate use and management of groundwater in South Africa.

Standard Descriptors for Geosites is Number 2.1 in the Toolkit for Water Services. The purpose of this document is to establish a nationally acceptable standard for the description of groundwater related data being generated in the execution of groundwater development projects funded by Government or government agencies.



Toolkit for Water Services

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PREFACE

Groundwater's strategic importance is growing. By now more than 70% of communities that have been served are receiving their supply from groundwater sources. At the same time groundwater must also be managed as a significant water resource in terms of the National Water Act, 1998.

All this cannot be achieved without also significantly improving the groundwater information base. This in turn requires that every information and data source is tapped and shared in the national interest, e.g. from other government departments, from local government, from NGOs and from drillers and consultants. That is where the "Standard Geosite Descriptors" come in. Systematic sharing of data is only possible when we all use the same terminology for the groundwater attributes we want to describe, measure and apply for many different purposes.

You will recognise that most of the described geosite attributes are not new, but this publication represents an effort to formalise everyday business practices used by most of us. New technological developments, e.g. the Global Positioning System, demand that new attributes be added and that these are described in some detail to explain their role in relation to groundwater data.

The standards for the description of other groundwater-related features equating to lines and polygons, e.g. faults and aquifers, will follow.

An appeal is herewith made to everyone dealing with groundwater data to carefully study the suggested standard descriptors and comment on their correctness and sufficiency. We thank those who have already done so, and look forward to many more comments.

Stefan van Biljon

DIRECTOR: HYDROLOGICAL SERVICES

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

EXECUTIVE SUMMARY

The objective of this document is to provide background information in support of a standard format for describing data, information, details, observations and/or materials associated with a geosite. It addresses, amongst others, the following aspects:

- Attributes to be described
- Units of measurement

Numerous projects within the South African Government's Reconstruction and Development Program (RDP) address the supply of domestic water to 12 000 – 15 000 previously disadvantaged communities. Many of these incorporate groundwater development projects involving exploration, the drilling of new boreholes and the development and protection of springs.

A wide range of people and professions is involved in groundwater source development and the analysis of geohydrological data. Each of these activities generates valuable data or information that is needed to improve the efficacy of groundwater development and ensure the sustainable utilisation of this national resource.

With the many different groupings of people involved in groundwater development and utilisation, there is an associated diversity of databases and means of recording geohydrological data. It can be difficult to exchange and/or compare data from different databases if the data are not standardised. Data standards for groundwater need to be developed to ensure the easy sharing of information and to reduce data misinterpretation as far as possible.

This document does not promote new standards *per sè*, it rather formalises current practices and standards. Although the document was primarily designed to be used as a field guide, it was felt that background information should be provided in support of the suggested standard.

Chapter 14 of the National Water Act (Act 36 of 1998) specifies that monitoring, recording, assessing and dissemination of information on water resources is critically important for achieving the objectives of the Act. To fulfil the requirements of the national information systems, it is necessary to capture geohydrological data. Since one of the fundamental building blocks of a groundwater information system is geosite data, it is essential that its recording and capture adhere to a standard that enhances its value.

The document includes the following chapters in which the following relevant aspects are addressed:
Introduction: A general introduction including reasons for establishing standard descriptors.
Basic geosite information: Descriptors pertaining to the position of a geosite and other static information.

- Geosite construction: Data associated with borehole drilling and construction.
- Geosite geology: Attributes of the geology/lithology associated with a geosite.
- Geosite geohydrology: Attributes of the groundwater resource associated with a geosite.
- Geosite design, development and completion.
- Geosite and aquifer testing.
- Geophysical logging
- Operational management and installed equipment
- Groundwater monitoring
- Conclusion
- Acknowledgements
- References

1 GENERAL INTRODUCTION

1.1 Introduction

Extensive groundwater exploration and development is currently being carried out throughout South Africa. This includes the siting and drilling of new boreholes, the refurbishment and equipping of existing boreholes, the development and protection of springs, etc. These activities involve a wide range of persons and professions, and provide a wealth of data that are important for the following reasons:

- enhancing the collective understanding of South Africa's scarce and precious groundwater resources,
- improving the efficacy of groundwater development, and
- ensuring the sustainable utilisation of this national resource.

Under the direction of the South African Government's Reconstruction and Development Program (RDP), which includes the supply of potable water to between 12 000 and 15 000 previously disadvantaged communities, more groundwater development projects are currently being implemented than all those of the past put together. The latest restructuring of the Department of Water Affairs and Forestry (DWAF) is resulting in District Municipalities having to accept responsibility for the development of their own water supply sources. Since groundwater has a major role to play in particular districts, more professionals and institutions are becoming involved in groundwater development projects.

1.2 Necessity for Standards

With the many different groupings of people involved in groundwater development and utilisation, there is an associated diversity in the manner and means of recording geohydrological data and information. In this regard, standards and standardisation facilitate the exchange and/or comparison of data between different users and databases.

The Standard Descriptors for Geosites project is just one component of DWAFs Directorate: Hydrological Services' groundwater data acquisition strategy. Many issues are addressed in this strategy. These include the forms for collecting geohydrological data, encouraging all those involved in the development of groundwater resources to provide the data to DWAF, facilitating access to the data in the National Groundwater Data Base (National Groundwater Archive), etc. (*pers. comm.* E. Bertram, 2002). Electronic data exchange standards also need to be developed to ensure the easy sharing of data, reduce its misinterpretation and redress the perception that data is a 'bargaining chip'. For example, using a standard co-ordinate reference system for the transfer of spatial data avoids confusion in terms of projection details such as the central meridian, standard parallels and spheroid. Establishing conventions in data management (e.g. negative values for artesian head measurements in free-flowing boreholes, positive values for water level measurements below the ground surface) avoids misinterpretation. Proper metadata procedures give the data supplier an opportunity to describe the reliability and limitations placed on the relevant data set. There are also significant financial savings to be realised from implementing standard geosite descriptors.

This document does not promote new standards *per sè*; it rather formalises current practices and standards. The benefit realised from this formalisation is that it enables the creation of dedicated data capturing software packages. A national data exchange standard will be established for those who have developed proprietary or bought commercial systems.

Although the terms "geohydrologist" and "geohydrology" have been used throughout this document, it is appreciated that use of the terms "hydrogeologist" and "hydrogeology" may, in some instances, be more appropriate. For the sake of standardisation and consistency, however, the former terms have been used throughout this document.

1.3 Document Objectives

Since the document is to be used as a field guide when reporting groundwater point source data and collecting relevant information, its objectives are to provide background information to all geosite attributes and propose a standard way of describing these items. In essence, a reference as to what recordable data are mandatory and the available options for each data item. As such, it will form part of the geohydrologists basic field kit comprising items such as a hand lens, geological pick, colour chart, GPS, water level meter, measuring tape, stopwatch, geological and geohydrological maps, etc.

1.4 Document Format

The document addresses each of the sequential activities typically associated with the development of groundwater resources in their order of execution.

Text boxes in each Chapter provide a concise summary of relevant standards provided in the document. Numerous tables summarise the options available for describing various aspects of a geosite, whether it be borehole drilling, testing and equipping, spring development and protection or mine-related information, amongst others.

The Appendices include a listing of chronostratigraphic, lithostratigraphic and lithological terms as defined by the Council for Geoscience. These terms represent the accepted standard for use in geological descriptions.

1.5 Legal Framework

Chapter 14 of the National Water Act (Act 36 of 1998) specifies that monitoring, recording, assessing and dissemination of information on water resources is critically important for achieving the objectives of the National Water Act. The national information systems required, and the objectives of these systems, are listed below:

Establishment of national information systems (139)

- *The Minister must, as soon as reasonably practicable, establish national information systems regarding water resources (1)*
- *The information systems may include, among others (2)*

A hydrological information system (2a)
A water resource quality information system (2b)
A groundwater information system (2c)
A register of water use authorizations (2d).

Objectives of national information systems (140)

The objectives of national information systems are:

- *To store and provide data and information for the protection, sustainable use and management of water resources (a)*
- *To provide information for the development and implementation of the national water resource strategy (b)*
- *To provide information to water management institutions, water users and the public (c)*

For research and development (c i)
For planning and environment impact assessments (c ii)
For public safety and disaster management (c iii)
On the status of water resources (c iv).

To fulfil the above requirements (particularly 2c), it is necessary to capture geohydrological data, one of the fundamental building blocks of a geohydrological information system. For example, the drilling of boreholes provides valuable point data of geological and geohydrological conditions. A synthesis of this data provides a clearer and more complete picture of the groundwater environment to the extent that associated interactions can be developed and understood. It is therefore essential that borehole data be captured and, perhaps more importantly, that the format of its capture be standardised in order to enhance its value. This sentiment applies equally to any other geosite.

2 GEOSITE BASIC INFORMATION DESCRIPTORS

2.1 Geosite Type

Although boreholes represent the most common type of geosite, it is relevant to recognise that there are many other features related to groundwater abstraction, occurrence and monitoring. A Geosite is defined as 'a naturally occuring or artificially cexcavated or constructed or improved underground cavity which can be used for the purpose of a) intercepting, collection or storing of water in, or removing water from an aquifer, b) observing and colleting data and information on water in an aquifet, or c) recharging an aquifer (Xu, et al, 2003). These features are listed in Table 2.1. Their positions can be measured, topographic settings assigned, current status and purpose determined and their location mapped or sketched.

Table 2.1 Geosite types

Descriptor
Borehole
Dug well
Wellpoint
Drain
Tunnel
Mine
Seepage pond
Spring
Sinkhole
Lateral collector

2.2 Geosite Position

2.2.1 Latitude, longitude and elevation

A geographic position(geosite) is typically referenced by its longitude and latitude values. Longitude and latitude are angles measured from the earth's centre to a point on the earth's surface. The angles are usually measured in degrees (Figure 2.1).

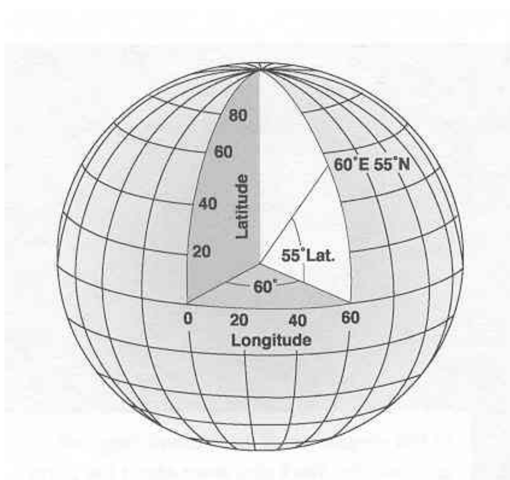


Figure 2.1 The world as a globe showing the longitude and latitude values.

In the spherical system, 'horizontal' or east-west lines represent lines of equal latitude or *parallels*. 'Vertical' or north-south lines represent lines of equal longitude or *meridians*. These lines encompass the globe and form a gridded network called a *graticule* (Figure 2.2).

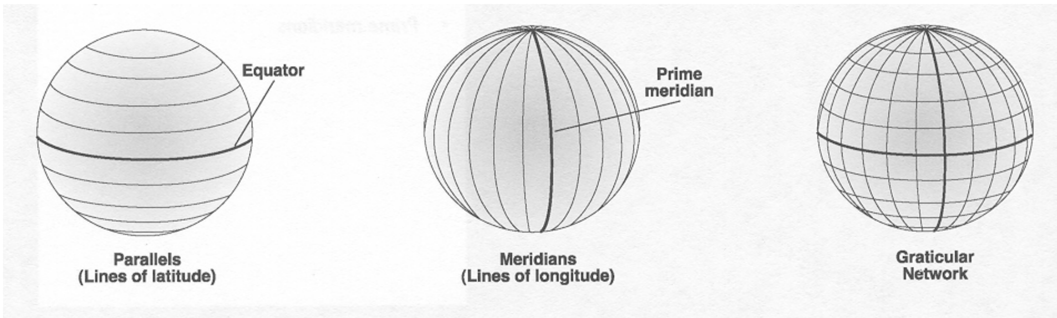


Figure 2.2 The parallels and meridians that form a graticule.

The line of latitude midway between the poles is called the equator. It defines the line of zero latitude. The line of zero longitude is called the prime meridian. For most geographic coordinate systems, the prime meridian is that which passes through Greenwich, England.

The origin of the graticule (0,0) is defined by where the equator and prime meridian intersect. The globe is then divided into four geographical quadrants that are based on compass bearings from the origin. North and south are above and below the equator, and west and east are to the left and right of the prime meridian, respectively.

Latitude and longitude values are traditionally measured in decimal degrees or in degrees, minutes and seconds (DMS). Latitude values are measured relative to the equator and range from -90^{o} at the South Pole to $+90^{o}$ at the North Pole. Longitude values are measured relative to the prime meridian. They range from -180^{o} furthest to the west, to $+180^{o}$ furthest to the east. Using Greenwich as the prime meridian, South Africa located south of the equator and east of Greenwich has negative latitude values and positive longitude values.

Although latitude and longitude can locate exact positions on the surface of the globe, they are not uniform units of measure. Only along the equator does the distance represented by one degree of longitude approximate the distance represented by one degree of latitude. This is because the equator is the only parallel as large as a meridian. (Circles with the same radius as the spherical earth are called *great circles*. The equator and all meridians are great circles).

Above and below the equator, the circles defining the parallels of latitude get gradually smaller until they become a single point at the North and South Poles where the meridians converge. As the meridians converge toward the poles, the distance represented by one degree of longitude decreases to zero. For example, using the Clarke 1880 spheroid, one degree of longitude at the equator equals 111.321 km, while at 60° latitude it is only 55.802 km. Since degrees of latitude and longitude do not have a standard length, distances or areas can not be measured accurately on a flat map or computer screen (Kennedy and Kopp, 2000).

A projected co-ordinate system is defined on a flat, two-dimensional surface. Unlike a geographic co-ordinate system, a projected co-ordinate system has essentially constant lengths, angles and areas across the two dimensions. A projected co-ordinate system is always based on a geographic co-ordinate system that itself is based on a sphere or spheroid. In a projected co-ordinate system, locations are identified by x and y co-ordinates on a grid, with the origin at the centre of the grid. Each position has two values that reference it to the central location. One specifies its horizontal position and the other its vertical position. The two values are called the x co-ordinate and y co-ordinate. Using this notation, the co-ordinates at the origin are $x = 0$ and $y = 0$. Units are consistent and equally spaced across the full range of x and y.

Whether the earth is treated as a sphere or a spheroid, its three-dimensional surface must be transformed to create a flat map. This mathematical transformation is commonly referred to as a map projection. Representing the earth's surface in two dimensions causes distortion in the shape, area, distance or direction of the data. A map projection uses mathematical formulae to relate spherical accordance on the globe to flat, planar co-ordinates. Different projections cause different types of distortion. For example, a projection could maintain the area of a feature but alter its shape. The choice of map projection depends mainly on the project scale and purpose. Thus geosite co-ordinates should be recorded as degrees, minutes and decimal seconds and not in projected x and y coordinates. This format is a good basic reference system that also facilitates the exchange of data. As already mentioned for the South African situation, longitude will be a positive value and the latitude will be negative.

If reference co-ordinates in spreadsheets or mapping software need to be checked, then degrees (dd), minutes (mm) and seconds (ss) are easily converted to decimal degrees significant to six decimals (i.e. dd.dddddd) by using the following formula:

$$dd + (mm/60) + (ss/3600) = dd.dddddd$$

It is recognised that different manufacturers of GPS instruments display the measured co-ordinates in different formats. Since these can be changed quite readily, positional data are to be recorded as degrees, minutes and decimal seconds with a zero as default value in the first decimal, e.g. 24°36' 19.0".

2.2.2 Method used to determine co-ordinates

There are basically three ways in which geosite positions can be measured. The geosite position can be plotted on a map relative to identifiable/identified features and the co-ordinates determined from the co-ordinate references of the map. The map may take the form of a topocadastral map, an orthophoto, a satellite image, etc. Using a topocadastral or orthophoto map is the cheapest means of determining a geosite position, although possibly the least accurate.

A second method is to use global positioning system (GPS) technology. GPS uses radio signals from a constellation of earth-orbiting satellites to determine the three-dimensional position of earth receivers. By using variations of the Doppler principle in connection with data on satellite position, velocity, orbit and timing, mathematical and statistical models can be created and solved to yield first-order accuracies of as little as one centimeter during less than one hour of observation time (Slonecker and Carter, 1990). Such levels of accuracy do come with an associated cost that is usually well beyond the budget of most heohydrological projects. Interestingly, if data on the satellite geometry, position and movement (called ephemeral data) are known, the distance to an earth-based receiver can be geometrically calculated. Ephemeral data on satellites is constantly monitored by a network of tracking stations on earth, and relayed back to the satellite where it is included in the transmitting signal that is emitted by the satellite and tracked by the GPS receiver. If this ranging process is repeated constantly from several satellites and known errors caused by clock timing and atmospheric effects are modelled, a precise earth position can be calculated and referenced to a known datum and co-ordinate system. Differential positioning involves determining a position, or positions, based on satellite data in conjunction with a known earth control point such as a trigonometric beacon or survey peg. A triangulated solution is then accomplished in a fashion similar to traditional surveying techniques. This approach can significantly improve the two-dimensional measurement of a geosite position.

A third method of determining geosite co-ordinates is to use traditional survey techniques. This is typically the most expensive but undeniably the most accurate of the three approaches. For particular projects this method would be recommended strongly, particularly where geosite elevations need to be determined accurately.

In low technology approaches where maps, GPS or survey techniques can not be utilised, the farm name and number, and if available and relevant, the portion number and name must be recorded. If the district name is also provided, then the extensive cadastral database that exists for South Africa allows the farm to be located and an approximate position for the geosite, usually taken as the centre of the farm, determined. Table 2.2 lists the different options for measuring a geosite position.

Table 2.2 Geosite position determination methods

Descriptor
Surveying
GPS (Global Positioning System)
Differential GPS
Estimated from 1:10 000 scale map
Estimated from 1:25 000 scale map
Estimated from 1:50 000 scale map
Estimated from 1:100 000 scale map
Estimated from 1:250 000 scale map
Estimated from other scale map
District and Farm Name and Number

2.2.3 Accuracy of co-ordinates

The concept of accuracy is central to any method of spatial measurement and is essential to understand because varying levels of accuracy are associated with different survey and positioning techniques. There are numerous ways to report spatial error. For example a proportional error can be reported, or confidence regions given, or ground units provided. The spatial extent of error in ground units (i.e. metres) is the ultimate measure, and the one that is probably of most interest to the geohydrologist, planner, regulator or data manager. Accuracy, in this context, is considered the closeness of an observation to a "true value".

Considering the first method of co-ordinate determination, viz. marking a position on a map, then the errors listed in Table 2.3 can be generated at the respective map scales when a 0.5 mm pencil point is used to mark a geosite position.

Table 2.3 Scale and uncertainty

Pencil point size (mm)	Map scale	Distance on ground (m)
0.5	1:10 000	5
	1:50 000	25
	1:250 000	50

This is just one source of error associated with the scale of the maps used. There are other sources, such as the uncertainty of the geosite position on the map due to a lack of identifying features, the inaccurate marking of the geosite position with the map edge graticules, the inaccurate scaling-off of the graticules, etc.

When using hand held GPS devices, the uncertainty of the point measurement is usually given by the instrument as a ground measurement. Depending on the satellite configuration, density and atmospheric conditions, it is quite often in the order of 5 to 15 metres for cheaper GPS instruments, with the accompanying elevation reading in error by a factor of 10 (i.e. 50 to 150 metres). It is therefore important to record the reported co-ordinate accuracy (in GPS jargon the Estimated Position Error or EPE), and to check the accuracy of the altitude clearly indicating the method used.

With conventional surveying techniques, inaccuracies in all three dimensions can be as small as a few millimetres.

2.2.4 Reference datum

The co-ordinate reference system previously used in South Africa as the foundation for all surveying, engineering and geo-referenced projects and programmes was the Cape Datum**.** As with other national control survey networks throughout the world, which were established using traditional surveying techniques, flaws and distortions in these networks have become easily detectable using modern positioning techniques such as the GPS. In addition to these flaws and distortions, most national geodetic networks do not have the centre of datum reference ellipsoids coincident with the centre of the earth, thus making them useful only to the datum area of application. The upgrading, recomputation and repositioning of the South African coordinate system has thus been driven by the advancement of modern positioning technologies and the globalisation of these techniques for navigation and surveying purposes.

Since 1 January 1999, the official coordinate system for South Africa is based on the World Geodetic System 1984 ellipsoid, commonly known as WGS84, with the ITRF91 (epoch 1994.0) coordinates of the Hartebeeshoek Radio Astronomy Telescope used as the origin of this system. This new system is known as the **Hartebeeshoek94 (WGS84) Datum** (Chief Directorate: Surveys and Mapping, 1999). Visit http://w3sli.wcape.gov.za/surveys/ for more information. Most GPS instruments offer the user a wide selection of reference datum. Although it is a legal requirement to use the **WGS84** when working in South Africa, a strong caution in this regard is needed. The fact is that a large number of the available printed topocadastral and topographic maps still reflect the Cape datum as reference. The difference between the Cape and WGS84 datums may be substantial (up to 300m), so that applying a WGS84-derived co-ordinate to a map based on the Cape datum will create confusion especially if the user is not aware of this. It is recommended, therefore, that users continue to employ their preferred reference system, but that the datum used be clearly indicated when reporting positional data.

All heights are referenced to mean sea level (msl) as determined in Cape Town and verified at tide gauges in Port Elizabeth, East London and Durban. Elevation values are therefore to be recorded as metres above mean sea level (mamsl).

2.2.5 Date Co-ordinates Determined

The date that the co-ordinates of a geosite was determined must be recorded in the international date format ccyy-mm-dd (e.g. the 24th January 2002 is represented as 2002-01-24).

- **Geosite coordinates (latitude and longitude) must be recorded in degrees, minutes and decimal seconds, with zero as default value in the first decimal of the second.**
- **Ground level at the geosite must be recorded as metres above mean sea level (mamsl).**
- **Measurements must be based on the Hartebeeshoek94 datum (WGS84 spheroid).**

2.3 Geosite Setting

Recording the setting of geosites assists with data accuracy verification and helps to understand the geohydrological parameters measured. Once the geosite has been recorded and captured on a database, it is always good data management practice to check the accuracy of the geosite position. One way of checking the positional accuracy is to plot the position on a topographical map or digital elevation model (DEM) and to check that the geosite position and the topographical setting agree.

Furthermore, cognisance of the topographical setting can promote a better understanding of the geohydrological environment. For example, a geosite located in unvegetated dune sands might be associated with a groundwater system that experiences a high rate of rainfall recharge. This example implies that both the topographic setting and land cover characteristics need to be recorded. A comprehensive list of geomorphological settings is provided in Table 2.5, and land cover types in Table 2.4.

Table 2.4 Land cover classification descriptors

Descriptor
Natural forest and woodland
Natural forest
Thicket and bushland
Shrubland and low fynbos
Herbland
Grassland
Forest plantations (indicate pine, wattle, eucalyptus, etc.)
Barren rock
Dongas and sheet erosion scars
Degraded[1]: forest and woodland
Degraded: thicket & bushland
Degraded: grassland
Degraded: shrubland and low fynbos
Degraded: herbland

[1] Degraded implies over-grazed, burnt, cleared for minor development or trees removed for firewood, etc.

Descriptor
Cultivated: permanent – commercial irrigated
Cultivated: permanent – commercial dryland
Cultivated: permanent – commercial sugarcane
Cultivated: temporary – commercial irrigated
Cultivated: temporary – commercial dryland;
Cultivated: temporary semi-commercial / subsistence dryland
Urban / built-up land: residential
Urban / built up land: residential (small holdings: woodland)
Urban / built-up land: residential small holdings: bushland)
Urban / built up land: residential (small holdings: shrubland)
Urban / built-up land: residential (small holdings: grassland)
Urban / built-up land: commercial
Urban / built-up land: industrial / transport
Mines and quarries

Table 2.5 Geomorphological classification descriptors

Descriptor
Hill / mountain top
Steep mountain slope
Low gradient hill slope
Raised terrace
Valley floor
Riparian zone
Flat / gently undulating surface
Water body (wetland, pan, river, spring)
Alluvial fan
Unvegetated shifting dunes
Vegetated dunes

There is merit in capturing land cover information associated with a geosite. The immediate benefit is that a query of the groundwater archive will immediately provide this information, adding value to the geohydrological data provided. This information can then always be correlated or updated with similar information, e.g. the ARC/CSIR land cover data, using a tool such as GIS.

2.4 Geosite Selector, Method of Selection and Target Feature

This is relevant for all artificial geosites, and excludes natural features such as springs. It is particularly relevant to a borehole, since this information can assist in determining if the geosite has been selected on a scientific or non-scientific basis. This information becomes relevant when groundwater data retrieved from a database is studied and analysed also in terms of the geohydrological setting. A comprehensive list of selector descriptors is provided in Table 2.6. The category “Not applicable” will only apply to natural geosites such as springs.

Table 2.6 Geosite selector

Descriptor
Geohydrologist
Geophysicist
Earth Scientist
Geotechnologist
Civil Engineer
Owner
Client
Driller
Diviner
Not applicable

If the siting of a new geosite such as a borehole has employed a scientific approach, the method(s) employed and the reason for selecting a particular site are relevant and need to be recorded. Methods used to select geosites are presented in Table 2.7. A combination of these methods is also possible.

Table 2.7 Geosite selection methods

Descriptor
Aerial photograph interpretation
Satellite image interpretation
Map interpretation
Resistivity survey: • Soundings • Profiling
Magnetic survey
Electromagnetic survey: • Time domain • Frequency domain
Seismic survey
Gravity survey
Controlled source audio magnetotelluric survey
Geological field observation
Other

If a geosite has been selected taking into account a target geological feature, then this information should also be captured. A list of geological target features is provided in Table 2.8. A combination of these features is also possible.

Table 2.8 Geological target features

Descriptor
Favourable geological formations
Favourable geological structures: • Anticlines • Synclines • Folds • Fault zone • Shear zone
Weathered zones
Fractures
Lineaments (unknown underlying cause of the lineament)
Intrusive igneous features: • Dykes • Sills
Favourable hydraulic conductivities
Favourable saturated thickness

2.5 Purpose of Geosite

The intended purpose of a geosite also needs to be recorded, as this is relevant to other factors relating to the site. For example, if the geosite is a borehole that will be used for production purposes, then the appropriateness of the drilling techniques, casing diameters, casing types, development methods, etc. can be assessed. The categories of geosite purpose are listed in Table 2.9. A combination of these categories is also possible.

Table 2.9 Geosite purpose

Descriptor
Exploration
Dewatering of mines, excavations, etc.
Monitoring
Production (abstraction): • Bulk water supply • Domestic water supply • Commercial irrigation • Domestic irrigation • Stock watering • Nature conservation – game watering • Industrial • Mining • Power generation (cooling)
Recharge – artificial
Waste disposal
Standby – water supply

2.6 Current Status of Geosite

The current status of a geosite is important to record, especially when it is being used for monitoring. Since the status of a geosite can change with time, this aspect must be noted every time the site is visited for a measurement. For example, if a water sample is collected from a production borehole, it should be noted whether the borehole is in fulltime production or not. If the borehole is not in use, and was only switched on for sampling purposes, then the status of the borehole might be indicated as "standby". These observations provide a measure of the representativeness of the water sample collected.

Perhaps the most important aspect of geosite status is information regarding the accessibility of the site for data collection purposes. This is catered for in Table 2.10, which lists various descriptors for describing the current status of a geosite. "Abandoned" typically describes a geosite that fails or is no longer able to meet its purpose. For example, a borehole drilled for water supply purposes fails to intersect water and drilling is discontinued. Similarly, a monitoring borehole loses this status when it experiences collapse, resulting in the data collection process being curtailed. Combinations of the descriptors listed in Table 2.10 are also possible.

Table 2.10 Geosite status

Description	Accessible for water level measurements	Accessible for sampling
In-use (functional)	Y N	Y N
Standby (production)	Y N	Y N
Inaccessible	—	—
Abandoned	—	—
Destroyed	—	—

2.7 Geosite Sketch Map

In cases where appropriate published maps are not available, a sketch map will suffice for showing the position of a geosite. Such a map is often very useful for re-locating a geosite in the future, e.g. for monitoring purposes. It can happen that when visiting a geosite such as a borehole during the dry season it is easily visible but, when returning in the wet season, there is tall grass and the vegetation has changed, making the site difficult to locate. The sketch map can also indicate the geosite number to ensure there is no confusion of numbers when sampling, especially if the geosite itself is unmarked. The nearest town, village or farm name must be indicated on the map. The sketch map should also indicate the position, i.e. start, end and length of traverses associated with any ground-based geophysical survey(s). Additional information regarding the method(s) used, e.g. magnetic, electromagnetic, resistivity, gravity, etc. could additionally be indicated.

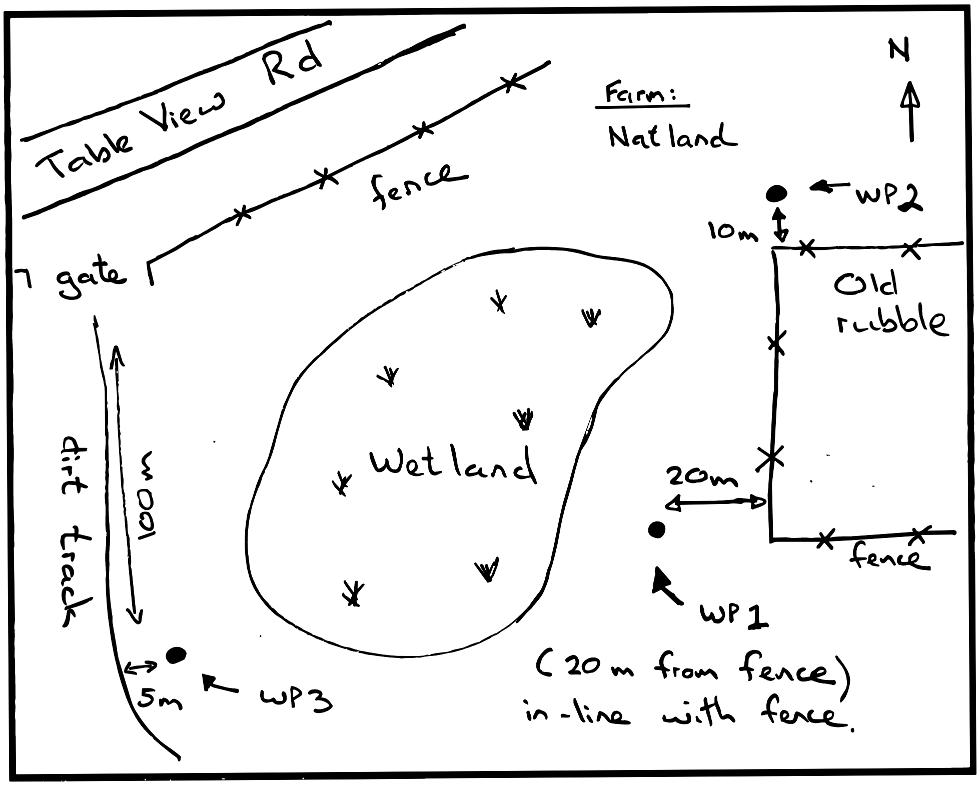


Figure 2.3 A simple useful sketch map for orientation and monitoring purposes

2.8 Confidentiality

It is important to note whether the data associated with a geosite is to be kept confidential or if the data can be made available to the public. It may well be that DWAF, for example, is performing groundwater monitoring and sampling within a sensitive and contentious area. This data must still be recorded, but will be flagged as confidential and not available to the public without the necessary authorisation. Should these circumstances change, then the associated status can be altered to render this data accessible to any DWAF client.

- **Observe and describe the geomorphological setting of the geosite.**
- **Note the profession/affiliation of the person who selected the geosite position.**
- **Determine the method used to select the geosite position.**
- **Describe the geological feature(s) targeted by the geosite.**
- **Determine the purpose and status of the geosite.**
- **Record the date the geosite position was determined.**
- **Assign a confidentiality rating to the geosite data.**

3 GEOSITE CONSTRUCTION DESCRIPTORS

3.1 Boreholes

Borehole construction typically comprises of four distinct operations. These are drilling, installation of casing (which could include the placing of borehole screens and filter pack(s) where and if required), grouting to provide sanitary protection and development of the borehole to ensure sediment-free operation to attain maximum yield. Two or more of these operations may be carried out simultaneously, depending on the drilling method used.

The parameters required to ensure that good quality data are recorded are discussed next in some detail. As it is envisaged that this document might also be used by persons with a poor, if any, understanding of borehole construction (e.g. district municipality staff involved in the allocation of groundwater development contracts), it includes a discussion of drilling techniques that are the most appropriate to water drilling in the relevant geohydrological environment.

3.1.1 Drilling methods

Various drilling methods have been developed because geological conditions range from hard rock such as granite and dolomite to completely unconsolidated sediments such as alluvial sand and gravel. Particular drilling methods have become dominant in certain areas because they are more effective in penetrating the local rock strata and thus offer cost advantages. In many cases, however, the drilling contractor may vary the usual drilling procedure depending on the depth and diameter of the borehole, type of formation to be penetrated, sanitation requirements and principal use of the borehole. It is obvious that no single drilling method is best for all geological conditions and borehole installations. In most cases, the drilling contractor is suitably qualified to select the particular drilling method for a given set of construction parameters. Successful drilling is both an art developed from long experience and the application of good geohydrological practices.

In order to evaluate the appropriateness of the drilling method in relation to the ultimate use of the borehole and to conceptualise some of the other parameters that follow, the drilling method needs to be recorded. Borehole drilling and installation methods are so numerous that only the basic principles and some of their applications are described in the following sections. Extensive reference was made to Driscoll (1989) in compiling this material. Table 3.1 at the end of these sections, provides a complete list of drilling method descriptors.

3.1.1.1 Cable tool

Developed by the Chinese, the cable tool percussion method was the earliest drilling method and has been in continuous use for about 4000 years. Cable tool drilling machines, also called percussion or "jumper" rigs (and in South Africa called a "stamper-boor") operate by repeatedly lifting and dropping a heavy string of drilling tools into the borehole. The drill bit breaks or crushes consolidated rock into small fragments, whereas it primarily loosens the material when drilling in unconsolidated formations. In both instances, the reciprocating action of the tools mixes crushed or loosened particles with water to form a slurry or sludge at the bottom of the borehole. If little or no water is present in the penetrated formation, water is added to form a slurry. Slurry accumulation increases and reduces the impact of the tools as drilling proceeds. When the penetration rate becomes unacceptably slow, slurry is removed from the borehole using a sand pump or bailer.

A full string of cable tool drilling equipment consists of five components, viz. drill bit, drill stem, drilling jars, swivel socket and cable. The cable tool bit is usually massive and heavy so as to crush and mix all types of earth materials. The drill stem gives additional weight to the bit, and its length helps to maintain a straight hole when drilling in hard rock. Drilling jars consist of a pair of linked, heat-treated steel bars. Shouldthe bit get stuck, it is freed most of the time by upward blows of the free-sliding jars. This is the primary function of the drilling jars. The swivel socket connects the string of tools to the cable. In addition, the weight of the socket supplies part of the upward energy to the jars when their use becomes necessary. The socket transmits the rotation of the cable to the tool string and bit so that new rock is cut on each down-stroke, thereby ensuring that a round, straight hole will be cut. The wire cable that carries and rotates the drilling tool is called the drill line.

Bailers, used to remove the mud or rock slurry, consist of a pipe with a check valve at the bottom. Another type of bailer is called the sand pump or suction bailer.

The characteristic up and down drilling action of a cable tool machine is imparted to the drill line and drilling tools by the walking beam. The walking beam pivots at one end while its outer end, which carries a sheave for the drill line, is moved up and down by a single or double pitman connected to a crankshaft.

Each cable tool machine has certain interdependent limits on borehole depth and diameter. For example, if a hole is relatively small in diameter, it may be drilled to comparatively great depth. In large diameter holes, the weight of the drill string and cable may become so excessive that the machine cannot function, thereby limiting borehole depth at the initial diameter.

Most boreholes completed in consolidated formations by the cable tool method are drilled "open hole," i.e. no casing is used during part or all of the drilling operation. When drilling in consolidated rock, the cable tool bit is essentially a crusher. Drilling in unconsolidated formations differs from hard rock drilling in two ways. Firstly, pipe or casing must follow the drill bit closely as the borehole is deepened, to prevent caving and to keep the borehole open. Usually the casing has to be driven by an operation similar to pile driving. Secondly, the drilling action of the bit is largely a loosening and mixing process. Actual crushing is of little importance except when a large stone or boulder is encountered.

The cable tool method has survived for thousands of years because it is reliable for a wide range of geological conditions. It may be the best, and in some cases the only, method to use in boulder deposits, all rock strata that are highly disturbed, broken, fissured or cavernous. It is also often the machine of choice when it comes to rehabilitating or refurbishing an old borehole.

3.1.1.2 Direct circulation (mud rotary)

The direct rotary drilling method was developed to increase drilling speeds and to reach greater depths in softer formations. This method is commonly used in South Africa in unconsolidated sands such as the Quaternary formation along the coast. The borehole is drilled by rotating a bit, and cuttings are removed by continuous circulation of a drilling fluid as the bit penetrates the formation. The bit is attached to the lower end of a string of drill pipe, which transmits the rotating action from the rig to the bit. In the direct rotary system, drilling fluid is pumped down through the hollow drill stem and out through the ports or jets in the bit. The fluid then flows upward in the annulus (the space between the hole and drill pipe) and carries the cuttings in suspension to the surface. At the surface, the fluid is channelled into a settling pit(s) where most of the cuttings drop out. Clean fluid is pumped from the far end of the pit or from a second pit, and re-circulated down the hole. The choice of drilling fluid is important to ensure that the borehole remains open during construction and does not collapse (see section 3.5 for more information).

The components of the rotary drilling machine are designed to serve two functions simultaneously, viz. operation of the bit and continuous circulation of the drilling fluid.

In direct circulation rotary drilling for water boreholes, the two most common types of bits used are the drag bit and the roller cone bit. Drag bits have short blades each forged to a cutting edge and faced with durable metal. Short nozzles direct jets of drilling fluid down the faces of the blades to clean and cool them. Drag bits have a shearing action and cut rapidly in sands, clays and some soft rock formations, but do not work well in coarse gravel or hard rock formations. Roller cone bits exert a crushing and chipping action, making it possible to cut harder formations. The rollers, or cutters, are manufactured with either hardened steel teeth or tungsten carbide inserts of varied shape, length and spacing, designed so that each tooth applies pressure at a different point on the bottom of the hole as the cones rotate. The tricone bit, used as an all-purpose bit in every type of formation, has three conical shaped rollers on spindles and bearings set at an angle to the axis of the bit.

3.1.1.3 Reverse circulation (mud rotary)

This method is less common in South Africa, and is more likely to be used where unconsolidated formations occur in greater abundance such as Mozambique. In direct rotary drilling, the viscosity and uphole velocity of the drilling fluid are the controlling factors in removing cuttings effectively. Unless cuttings are removed, drilling cannot continue. In reverse circulation rotary drilling, flow of the drilling fluid is reversed compared with the direct rotary method. The suction end of the centrifugal pump, rather than discharge end, is connected to the swivel, kelly and drill pipe. The drilling fluid and its load of cuttings move up inside the drill pipe and are discharged by the pump into the settling pit. Centrifugal pumps with large passageways are often used to pump the drilling fluid because they can handle sand-laden fluids without excessive wear on the pump. The fluid returns to the borehole by gravity flow, continually moving down the annular space between the drill pipe and borehole wall to the bottom of the hole, picking up newly-cut material and re-enterering the drill pipe through ports in the drill bit. To prevent caving of the hole, the fluid level must be kept at ground level at all times. Many reverse rotary drilling rigs are equipped with air compressors to aid in circulating the drilling fluid. Reverse circulation drilling is the least expensive method for drilling large diameter boreholes in unconsolidated formations. It is most successful in soft sedimentary rocks and unconsolidated sand and gravel where the static water level is 5 m or less below ground level.

3.1.1.4 Rotary air percussion

Two different drilling methods use air as the primary drilling fluid. These are direct rotary air and down-the-hole air hammer.

Air drilling can be done effectively only in semi-consolidated or consolidated materials (hard rock or bedrock) and is used for 90 % of South African drilling. To achieve the capability to operate in completely unconsolidated as well as consolidated formations, air rotary drilling machines can be equipped with a mud pump in addition to a high capacity air compressor. Conventional water-based drilling fluids are then used when drilling through the overlying less stable formations above the bedrock, whereas air is used once bedrock has been reached. Drillers therefore utilise various options of the drilling technology to adjust to the different physical characteristics of the geological strata. In most instances, casing may have to be installed through the overburden to avoid caving or excessive erosion of the borehole wall after changing to air circulation.

In the rotary air method, air alone lifts the cuttings from the borehole. A large compressor provides air that is piped to the swivel hose connected to the top of the drill pipe. The air, which is forced down the drill pipe, escapes through small ports at the bottom of the drill bit, thereby lifting the cuttings and cooling the bit. The cuttings are blown out the top of the hole and collect at the surface around the borehole. Injecting a small volume of water or surfactant and water into the air system controls dust and lowers the temperature of the air so that the swivel is cooled.

The capacity of the compressor dictates the drilling depth and diameter. Removal of the cuttings is dictated by the uphole velocity of the air, which should be sufficient to lift them to the surface provided the material is ground finely enough. Roller-type and tricone rock bits can be used when drilling with air in softer rock. Button bits are used successfully in many areas with hard geological strata.

A second direct rotary method using air is called the "down-the-hole" drilling system. A bit attached to a pneumatic hammer operated at the end of the drill stem rapidly strikes the rock while the drill stem is slowly rotated. The bit is manufactured from alloy steel with heavy tungsten carbide inserts that provide the cutting or chipping surfaces. Rotation of the bit helps to ensure even penetration and, therefore, straighter holes even in extremely abrasive or resistant rock types. The air used to drive the hammer removes cuttings continuously. The air hammer is particularly efficient in hard geological strata.

3.1.1.5 Jet percussion drilling

There are two methods for installing boreholes in which a high velocity stream of water is used in the drilling procedure. One of these, the jet percussion system, is generally limited to drilling 76 to 102 mm diameter bores to depths of around 60 m. Drilling tools for the jet percussion method consist of a chisel-shaped bit attached to the end of a pipe string. Holes on each side of the bit serve as nozzles for water jets that keep the bit clean and help loosen the material being drilled. Water is pumped under moderate pressure through the drill pipe and out the nozzle. The water then flows upward in the annulus, carrying the cuttings in suspension. It overflows at the ground surface and is led into one or more pits where the cuttings settle to the bottom. The water is then picked up by the suction of the pump and recirculated through the drill pipe. The discharge from the pump is delivered through a pressure hose and water swivel attached to the top of the drill pipe. The fluid circulation system is similar to that of direct rotary drilling. With water circulation maintained, the drill rods and bit are lifted and dropped in a manner similar to cable tool drilling but with shorter strokes. The chopping action of the bit in combination with the washing action of the water jet opens the hole. The drill rods are rotated by hand so that the bit cuts a round hole. Open holes can be drilled to limited depths in unconsolidated materials by the jet method if drilling fluid additives are mixed with the water to form a high viscosity drilling fluid. The viscosity is useful for lifting cuttings, but cannot be so great that it impedes the force of the jetting action at the bit.

Casing must be installed, however, and must follow the bit rather closely whenever the uncased hole tends to cave or passes through zones of high fluid loss. Jet percussion drilling is commonly used for drilling small-diameter boreholes in water-bearing sand, but can also be used to penetrate some semi-consolidated geological strata that are not too hard.

A second drilling procedure uses small diameter pipe and well points with open bottoms that can be sunk in sandy formations by the washing action of a water jet without any type of drilling tools. An improvement is to fit a non-return valve to the bottom end of the well point. This circumvents the problems of an open-ended pipe. Well points can be installed only in unconsolidated formations that are relatively free of cobbles or boulders. They can be driven by manual methods to depths of about 10 m, depending on the soil conditions. Well points driven by hammers reach depths of 15 m and more in favourable conditions. In some cases, well points are driven out the bottom of larger diameter casing when the aquifer has been reached. Well points may be set to greater depths if casing protects the screen during installation. At a predetermined depth, the casing is pulled back to expose the screen. Well point systems are widely used for exploiting sandy riverbeds and the unconsolidated dune-sands along the South African coast. Many thousands have been installed in the sands of the Cape Flats for domestic irrigation (garden watering) purposes.

3.1.1.6 Boring with earth augers (manual drilling)

Earth augers of various sizes and designs are used in certain areas for drilling water bores. Three principal types are commonly used.

Large diameter bucket auger
Solid stem auger
Hollow stem auger.

Bucket auger

This method utilises a large diameter bucket auger to excavate earth materials. This method is referred to as rotary bucket drilling. The excavated material is collected in a cylindrical bucket that has auger-type cutting blades on the bottom. Rotary bucket drilling of water bores has found primary application in areas of clay formations that stand without caving while the hole is drilled and pipe installed to serve as casing. Drilling in sand below the water table is difficult but not impossible if the hole is kept full of water or drilling fluid. A considerable supply of water may be needed if the sand formation is quite permeable. Cobbles and boulders can cause much difficulty in the bucket augering procedure.

Solid stem auger

A second boring method uses a solid-stem auger with either a single flight (one section) or continuous flight (multiple sections). Augers having a single section of flight are commonly called earth augers, construction augers, or large diameter augers. Earth augers with diameters as large as 1.4 m have been used in shallow holes, but 356 to 610 mm single flight augers are more common. Hole depths up to 18 m have been reached in stable soil using the smaller diameter augers. This method is ineffective in loose soil or when augering below the water table.

Hollow-stem auger

The third method is the hollow-stem continuous-flight auger method. Although geotechnical and exploration drillers have been using the hollow-stem auger since the early 1950s, its use by the water borehole drilling industry has been quite limited until recently. The flights for the hollow-stem auger are welded onto larger diameter pipe with a cutter head mounted at the bottom. Unlike the solid stem method, drill rods can pass through the centre of the auger sections. A plug is inserted into the hollow centre of the cutter head to prevent soil from coming up inside the auger. This centre plug has an attached bit that helps advance the auger. The drill rod and plug connect through the auger flights to the top-head drive unit by small-diameter drill rods to insure that the drill rods and plug rotate with the flights. The centre plug is omitted in stiff or dense formations. Hollow-stem augers with outside diameters ranging from 160 to 560 mm have been used to drill water bores, although more common outside diameters are 160 to 330 mm. Auger lengths are usually 1.5 m, but on larger hollow-stem auger rigs, especially those equipped with carousel racks, the auger flights are 3 m long and stored in 6 m sections. Holes as deep as 90 m have been drilled with 165 mm diameter hollow-stem augers. More common maximum depths in stable formations are 37 m with 165 mm diameter hollow-stem augers, and 12 m with 305 mm diameter hollow-stem augers.

Hollow-stem augers are more effective than solid-stem augers because they can be used as temporary casing to prevent caving and collapse of the borehole sides. The hollow-stem method is a fast and efficient means of drilling and completing small diameter boreholes to moderate depths. Screen and filter packs can be installed without using casing or drilling fluids. Use of the hollow-stem auger method is also particularly advantageous in obtaining accurate samples. A major disadvantage of this method is the relatively high cost of hollow-stem flight augers. This method is commonly used to install monitoring boreholes in unconsolidated sands, and is especially useful when it is important not to contaminate the sub-surface with introduced drilling fluids.

3.1.1.7 Hand augured tube wells

The term is not in common use in South Africa (Deverill *et al.*, 1999). A tube well is a small diameter borehole typically 60 – 170 mm diameter, sunk often by hand into a shallow aquifer. The tube wells developed as part of the Ubombo Family Wells Programme (UFWP) are hand augured to the water table using the simple but effective *Vonder Rig* produced in Harare, Zimbabwe by V&W Engineering. The equipment consists of a tripod and winch, a worktable that keeps the hole straight, drill rods and a number of auger bits and slotted PVC casing.

Table 3.1 provides a summary of the methods discussed.

Table 3.1 Drilling method

Descriptor
Cable tool
Direct circulation (mud rotary)
Reverse circulation (mud rotary)
Rotary air percussion
Jetting: Percussion drilling Well pointing
Boring with earth augers: Bucket Solid-stem Hollow-stem
Driven wells (well points), i.e. the jetting method
Tube wells

- **Indicate the method used to drill the hole.**

3.1.2 Drilling fluids

3.1.2.1 Introduction

The term "drilling fluid" in the groundwater industry refers variously to clean water, dry air, a suspension of solids or a mixture of liquid additives in water, and droplets of water dispersed in air, or a mixture of water, surfactant and colloids dispersed in air.

The technology of drilling fluids has advanced as rapidly and extensively as rotary drilling machine development. In the late 19th century water was the principal fluid used in rotary drilling. The general term "mud" originated when certain types of clays were added to form drilling fluid. Recent advances, however, have made the term "mud" somewhat obsolete. Modern mud systems are now referred to as drilling fluids because of the large number of additives that can be used to impart special properties to drilling fluids.

3.1.2.2 Function of drilling fluids

Drilling fluids can perform many functions, depending on the physical and chemical conditions encountered in the borehole. The most important are the first three in the following list:

Remove cuttings. The rate at which cuttings can be removed depends on the viscosity, density and uphole velocity of the drilling fluid, and the size, shape and density of the cuttings. Ideally, the fluid should entrain the cuttings at the bit, carry them to the surface and allow them to drop into a settling pit or tank before the fluid is recirculated. Inefficient removal of cuttings can reduce the penetration rate of the drill bit, adversely affect the physical properties of the drilling fluid and increase the energy required to recirculate the drilling fluid.
Stabilise the borehole. To maintain an open borehole, the drilling fluid stabilises the borehole walls. Drilling fluid can also prevent expansion of swelling clays. To ensure that the side-wall does not collapse, the fluid level is kept at ground level, i.e. the pressure of the fluid from the borehole outwards is greater than the inward-directed pressure of groundwater.
Cool and lubricate the drill bit. Fluids circulating through the drill string cool and lubricate the bit, thereby avoiding unnecessary bit wear and reducing maintenance.
Control water losses. All water-based drilling fluid systems must control drilling fluid loss in highly permeable formations by creating a nearly impermeable clay filter cake on the borehole side-wall.
Drop cuttings into a settling pit. As the drilling fluid is circulated through the settling pit, cuttings should drop out so that they are not recirculated. The gel strength of the drilling fluid is the primary factor controlling the rate of settlement.
Facilitate acquisition of information about the borehole. Drilling fluid systems should facilitate the recovery of representative cuttings, although mixing of cuttings may still occur.
Suspend cuttings in the borehole when the drilling fluid is not being circulated. During the time that the drilling fluid is not in motion, cuttings tend to settle in the borehole. If the rate of settlement is excessive, cuttings may settle around the drill bit or stabiliser and jam the rotation of the drill string when drilling is resumed. The rate of particle settlement is controlled by the gel strength of the drilling fluid.

No single drilling fluid can fulfil all of these functions perfectly. In most cases, continuous monitoring of the drilling fluid is necessary to achieve the best results.

3.1.2.3 Type of drilling fluids

Drilling fluids used in the groundwater industry include water-based and air-based systems. Water-based drilling fluids consist of the following:

A liquid phase.
A suspended particle phase (the colloidal phase may range from < 1 % to 50 % by volume).
Cuttings entrained during drilling.
Air-based drilling fluids may consist of only a dry air phase, but often they contain some water to which a surfactant (soap) is added to produce foam. Occasionally a small amount of clay or polymer may be added to stiffen the foam. Thus, the primary drilling fluids, water and dry air, may be used alone, but a great variety of additives are available to modify their physical and chemical properties so they will perform more satisfactorily.

3.1.2.4 Additives

The 3 major types of drilling fluid additives are:

Clays (commonly added to water-based systems) (rare in South Africa).
Polymers (commonly added to water-based systems).
Surfactants (commonly added to dry air systems).

Water with clay additives produces a high-solids drilling fluid, whereas a combination of polymeric additives and water produces a low-solids drilling fluid. Many other special additives, such as flocculants, thinning agents (dispersants), weighting materials, corrosion inhibitors, filtrate reducers, lubricants, preservatives, bactericides and lost-circulation materials, are used to further adjust the properties of drilling fluids. The exact drilling fluid system selected will depend principally on the rock formation expected and the equipment available. Remoteness of the drilling site, availability of drilling equipment and water supplies, environmental regulations and the experience of the drilling crew also play an important part in selecting the fluid system.

3.1.2.5 General use of drilling fluids and additives

In general, the following combinations apply:

- Unconsolidated formations: water-based drilling fluids mainly with polymeric additives (could include clay, but this is rare in South Africa).
- Semi-consolidated: air
- Consolidated: air.

The success of any drilling fluid system depends mainly on the chemistry of the mix water, the particular additives selected and the physical and chemical characteristics of both the cuttings and the water in the formation being drilled. The acceptable types of additives for drilling of water boreholes are as follows:

- Dissolved additives.
- Surfactants, drilling detergents and foaming agents.
- Mud thinning agents and inorganic phosphates.
- Non-dissolved additives.
- Bio-degradable polymers.

- Native solids (clay).
- Bentonite.

It is important to note that these fluid additives (such as bentonite and native clays) must be used with care and ideally only under supervision of a properly trained person, due to their ability to permanently damage productive aquifer horizons.

Table 3.2 Drilling fluid types

Descriptor
Water-based: • Clean, fresh water • Water with clay additives • Water with polymeric additives • Water with clay and polymeric additives
Air-based: • Dry air • Mist; droplets of water entrained in the air stream • Foam; air bubbles surrounded by a film of water containing a foam-stabilising surfactant • Stiff foam; foam containing film-strengthening materials such as polymers and bentonite

- **Record the drilling fluid used.**

3.1.3 Formation sampling

The rock samples and/or core gathered during the drilling operation are the geohydrologist's only means of direct access to the different geological strata intersected by the borehole. It offers the only opportunity to observe, measure and describe aspects such as degree of weathering and/or fracture spacing, fracture geometry and the other geological aspects described in chapter 4. It is thus of great importance that diligence and care be taken to execute the tasks described in this chapter rigorously.

The drilling contractor must collect samples at one (1) metre intervals and at any visible change, i.e. colour, lithology, etc. These samples necessarily represent an aggregate of the strata associated with the metre drilled, and must be laid out in a neat and orderly fashion at the drilling site for inspection by the technical supervisor. Prior to drilling, the contractor should be sure (and demonstrate this to the supervisor) of the length of the various components of the drill string to ensure that the sample depths will be recorded correct. Any change of drilling equipment after drilling has commenced should similarly be accurately measured.

To avoid inadvertent mixing of samples or disturbance by natural factors (rain, wind, animals, etc.), the drilling samples should be laid out in a sample box with separate compartments for each sample. If sample boxes are not available, the samples should be set out in a clearly demarcated area, away from site traffic of any kind. The specific interval represented by the sample (i.e. 30 – 31 m) must be indicated clearly, particularly if samples are collected for a specific feature. The drilling contractor should take every possible precaution against sample contamination due to poor circulation, caving or hole erosion.

Each water strike should be marked clearly in the sample sequence, and a water sample taken if the temperature, pH and electrical conductivity cannot be measured at the site. These water samples should be kept cool and stored in a safe place.

3.1.4 Drilling diameter and depth

Borehole diameters may vary with depth for a number of reasons. To record borehole diameters it is necessary to measure the drill bit diameter between gauge buttons if air percussion or rotary drilling is being used. If augering or jetting techniques are used, the diameter of the penetrating device must be recorded. Augering tends to produce a relatively neat hole, whilst jetting produces a very variable diameter hole. Nonetheless for jetting, the inner diameter of the installed well point should be recorded rather than the indeterminate diameter of the jetted hole.

The borehole depth and associated borehole diameter are to be recorded in metres and millimetres respectively. An example is given in Table 3.3.

Table 3.3 Example of borehole diameter and depth recording

Start depth (m)	End depth (m)	Diameter (mm)
0	55	205
55	90	165
90	120	150

3.1.5 Final/total depth

The depth of a borehole is usually determined by one of the following methods:

Data recorded during drilling.
Measuring the borehole depth with a plumb-line and tape measure.
Information from the driller's log.
Down-hole geophysical logging measurements of the borehole

Since the payment of the contractor is based, amongst other factors, on drilling depth, this parameter must be recorded at all times as metres below surface/ground level. When drilling with drill rods, ensure the length of the drill bit, collars, etc. is included and that the measurement is not just the summation of the drill rod lengths.

3.1.6 Drilling data quality

To assist in the assessment of borehole drilling records for analysis purposes, an indication of borehole drilling data quality should be included. This indicator essentially relates to the competence and care the drilling contractor exercises whilst drilling a borehole. It provides an assessment of the following factors:

- How careful depth measurements were noted.
- How meticulous geological samples were collected and laid out and marked.
- How accurate penetration rates and blow yields were measured and recorded.
- How accurate water strikes were noted and recorded.
- How careful drilling fluid characteristics were measured and recorded.
- How careful changes in borehole diameters were noted and recorded.

This indicator is to be completed only by the technical supervisor. It is assumed that the geohydrologist has sufficient experience to make the evaluation. The available categories are given in Table 3.4.

Table 3.4 Drilling contractors adherence to standards and quality control levels

Descriptor
Good adherence to standards and good quality control
Moderate adherence to standards and moderate quality control
Poor adherence to standards and poor quality control

3.1.7 Drilling penetration rate

In conjunction with descriptions of the geological formations, drilling penetration rates provide not only valuable data about the nature of the geological strata penetrated, but also about the drill bit and drilling fluid performance. Drilling penetration rates can indicate relative hardness of geological strata and provide insight into the geohydrological characteristics of the aquifer. For example, a sudden increase in penetration rate may indicate the presence of a fracture zone that may be associated with a high hydraulic conductivity. It is important that penetration rates must always be used in conjunction with geological logging and where and when available geophysical data, to be of value in understanding the geohydrological characteristics of the aquiferat the position of the borehole. A higher penetration rate may not in all cases indicate a more fractured zone; it may just be a softer zone such as a shale layer within a sandstone sequence.

The penetration rate is the time taken per metre drilled, and must be recorded in minutes and seconds. If sudden and obvious changes in penetration rates occur, the depth at which these changes occur should also be recorded.

The following must be noted:

- **Drill bit diameter (mm) and drilled depth (m). These recordings must be repeated if drill bit diameters change.**
- **Final total depth of the borehole (m).**
- **Indicate the level of adherence to good drilling practices.**
- **Record the drilling penetration rate in minutes and seconds per metre.**

3.1.8 Drilling contractor

The information listed in Table 3.5 regarding the drilling contractor must be captured.

Table 3.5 Drilling contractor information

Descriptor
Name of company
Postal and physical address of company
Telephone and fax number of company
Name of driller and professional affiliation
Contact telephone number (cell and/or land line) of driller

3.1.9 Drilling date

The date that drilling of a borehole started must be recorded in the international date format ccyy-mm-dd (e.g. the 24th January 2002 is represented as 2002-01-24). The date that drilling is completed must be recorded in the same format. The start date is the day the drill bit enters the ground, and the completion date the day when the borehole reaches its final (completion) depth. This date therefore does not include subsequent borehole development time, even if the drilling equipment is used for airlifting/flushing the borehole or for borehole treatment applied immediately after drilling is completed.

All dates must be recorded in the international date format:
ccyy-mm-dd

3.2 Dug Wells

3.2.1 Purpose and construction methods

A dug well is a man-made pit/hole of varying sizes, through which groundwater may flow or be pumped to the surface. The pit is normally dug by hand or using an excavator or auger, lined with concrete rings, stones, brick, tile or other material to prevent collapse, and covered with a cap of wood, stone or concrete. A dug well can therefore be defined as a shallow excavation or artificially constructed cavity with a diameter of 0.5 m or larger

Some disadvantages of this type of facility are their typically shallow depth which, when combined with a lack of a continuous lining, makes them susceptible to contamination from nearby surface sources of pollution. They are also prone to drying up during periods of drought when the water table drops below the pit bottom. Table 3.6 lists the various construction method descriptors.

Table 3.6 Dug well construction method

Descriptor
Dug by hand
Excavated by machine
Augered

- **Indicate the method used to construct the well.**

3.2.2 Formation sampling

The large diameter of dug wells, when compared to that of typical water supply boreholes, can facilitate the more discrete and selective collection and description of formation samples by means of the soil profiling methods commonly employed by engineering geologists. The guide to soil profiling developed by Jennings *et. al.* (1973) is promoted by the Council for Geoscience as the standard in this regard. This activity, however, necessarily requires physical access to the well by the soil profiler, and offers the opportunity to obtain representative formation samples in situ. These samples must be stored in a sample box or plastic bag labeled with the name of the soil profiler, well identifying information, sample depth and date of collection.

Table 3.7 Formation sampling

Descriptor
Name of sampler/profiler
Well identifying information, e.g. name/number and co-ordinates
Date sampled/profiled
Type of sample: Aggregate Profile Discrete Combination of the above (define)
Aggregate sample: Sample interval depth (from _ to _ metres below surface) Sample description
Profiled sample: • Horizon sampled (from _ to _ metres below surface) Horizon description
Discrete sample: Sample depth (metres below surface) Sample description

3.2.3 Geometry of well

A dug well does not conform to standard water borehole dimensions. It can assume any diameter, although the tendency to maintain a cylindrical shape is generally followed. The geometry (diameter and depth) of the well must be recorded together with the information listed in Table 3.8.

Table 3.8 Geometry and general construction information

Descriptor
Well Constructor: • Name of company • Postal and physical address • Telephone and fax number • Name of well digger/excavator • Contact telephone number (cell and/or land line) of well digger/excavator
Start and end date of construction
Geometry: • Diameter (minimum and maximum) • Depth
Covering: • Wooden lid • Concrete lid • Other

3.3 Springs

3.3.1 Use

Pearson *et. al.* (2003) identify springs as potential sources of potable water for the following reasons:-

They generally provide good quality water.
When situated above a settlement, they can be utilised with gravity flow and without incurring energy costs.
Protected springs have low maintenance costs relative to other technologies.
Historically, almost all rural settlements in South Africa were established near springs. As a result, there are often springs located close to existing settlements.

3.3.2 Origin and classification

A spring marks the position where groundwater emerges on surface. It represents the natural leakage or overflow from an aquifer through some form of opening in the ground. The yield of a spring is not so much a function of the size of the opening, as it is a measure of the transmissivity and hydrostatic head of/within the source aquifer. The position of a spring is generally associated with one or a combination of topographical, lithological and structural controls.

Rain water that infiltrates permeable sediments such as sand, may ultimately reach a relatively impermeable horizon, such as clay. The water then migrates down the slope formed by the upper surface of the impermeable horizon to where this outcrops on surface, and issues as a spring or seep of gravitational origin. Groundwater confined in permeable sediments beneath impervious confining horizons, that is under sufficient hydraulic pressure to rise to the surface through a natural breach in the confining horizon, forms a spring of non-gravitational origin.

The second tier of spring classification recognises the seasonality of the flow regime. Pearson *et. al.* (2003) defines this as either seasonal or non-seasonal, with the additional criteria of either phreatic or bounded (i.e. with boundaries) as a further classifier. This classification is set out in Table 3.9.

Finally, springs are classified according to their geomorphological and geological controls as illustrated in Figure 3.1. Depression springs are formed due to the land surface cutting the water table in permeable formations. Contact springs are due to permeable water-bearing formations overlying relatively impermeable formations. Perched water table springs occur when a water-bearing formation overlies a low permeability formation, which in turn overlies an unsaturated zone. Hard, compact formations generally give rise to springs that are more defined and localised. These springs generally issue from joints/fissures and are called fractured/fissured springs. Artesian springs result when a water-bearing formation is sandwiched between two relatively impermeable confining layers.

Table 3.9 Seasonal spring classification (after Pearson *et al.*, 2003)

Classification	Description	Discharge regime
Seasonal phreatic	A shallow aquifer system with spring outlets solely related to the interception of the phreatic surface with the ground topography. These springs usually dry up during low rainfall seasons.	Discharges in the wet season may be quite high (> 0.1 L/s), but highly variable and strongly correlated with rainfall events. The discharge in the dry season will usually dwindle to zero.
Seasonal with boundaries	As for seasonal phreatic, but there exist impervious boundaries that affect the outflow of the system. These boundaries could reduce the wet season outflows by reducing the catchment size, but will also usually extend the dry season outflows by channelling deeper groundwater out at the level of an impervious layer.	Same as seasonal phreatic, but with greatly extended dry period discharges. Variability of discharges is still high and correlated with rainfall events. In many cases these springs will continue to provide water throughout the dry period, even though the discharge rate decreases substantially.
Non-seasonal phreatic	These springs obtain their water from deep aquifers or from very extensive shallow aquifers. As with the seasonal phreatic springs the outflow is derived from the point of interception of the phreatic surface with the topography. However the water stored in the aquifer is large enough so that the phreatic surface does not fluctuate significantly between seasons or with rainfall events.	The outflow from these springs fluctuates to a small extent between seasons, but not more that 20%. Rainfall event peaks may occur, but the baseflow makes up at least 80% of the flow. The springs provide a reliable supply of water throughout the year.
Non-seasonal with boundaries	Same as non-seasonal phreatic, with the addition that the aquifer is bounded by impervious layers, either horizontally or vertically. These boundaries will usually mean that the variability of flow is reduced further, with almost no difference in flow between summer and winter periods.	Same as non-seasonal phreatic, but with even smaller variations in discharge.

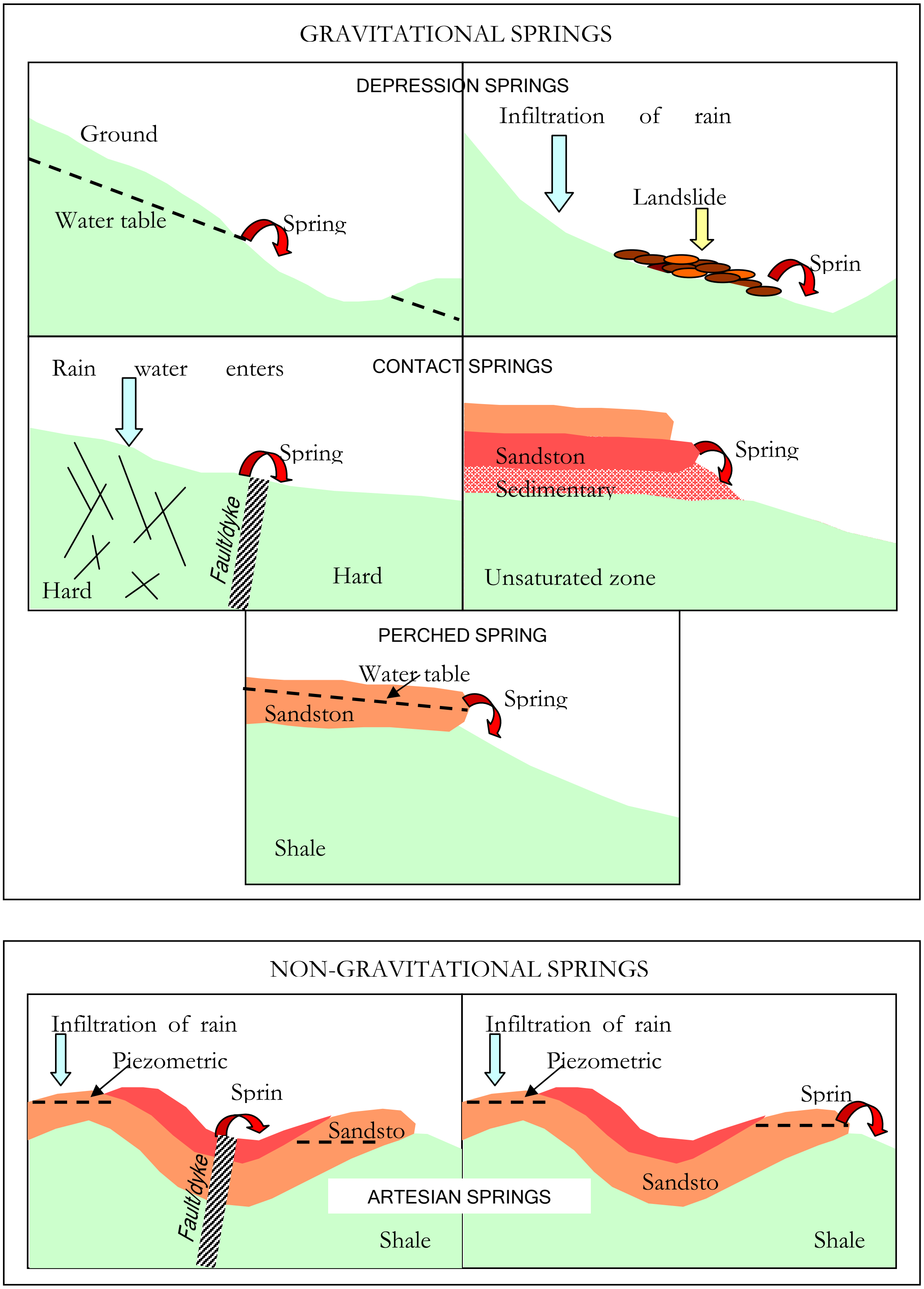


Figure 3.1 Spring classification based on geomorphological/geological controls

The three-tier spring classification system is summarised in Figure 3.2.

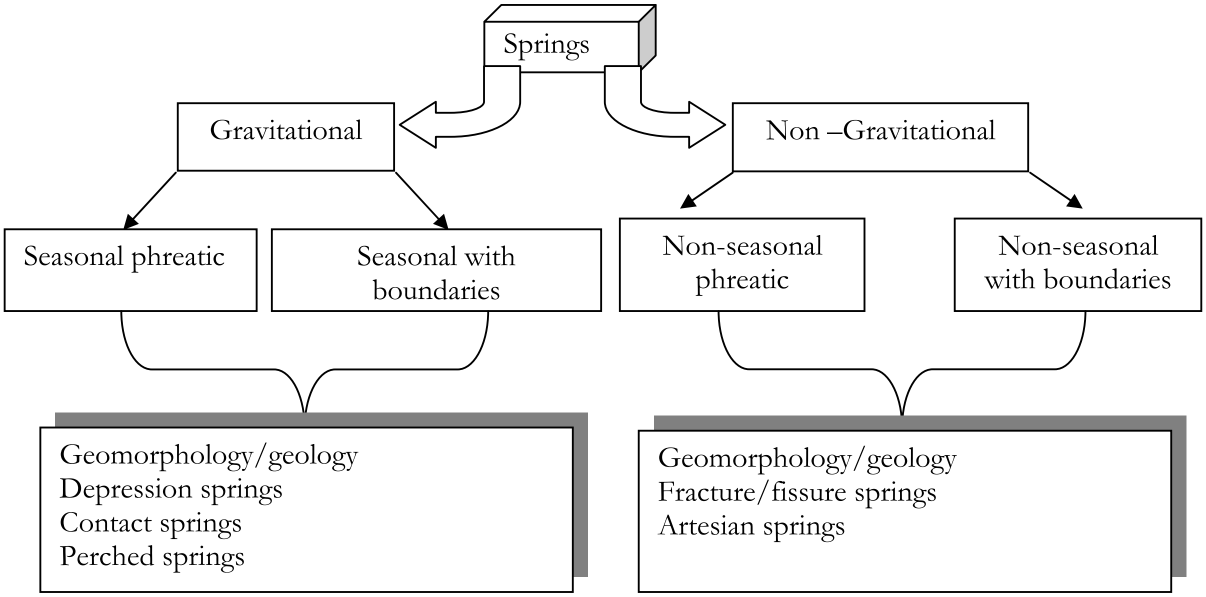


Figure 3.2 Three-tier classification of springs

Table 3.10 presents a summary of the descriptors used to classify springs.

Table 3.10 Descriptors for the classification of springs

Descriptor
Tier 1 (Hydrodynamic controls): • Gravitational • Non-gravitational
Tier 2 (Seasonality): • Seasonal phreatic • Seasonal with boundaries • Non-seasonal phreatic • Non-seasonal with boundaries
Tier 3 (Geomorphological/geological controls): • Depression spring • Contact spring • Perched spring • Artesian spring
Other (e.g. seeps*)

* Seeps fall under the category of wetlands (see Section 2)

3.4 Lateral Collectors/Drains

3.4.1 Purpose and types

A lateral collector or groundwater drain is a subsurface channel or piping system used primarily for intercepting, collecting and removing water from a shallow sol horizon or aquifer. The internet site www.ecy.wa.gov recognises the following types of lateral collector and drain.

3.4.1.1 Interceptor drain

An interceptor drain is a gravel trench that is excavated into a relatively impermeable soil layer, and installed to intercept groundwater as it flows across the impermeable layer (see Figure 3.3). The trench is typically placed across a contour of a slight to moderate sloping area to intercept groundwater prior to influencing slope stability. Water carried by the trench pipe should be conveyed to a solid pipe that transfers water down the slope to an appropriate discharge point.

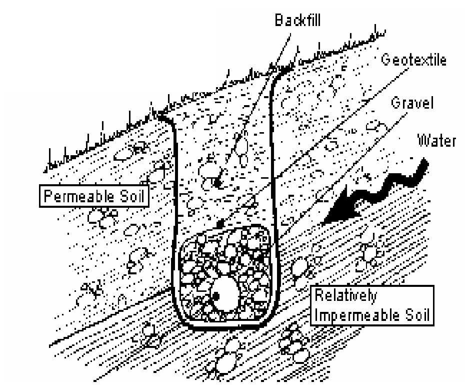


Figure 3.3 Schematic diagram of an interceptor drain

3.4.1.2 Relief drain

Relief drains (Figure 3.4) are installed similarly to interceptor drains, except that the design pattern is arranged to artificially lower the groundwater elevation in the slope soils to a specific elevation. They can also be constructed to intercept surface water drainage if placed at the surface. Typically, these drains are shallower sloped trenches draining to a collection pipe. Groundwater continues to flow below the drains, which are not typically excavated into the impermeable soil. Relief drains are usually used to prevent groundwater from daylighting on a slope face.

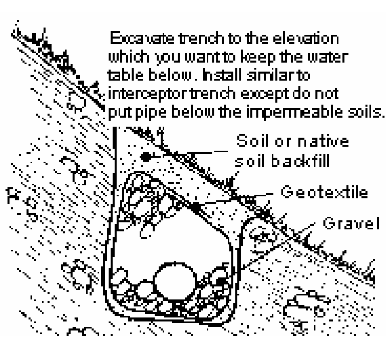


Figure 3.4 Schematic diagram of a relief drain

3.4.1.3 Strip drain

Strip drains (Figure 3.5) are thin rectangular conduits that can be placed into narrow trenches in order to minimise the degree of disturbance to the slope soils and vegetation. These drains, which serve a similar purpose as relief drains, are better suited for low-volume flows like groundwater seepage.

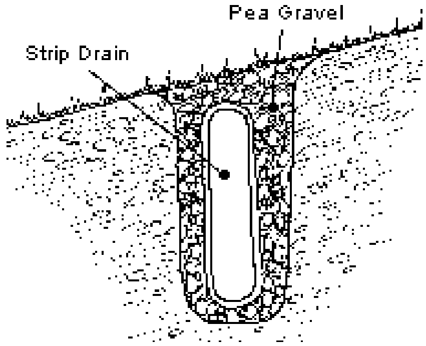


Figure 3.5 Schematic diagram of a strip drain

3.4.1.4 Agricultural drain

A subsurface agricultural drainage system removes excess soil water by lowering the groundwater level sufficiently to allow agricultural activities, such as the planting of crops to take place (see Figure 3.6). This drainage system comprises different components such as i) a drainage outlet, ii) a main drainage channel, iii) some collector drains, and iv) field or lateral drains. The main drainage channel collects run-off from one or more collector drains (typically perforated plastic pipes wrapped in some form of lining or geotextile), and discharges it via a pumping station or by gravity drainage into a river, lake or the sea. Both collectors and lateral drains can be open ditches or pipe drains. The agricultural drainage system design criteria are based on the requirements for drier soils with better accessibility and greater bearing capacity, an extension of the period in which tillage operations can take place and protection of crops from excessive soil water conditions.

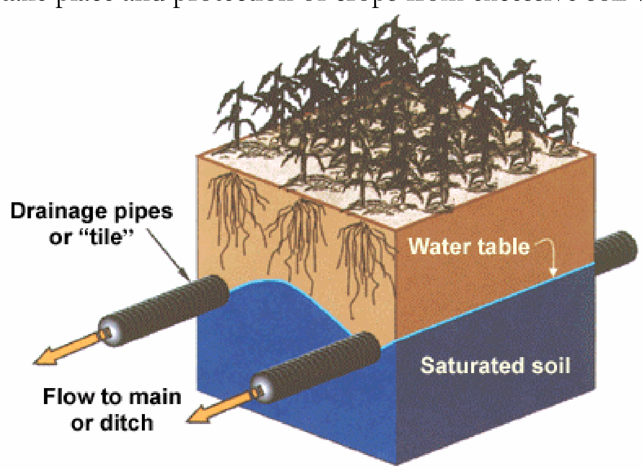


Figure 3.6 Schematic diagram of an agricultural drain

NOTE
French drains are sometimes confused with interceptor drains. However, French drains generally use large gravel without a pipe and the trench itself conveys the water across and down the slope. Consequently, the trench must be sloped. These drains must still convert trench flow to pipe flow in order to get drainage down the slope. French drains are not generally the system of choice for slope applications.

Table 3.11 lists the descriptors for types of lateral collectors/drains.

Table 3.11 Descriptors for lateral collector/drain type

Descriptor
Type of drain:
Interceptor
Relief
Strip
Agricultural
Other

3.4.2 Construction and drainage materials (summarised from www.ecy.wa.gov)

3.4.2.1 Drainage pipe

Drainage pipe is available in rigid wall and flexible wall lengths. Generally, plastic pipe is used by contractors due to its cost, ease of installation and availability. The pipe sidewalls vary from thin and corrugated to thick and solid. Plastic drainage pipe is produced from different materials, the most common of which are polyvinyl chloride (PVC), polyethylene (PE) and high density polyethylene (HDPE) synthetic material. Perforated pipe allows water to enter or exit through small openings along a length of a pipe. The openings can be circular or slots. The more openings per metre of pipe, the greater the capacity of the pipe to collect water. Slotted openings have an advantage over circular holes in that they tend to reduce the amount of fine soil particles entering a drainage system.

3.4.2.2 Geotextile

A geotextile is a permeable fabric made from synthetic polymers. The primary functions of a geotextile in drainage applications are filtration and drainage, i.e. retaining soil while letting water pass through into the drainage collection system.

3.4.2.3 Drainage gravel

Drainage gravel should be rounded rock ranging in size from 20 to 40 mm in diameter. The gravel provides a uniform bedding for drainage pipes to create a consistent slope and provide free draining material adjacent to perforated pipes. Water moves through the spaces between the gravel before entering a pipe or other means of conveyance. In instances where the gravel itself must serve a filtration function, its grading should be based on that of the natural surrounding material.

Table 3.12 lists the construction details of a lateral collector/drain.

Table 3.12 Construction descriptors for lateral collectors/drains

Descriptor
Construction contractor: • Name of company • Physical and postal address of company • Telephone and fax number of company • Contractor's name • Contractor's telephone numbers
Start and end date of construction
Drainage pipe: • Material • Solid/slotted/perforated Geotextile material Gravel: • Size/grading of gravel
Surface elevation Depth of lateral collector/drain below surface
Cross-sectional area of lateral collector/drain
Length of collector (in case of radial collector boreholes length and number of laterals)
Drainage/abstraction rate
Formation sampling: • Sample depth • Geological description of sample • Depth of groundwater level/piezometric level • Water quality of water strike (temperature, pH and electrical conductivity)

3.5 Tunnels

A tunnel is a long, narrow, essentially linear, excavated underground opening the length of which greatly exceeds its width or height. Most such excavations attract the inflow of groundwater from the surrounding soil and rock and, as a consequence, are vulnerable to ground instability, erosion and flooding during construction. Drainage to a tunnel and the consequent lowering of groundwater levels in the vicinity can impact on the surrounding environment and third party assets. If poorly managed, the collection and disposal of groundwater from a tunnel may lead to instances of pollution and environmental impacts on flora, fauna and existing surface water bodies. Tunnels serve manly as a route for transporting various objects, media, materials and substances. The descriptors for tunnel use are summarised in Table 3.13.

According to Wahlstrom (1973), tunnel designs employ a shape that will prove the most stable. For example, when tunnelling in strongly stratified rock such as shale, the roof is often cut flat, taking advantage of the rock's natural tendency to break along bedding planes. For the most part, however, tunnels are excavated with roofs that are circular segments, which is the most stable geometric shape with regard to externally applied stress. Also common are tunnels cut in horseshoe shapes, which provide maximum stability in the roof section. Tunnels that convey water are normally circular.

Table 3.13 Tunnel use descriptors

Descriptor
Purpose: • Transport route for traffic • Mining • Industrial • Power generation • Waste disposal
Medium transported: • Road traffic • Rail traffic • Pedestrian traffic • Services (electricity/communication cables) • Liquids • Gases

In addition to the shape of the tunnel section, the size is also important, as it has to be constructed in such a way as to support surrounding geological formations. The descriptors used to describe the type and geometry of tunnels are listed in Table 3.14.

Table 3.14 Tunnel type and geometry descriptors

Descriptor
Shape: • Circular • Rectangular • Horseshoe
Geometry: • Diameter • Width and height • Length

3.6 Sinkholes

3.6.1 Types and Origin

Sinkholes are subsidence or collapse features that form at points of local instability associated primarily with dolomitic strata, where mildly acidic groundwater has dissolved rock such as limestone, dolomite or gypsum. They also occur in areas where intensive mining activities were or are taking place. Surface structures in the vicinity of sinkholes are at risk of structural damage unless they have been adequately designed. Since sinkholes are natural holes in the ground surface, they are inviting sites for the dumping of waste. In instances where lakes have formed in sinkholes, they are/have been used for recreational and/or water supply purposes. The following types of sinkhole, solution and subsidence features are recognised.

3.6.1.1 Collapse sinkhole

These are the most dramatic of the sinkhole types, forming with little warning and leaving behind a deep, steeply sided hole. The mechanism and progression of a collapse sinkhole is shown in Figure 3.7.

3.6.1.2 Subsidence sinkhole

The mechanism and progression of a subsidence sinkhole is shown in Figure 3.8. Gradually subsiding sinkholes commonly form where slow dissolution takes place, mostly along joints in the karst formation.

3.6.1.3 Solution sinkhole

Solution sinkholes form where the overburden is absent and the karst formation is exposed at land surface.

3.6.1.4 Doline

A doline is a shallow funnel-shaped depression of the ground surface.

3.6.1.5 Grike

A grike is a solution fissure or vertical crack of about 0.5 m wide.

Sinkhole and subsidence features are triggered by the following circumstances: -

Excessive pumping of groundwater from dolomitc aquifers may rapidly lower the water table and cause a sudden loss of buoyant forces that stabilise the roof of cavernous openings. Changes in surface water flow and infiltration induced by human activity may also cause collapse. Most sinkholes that form suddenly occur where soil that overlies bedrock collapses into a pre-existing void.
Dewatering in an urban environment, e.g. pumping groundwater out of basements.
Leaking pipes, swimming pools, dams and taps in a karst environment.
The collapse of a void associated with underground mining activities due to an incapacity to carry the load of overlying sediments results in land subsidence that might take the form of any of the above-listed types of features. The descriptors for the classification of sinkhole and subsidence features are listed in Table 3.15.

Table 3.15 Descriptors for sinkhole and subsidence features.

Descriptor
Type: • Collapse • Subsidence • Solution • Doline • Grike
Natural Artificial
Probable trigger: • Abstraction of groundwater • Infiltration of water from surface • Losses from the water distribution and / or waste water system • Dewatering • Underground mining activity

3.6.2 Geometry of sinkhole and subsidence features

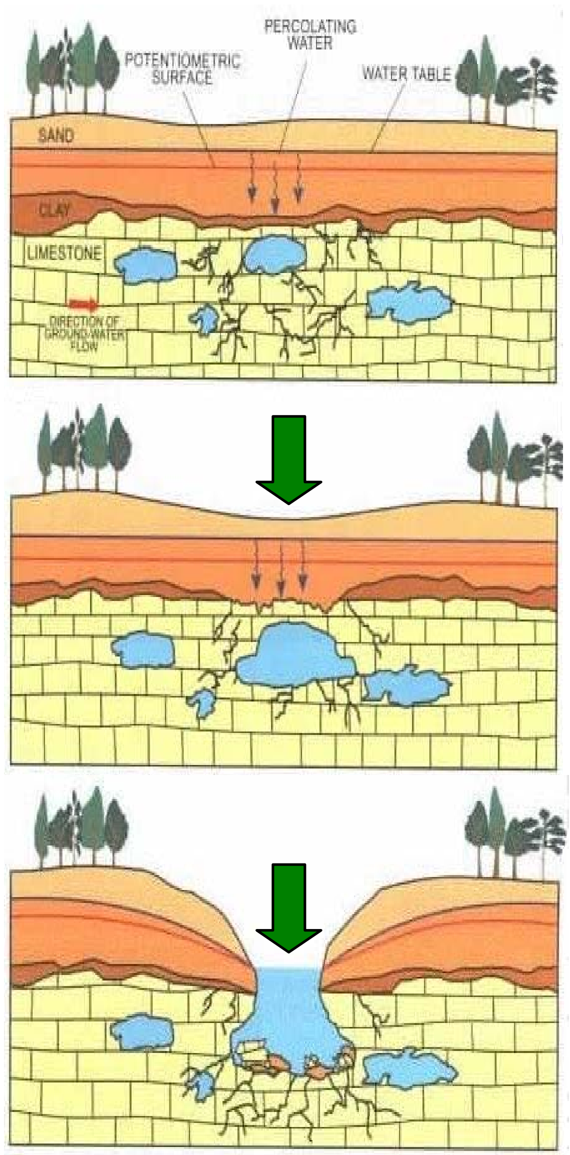
Buttrick et. al. (2001) recognise that the size of a sinkhole in a karst environment is dependent on the following factors:

- The amount of space within the formation available for development.
- Small interconnected openings in the over-burden.
- Estimated depth below ground surface to the potential throat.
- Size of the throat or potential throat.
- The estimated 'angle of draw' in the various horizons of the formation. This angle describes a cone and defines the angle of a metastable slope in which there will be movement of the dolomitic overburden.

Buttrick and Van Schalkwyk (1995) present the size classification for sinkholes in Table 3.16.

Table 3.16 Classification of sinkhole sizes (after Buttrick and Van Schalkwyk, 1995)

Maximum potential development space	Maximum diameter of surface manifestation (m)	Size Classification
Small potential development space	< 2	Small sinkhole
Medium potential development space	2 - 5	Medium size sinkhole
Large potential development space	5 - 15	Large sinkhole
Very large potential development space	> 15	Very large sinkhole



No evidence of land subsidence, small- to medium-sized cavities in the rock matrix. Water from surface rock percolates through to rock, and the erosion process begins.

Cavities in limestone continue to grow larger. Note missing confining layer that allows more water to flow through to the rock matrix. Roof of the cavern is thinner, weaker.

As groundwater levels drop during the dry season or due to over-abstraction, the weight of the overburden exceeds the strength of the cavern roof, and the overburden collapses into the cavern, forming a sinkhole.

Figure 3.7 Mechanism for the formation of collapse sinkholes (from http://waterquality.ifas.ufl.edu/primer)

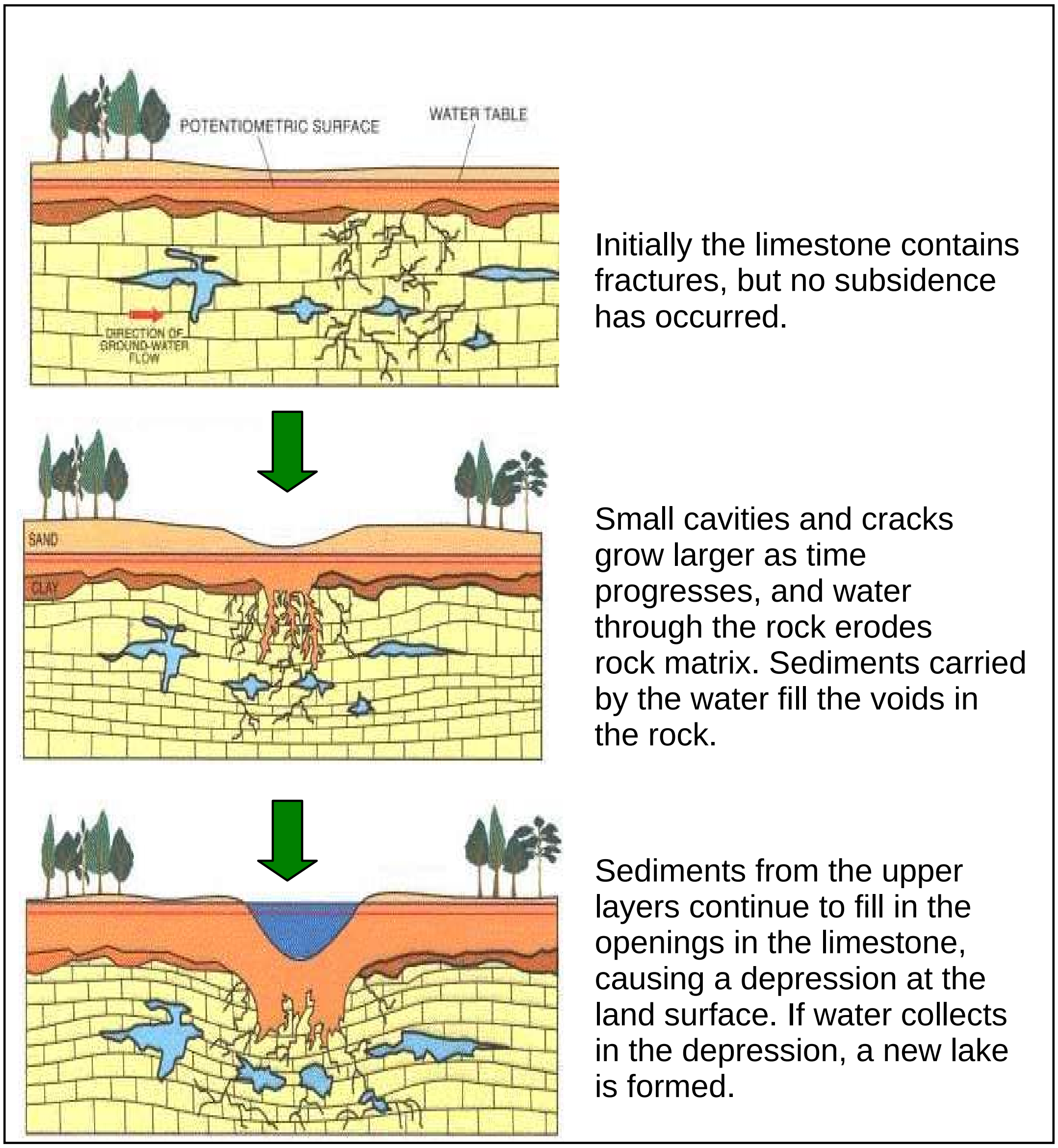


Figure 3.8 Mechanism for the formation of subsidence sinkholes (from http://waterquality.ifas.ufl.edu/primer)

3.7 Mines

A mine can be defined as an excavation in the earth from which substances such as ores and minerals are extracted. Three basic mining-related geosites have been identified, namely shafts/adits, underground mines and opencast mines (including quarries). Mines are further classified according to the extraction method employed, a listing of which is presented in Table 3.17. The final type descriptor relates to the material(s) mined.

A mine has a life cycle that consists of three distinct phases identified as the following:

- Pre-operational phase.
- Operational phase.

- Post-operational/closure phase.

Each of the above-listed phases identifies the status of a mine within its life cycle, and is associated with a start and an end date. It is also not uncommon for the extraction method to change during the operational phase of especially an underground mine. The areas encompassed by the various extraction methods is typically indicated on the mine plans.

Table 3.17 Mine types and extraction methods

Descriptor		Description
Underground mining	Bord-and-pillar mining	An underground mining procedure whereby a rectangular maze is mined, leaving pillars to prevent the overlying strata from collapsing.
	Longwall mining	The total extraction of an underground panel of the mined material, usually with a panel width in excess of 180 m, by mechanised methods and causing the collapse of the strata above the mined-out portion of the panel.
	Shortwall mining	Only conducted on a limited scale in South Africa. Shortwall mining also removes all support of the overlying strata, though over much smaller widths than in the case of longwall mining.
	Stooping	The selective removal of material pillars that have been left behind during bord-and-pillar mining.
	High extraction mining	All underground coal-mining methods that remove the roof support, and which can result in the collapse of overlying strata.
Opencast mining	Strip mining	The total removal of overburden and rock above the ore seam(s) to create an open void on surface. Such mines typically exhibit a rectangular shape, most of the material is easily excavatable and the ore horizon has a sub-horizontal attitude.
	Quarrying	Similar to strip mining, except that such mines typically exhibit a circular or semi-circular shape, the ore and host rock requires substantial blasting and the ore body is extensive in depth.
Other		On the coastline of Namaqualand and KwaZulu Natal, beach or marine alluvial deposits are worked by surface sand-stripping methods, by gravel and pothole exploitation methods in shallow water, and by suction dredging in deeper water to considerable distances off the coast.

The descriptors that characterise a mine are listed in Table 3.18.

Table 3.18 Mine descriptors

Descriptor

Geometry:
• Shafts/adits
    o Co-ordinate of centre of entrance
    o Length
    o Angle with surface
• Mine workings
    o Co-ordinate of centre point of mine
    o Dimensions of workings (length, width, height)
    o Depth of workings (minimum and maximum below surface)

Type: • Underground • Opencast
Extraction method(s): • Bord-and-pillar mining • Longwall mining • Shortwall mining • Stoping • High extraction mining • Strip mining • Quarrying • Other
Status: • Pre-operational phase • Operational phase • Post-operational/closure phase
Material/commodity mined

4 GEOLOGICAL DESCRIPTORS

4.1 Introduction

The geological description of a geosite entails two important aspects, namely lithology and stratigraphy. The former is a broad term comprising characteristics such as colour, composition, texture, grain size, particle shape, composition and origin of the rocks, whereas stratigraphy deals with the systematic organisation of rocks of the Earth's crust. The accurate description of these characteristics provides valuable information of and insight into the groundwater environment.

4.2 Lithology

With regard to lithology, a distinction can be drawn between soils, unconsolidated material and hard rock strata, the latter in the form of either rock chips or core. In the description of the sample, clear and unambiguous distinction should be made between observable characteristics and interpretation. Interpretations will usually contain words such as "possibly", "probably" and "interpreted as", automatically clarifying the assessment being made.

Due to their many common elements and characteristics, soils and unconsolidated strata will be grouped together, but a distinction between core and rock chip samples will be made.

4.2.1 Soil and unconsolidated strata

For soil/unconsolidated formations the descriptors colour, particle size, shape and origin are used. The following text is taken from Bruin and Brink (1994).

4.2.1.1 Colour

To obtain a standardised basis for judging the colour and to take cognisance of changes in colour with changes in moisture content, it is recommended that the sample be described when wet. (A small portion of the sample is taken in the palm of the hand and sufficient water is added to create a paste).

Due to the difficult and subjective nature of the task of assigning colour descriptions, the Munsell colour chart must be used.[2]

4.2.1.2 Particle size

The particle size is essentially described on the basis of grain size diameter. The following descriptions, based on the Wentworth and USGS classifications, are to be used.

[2] The Munsell colour chart can be purchased from: Corstor (Pty) Ltd, PO Box 35, Kya Sand 2163. Tel: 011-462-6026, Fax: 011-462-6117

Table 4.1 Particle size classification

<table>
<tr><th>Descriptor</th><th>Size</th><th colspan="3">Comments</th></tr>
<tr><td>Boulder</td><td colspan="4">256 mm and above</td></tr>
<tr><td>Cobble</td><td colspan="4">64 mm to 256 mm</td></tr>
<tr><td rowspan="6">Gravel</td><td rowspan="6">Gravel consists of fragments of rock between 64 mm and 2mm in size.</td><td>Size (mm)</td><td colspan="2">Description</td></tr>
<tr><td>32 to 64</td><td colspan="2">Very coarse gravel</td></tr>
<tr><td>16 to 32</td><td colspan="2">Coarse gravel</td></tr>
<tr><td>8 to 16</td><td colspan="2">Medium gravel</td></tr>
<tr><td>4 to 8</td><td colspan="2">Fine gravel</td></tr>
<tr><td>2 to 4</td><td colspan="2">Very fine gravel</td></tr>
<tr><td rowspan="6">Sand</td><td rowspan="6">Sand consists of discrete particles between 2.0 mm and 0.063 mm.</td><td>Size (mm)</td><td>Description</td><td>Recognition</td></tr>
<tr><td>1 to 2</td><td>Very coarse</td><td>Grains measurable</td></tr>
<tr><td>0.5 to 1</td><td>Coarse</td><td>Grains clearly visible to the naked eye</td></tr>
<tr><td>0.25 to 0.5</td><td>Medium</td><td>Grains clearly visible under hand lens, just visible to the naked eye</td></tr>
<tr><td>0.125 to 0.25</td><td>Fine</td><td>Just visible as individual grains under hand lens</td></tr>
<tr><td>0.063 to 0.125</td><td>Very fine</td><td>Individual grains cannot be seen with a hand lense</td></tr>
<tr><td>Silt</td><td colspan="4">Silt consists of discrete particles that are smaller than 0.063 mm and larger than 0.004 mm in size. In general, silt particles are barely felt when rubbed with water on the palm of the hand.</td></tr>
<tr><td>Clays</td><td colspan="4">Particle size < 0.004 mm and are slippery when rubbed as a thin wet smear on the palm of hand.</td></tr>
</table>

Most natural soils or unconsolidated formations are a combination of one or more different textures. In describing such a sample, the adjective is used to denote the lesser constituent, e.g. a silty clay is a clay with some silt.

4.2.1.3 Sorting

The grain size distribution can be accurately described if the samples are properly analysed by drying and subjected to a sieve analysis in a soil laboratory. Alternatively, an indication of size distribution can be done in the field using a hand lens that incorporates a fractional millimetre scale such as used by the garment industry to count threads per millimetre.

4.2.1.4 Particle shape

The shape of the sediment particles should also be described, as this assists in the interpretation of origin (see Figure 4.1). The categories to be used are the following.

- Well rounded
- Rounded
- Sub-rounded
- Sub-angular
- Angular.

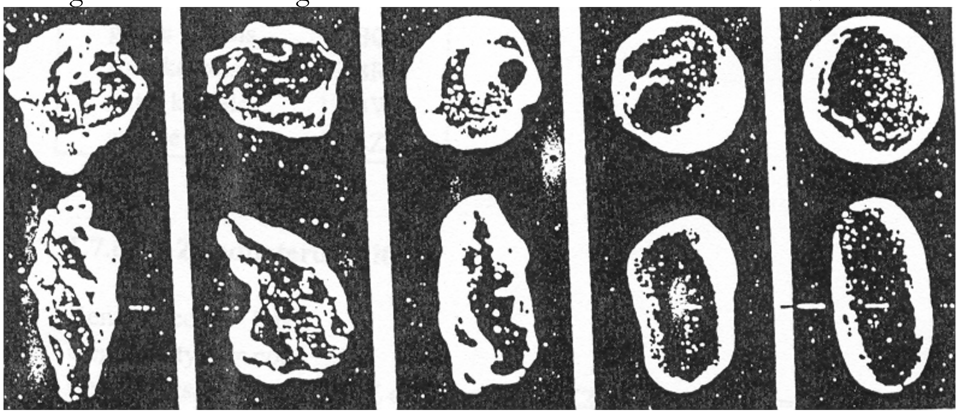


Figure 4.1 Sedimentary particle shapes (after Bosch, 1999).

4.2.1.5 Lithological composition

Where possible, the composition of the sample should be given, e.g. quartz, dolomite.

4.2.1.6 Origin

Where possible, the origin of the sample should be given, e.g. alluvium, residual dolomite.

4.2.1.7 Order of description

The order of description of the sample is to be standardised as follows:

Colour
Particle size
Particle shape (including ratios)
Lithological composition
Origin of the sample

For example, cream coloured; 10 % fine 90 % very fine; quartzose sand; well rounded with minor shelly material.

Unconsolidated material

The following must be described:

- **Origin of the sample**
- **Colour (Munsell colour chart)**
- **Particle size**
- **Particle shape (including ratios)**
- **Lithological composition**
- **Origin of the sample.**

4.2.1.8 Overburden thickness

The thickness of the overburden in a dolomitic environment plays an important role in the formation and size of sinkholes. The classification of overburden thickness after Wagener (1981) is summarised in Table 4.2.

Table 4.2 Thickness of overburden descriptors (after Wagener, 1981)

Descriptor	Thickness (m)
Moderately thin overburden	> 3
Moderately thick overburden	3 – 15
Thick overburden	> 15

4.2.2 Hard rock component

The hard rock component descriptors are sub-divided according to rock chips and core samples. However, parameters generic to both components will first be described and then those unique to each. The following description sequence must be used.

- Lithological composition
- Colour
- Degree of weathering
- Fracture spacing

The moisture condition is generally not described, since a number of factors may influence the final value, e.g. the addition of water during the drilling process, samples left exposed before being sealed, desiccation during the air-flushing process, etc.

4.2.2.1 Lithological composition

It is important to describe the major portion of the sample first. The subordinate portions of the sample are described using the aforementioned descriptors incorporating the quantifications shown in Table 4.3.

Table 4.3 Descriptors for sample proportions

Ratio	Description
Traces	The subordinate amount is less than 10 % of the total sample
Minor	The subordinate amount is between 10 % and 30 % of the total sample
Abundant	The subordinate amount is between 30 % and 50 % of the total sample
Equal amounts	The major factions occur in equal amounts

4.2.2.2 Colour

To ensure that colour is representative of the rock material, only freshly broken surfaces must be examined for the description. Surfaces altered by contaminants or surface abrasion should be avoided. Due to the difficult and subjective nature of the task of assigning colour descriptions, the Munsell colour chart must be used Where a rock chip displays a secondary colour, this may be added to the predominant rock colour as an adjective, e.g. yellowish brown. Where significant, the colour could further be enhanced by using the following descriptions for further distinction:

lustrous, light, dull, dark and bright as described in Table 4.4. The description criteria can also be expanded and, where relevant, the qualifiers included in Table 4.4 applied.

Table 4.4 Additional qualifiers of unconsolidated and consolidated rock material

Composition Qualifiers	Fabric Qualifiers		Colour Qualifiers	Hardness Qualifiers
	Unconsolidated material	Consolidated material		
Argillaceous	Clayey	Brecciated	Bright	Solid
Arenaceous	Coarse	Banded	Dark	Hard
Calcareous	Cobbly	Bedded	Dull	Soft
Carbonaceous	Fine	Baked	Light	Fresh
Cherty	Gravelly	Broken	Lustrous	
Chloritic	Medium	Cemented		
Ferruginous	Muddy	Coarse grained		
Feldspathic	Pebbly	Cross-bedded		
Clauconitic	Sandy	Crystalline		
Graphitic	Shaly	Consolidated		
Micaceous	Shelly	Fibrous		
Heavy mineral bearing	Silty	Fine grained		
Phosphorite bearing		Granular		
Peaty		Interlaminated		
Pyritic		Intercalated		
Siliceous		Jointed		
		Laminated		
		Massive		
		Medium grained		
		Nodular		
		Porphyritic		
		Oolitic		
		Phyllitic		

4.2.2.3 Degree of weathering

The state of weathering of the rock should be described in the broad categories defined in Table 4.5

Table 4.5 Degree of weathering descriptors

Description	Surface Characteristics
Unweathered	Unchanged
Slightly weathered	Partial discolouration
Medium weathered	Partial to complete discoloration, not friable except poorly cemented rocks
Highly weathered	Friable and possibly pitted
Completely weathered	Resembles a soil

4.2.2.4 Discontinuity spacing

A discontinuity is defined as any surface across which some property of a rock mass is discontinuous. This includes fractures, bedding planes and joints. Discontinuities include three major categories, namely those related to

- the origin of the rock such as bedding, foliations, cleavage planes and flow bands,
- features resulting from tectonic rupture and effect of off-loading such as joints, faults, shear-zones and fractures.

The spacing is measured normal to the inclination of the discontinuities or the various discontinuity sets. In the determination of discontinuity spacing, only natural discontinuities are included.

Table 4.6 Discontinuity spacing descriptors

Descriptor	Spacing (core drilling)
Very highly fractured	< 20 mm
Highly fractured	20 mm – 0.2 m
Moderately fractured	0.2 –0.6 m
Slightly fractured	0.6 – 2.0 m
Very slightly fractured	> 2.0 m

The nature of percussion drilling does not allow an accurate measurement of discontinuity spacing as can be done with core. However, parameters such as penetration rate, chip size and colour can be evaluated to enable one to classify drill chips as highly fractured, moderately fractured, slightly fractured and no fracturing.

Table 4.7 Discontinuity descriptors – percussion drilling

Descriptor	Penetration Rate	Drill Chip Size	Colour Changes
Highly fractured	Rapid change, hammer action can cease	Abundant large drill chips and variable size chips	The larger chips have staining on all or most faces of the chips, the smaller chips have one or more stained faces.
Moderately fractured	Noticeable change in drill rate	A few large drill chips, some medium size, some normal size	The larger chips have one or more stained faces, but seldom all faces stained. The smaller chips may have one or more stained face.
Slightly fractured	Slight change in drill rate	Occasional medium size drill chip, mostly uniform	The larger chips have one or more stained faces, the smaller chips usually have no staining.
No fracturing	Uniform drill rate	Uniform drill chip size	No staining is evident.

4.2.2.5 Formation strength

The most important consideration when excavating a tunnel in a formation is the stability of the latter. The geological classification of tunnels is based on the strength (resistance to deformation) of the formation(s) intersected as described in Table 4.8, and its weathering (see Table 4.4). Igneous and metamorphic formations, in general, are more resistant to deformation and weathering than sedimentary formations.

Table 4.8 Formation strength classification (after Parker, 1996)

Descriptor	Stress range (MPa)
Extremely soft	0.2–0.7
Very low strength	0.7-7
Low strength	7-28
Moderate strength	28-55
Medium high strength	55-110
High strength	110-220
Very high strength	>220

4.3 Lithostratigraphy

Two subsets of stratigraphy are distinguished here, namely lithostratigraphy and chronostratigraphy. The former is defined as "the element of stratigraphy that deals with the description and systematic organization of the Earth's crust into distinctive named units based on the lithologic character of the rocks and their sratigraphic relations". In contrast, chronostratigraphy is defined as "the branch of stratigraphy that deals with the age of strata and their time relations".

Neither of the above is a directly observable nor measurable criterion such as those in the foregoing sections. Their description is based on an in-depth knowledge of the geology of the area under investigation and should, therefore, only be undertaken by qualified and experienced geoscientists. The rock should be described both chronostratigraphically and lithologically, if possible, e.g. Lebowa Suite granite.

Appendix 3 contains codes for the litho- and chronostratigraphic units. It contains the Unit names and ranks as well as the parent unit names and ranks, and other relevant codes. These codes have been supplied by the Council for Geoscience.

Appendix 3 contains the labels used for the chronostratigraphic units as defined by the Council for Geoscience.

Consolidated material

The following must be described:

- **Lithological composition**
- **Colour**
- **Degree of weathering**
- **Discontinuity spacing**
- **Subordinate descriptions (e.g. mineral size)**

5 GEOHYDROLOGICAL DESCRIPTORS

5.1 Introduction

Together with geological characteristics, certain additional geohydrological parameters need to be observed and recorded. These include the depth of the water strikes, depth to the static water level, the estimated yield and the water quality of each water strike encountered. This information, interpreted in conjunction with geological parameters as described in chapter 4, assists with developing a conceptual geohydrological model of the underlying aquifer. It also provides practical information required for optimised borehole design.

Borehole design incorporates amongst others, specifying the physical materials and dimensions for borehole casings, pumping equipment, etc. The principal objectives of good design should ensure the following for a water supply geosite.

- The highest sustainable water yield with proper protection from contamination
- Water that remains sediment-free to protect pumps and silting up of instalaltions
- A geosite that has a long life (at least 25 years or more in the case of boreholes)
- Optimum operating costs in the short and the long term.

Although geosite design may appear to be a straightforward procedure, local geohydrological conditions and practical considerations more often than not complicate the process.

Important geological and geohydrological information required for the design of efficient high-yielding water supply geosites includes the following.

- Grain size analyses of unconsolidated aquifer materials and identification of mineral types if necessary
- The nature and character of the water-bearing horizons, e.g. degree of stability/instability even in the case of hard-rock aquifers
- Transmissivity and storage coefficient values for the aquifer
- Current and long-term water balance conditions in the aquifer
- Water quality (not only of the aquifer to be tapped but also that of aquifers producing water of a poorer quality and which, as a result, must be sealed off)
- Stratigraphic information concerning the aquifer and overlying sediments

5.2 Water Strike Depth

5.2.1 Unconsolidated strata

No discrete water strike depths can be observed. The top of the aquifer would either be a confining layer or, in the case of an unconfined aquifer, the static water level. The depth to the saturated zone is measured in metres from the ground surface. For auger drilling or drilling without drilling fluids, as the capillary fringe is penetrated just prior to entering the saturated zone, the unconsolidated formations become darker in colour and damp. This depth generally marks the water table in unconfined unconsolidated formations, and can be confirmed after the borehole is completed and developed by measuring the depth to the static water level (for details see section 5.4).

5.2.2 Consolidated strata

Any water strike may be recognised by an increase in blow yields and/or a discolouration of the water. Any dramatic change in penetration rate may also be associated with a water strike. The drill cuttings (rock fragments) usually reflect fracture zones and provide insight into the size and nature of the fracturing. The depth from surface of all water strikes should be recorded in metres below ground level (to the nearest 0.5m) and the widths of the individual water-bearing horizons estimated as accurately as is possible and recorded.

With (mud) rotary drilling the yield of the various water-bearing horizons is difficult to recognise and estimate. However, the nature of the drill cuttings and thinning of the drilling fluid will provide clues as to the probable intersection of water yielding zones in hard rock aquifers.

In the case of tunnels and mines, the position of any water strike can be surveyed and expressed as a co-ordinate. If the position remains accessible, the geology associated with a water strike (typically a contact between different strata, fracture, fault or joint) can be described.

5.3 Water Strike Yield

Measurement of the flow of groundwater emitting from a borehole whilst it is being drilled (blow yield) gives an approximate and often conservative estimate of the yield of the borehole. Blow yields do not provide an indication of the long-term yield of either the borehole or the aquifer, and these flow rates must not be used for the selection of pumping equipment. This does not, however, negate the fact that this parameter should be recorded as it provides an insight into the potential aquifer productivity.

The blow yield may be measured regularly while drilling to ensure that any change of yield is picked up, and must be recorded with every strike encountered. Subsequent measurements represent the cumulative blow yield from which the relative yield or contribution of each water strike can be determined. This information will be valuable for test pumping design and for deciding the depth of installation of both the test and final production equipment. Since the blow yield while drilling is relatively inaccurate, it should preferably also be recorded when the drill bit is lifted half a metre off the bottom of the borehole. The blow yield can be measured in several ways:

- By estimating the flow. By its nature this method is the most inaccurate.
- By digging a furrow leading from the borehole to a small pit able to accommodate a container of known volume. The time taken to fill the container is measured and the flow rate calculated and recorded as litres per second (volumetric method).
- A more reliable approach with higher yields (typically >2 L/s) is to excavate a furrow and to place a V-notch or similar weir in it. The height of flow through the notch provides an indication of the flow rate. If the specifications for notch installation and use are not closely adhered to, the measurement accuracy will be significantly compromised.

The above-listed methods can also be employed to measure the discharge rate of magnitude 4 and lower-yielding (Table 5.1) springs. More sophisticated gauging weirs are required to measure the discharge of magnitude 3 and higher-yielding (Table 5.1) springs.

It may be substantially more difficult to determine the rate of ingress of large volumes of water associated with water strikes in a tunnel or mine. Often a best guess (or estimate) must suffice.

Table 5.1 Classification of springs by discharge rate (after Meinzer, 1923)

Magnitude	Discharge rate (L/s)	Example
1	2800 or more	Kuruman eye
2	280 – 2800	Schoonspruit spring
3	28 – 280	The Baths at Citrusdal
4	6 – 28	Caledon thermal springs
5	0.6 – 6	Springs on farms in the Southern Free State
6	Less than 0.6	Sixuzulu spring in the Eastern Cape

5.4 Static Water Level

The static water level is the level at which the water in a borehole stands at the time of measurement. The term static water level (SWL) is used widely and is recommended in preference to the term rest water level (RWL). Since it is recognised that the water level is not static and will fluctuate (e.g. seasonally), it is of utmost importance that the date and time of the measurement plus the actual water level measurement (metres below ground level) be recorded. Any abstraction near enough to possibly influence the static water level, and the distance to this production borehole(s) and its/their operational status at the time of the measurement must also be recorded, e.g. 'Running' or 'Standing'. If these abstractions have a clear influence on the water level, the water level should be indicated as 'Affected', otherwise it should be indicated as 'Static'. If uncertain whether 'Running' pumps are affecting the water level, a control measurement can be taken after a 5 – 10 minute lapse.

The standard for the static water level measurement is in metres below a datum. The datum for water level depth measurements is the top of the borehole casing. The height of this datum above ground level (collar hight) must be measured and recorded as well. To reduce any uncertainty in the recording of static water levels, the datum height and the depth to groundwater below surface level must be recorded. The water level in many low-yielding boreholes can take a long time to recover to its true static level after the completion of drilling. Under these circumstances, the static water level must also be measured 24 hours after the completion of drilling.

All measurements are to be made in metres accurate to two decimal places (i.e. centimeters). Table 5.2 provides an example of the measurements associated with SWL measurements.

Table 5.2 Example of measurements associated with SWL recordings

Descriptor	Measurement/Observation
Height of casing above ground level (m)	0.35
Depth to water level from top of casing (m)	12.77
Surveyed ground level elevation (mamsl)	243.51
Water level status	Static, Affected or Recovering

When the geographic coordinates of the geosite are determined, the altitude of the surface level must also be measured and recorded. The static water level can then be converted to an absolute elevation. This is essential for determining groundwater flow directions and calculating flow velocities. The standard reference level is mean sea level.

For an artesian borehole that flows at the ground surface, the static water level is expressed as a negative distance above the ground surface. When artesian flow is stopped or contained at the ground surface, the pressure developed is referred to as the shut-in head. For example, if a borehole has a shut-in head of 20.7 kPa at the surface, it means that the confining pressure will cause the water to rise approximately 2.07 m in a pipe extending sufficiently far above the ground surface. In the case of a water level rising to exactly surface or datum, the value to record is 0.00 m. A qualifier (comment) to indicate that the water level is at surface must be added to avoid any confusion. In instances where no water level measurement is possible, it should be reported as 'not measured' and a short comment on the reason provided.

The water level associated with a spring is typically recorded as 0.00m under circumstances where it is seldom possible to establish the shut-in head. This necessarily sets the water level elevation equal to that of the surface elevation occupied by the spring.

In the case of tunnels and mines, it is more important to establish the static water level in the surrounding host groundwater environment. This necessarily requires the existence of facilities (typically boreholes) that intersect this environment and in which the required measurements can be made. The exception in this regard is represented by mines that are either partly or completely flooded as a result of re-watering. This is not limited to defunct mines, since even active mines may have flooded sections.

5.5 Water Quality

5.5.1 Introduction

To be able to check possible changes in the ionic balance of a water sample the most common well head measurements are the electrical conductivity (EC), temperature (T) and pH of the groundwater and thus should be measured. Other field instruments coming into use more commonly, allow for the measureing of the Redox Potential and Disolved Oxigen at the well head. It is also advisable to collect and store a water sampling from the drilling phase in case analytical results are required prior to the execution of a pumping test.

5.5.2 Electrical conductivity

The integrity of the EC measurement is ensured if the instrument is checked and calibrated regularly using a standard solution of EC-values in the same range as that of the groundwater to be measured. At the same time the groundwater temperature should be measured. Electrical conductivity values must be reported in milliSiemens per metre (mS/m) to an accuracy of two decimals. Table 5.3 provides EC conversion factors associated with the various reporting units.

Table 5.3 Conversion factors for electrical conductivity units (after Weaver, 1992)

1 Siemens per cm (1 S/cm)	x	100 000	=	1 milliSiemens per metre
1 milliSiemens per cm (1 mS/cm)	x	100	=	1 milliSiemens per metre
1 microSiemens per cm (1 μS/cm)	x	0.1	=	1 milliSiemens per metre
1 micromho per cm (1 μmho/cm)	x	0.1	=	1 milliSiemens per metre

5.5.3 Temperature

In the case of thermal springs and water strikes encountered in tunnels and mines, it is necessary to measure the temperature of the groundwater . This will facilitate the thermal characterisation of the water in terms of the classification system proposed by Kent (1949) as presented in Table 5.4.

Table 5.4 Spring temperature classification (after Kent, 1949)

Descriptor	Temperature	Example
Cold	< 20°C	Many farm springs in the southern Free State
Hypothermal	20 – 30°C	Florisbad
Thermal	30 – 40°C	Aliwal North
Hyperthermal	> 40°C	Montaqu Baths

The proper collection of a groundwater sample for this purpose is imperative to allow meaningful interpretation of analyses. For the appropriate containers and prescribed sampling methodologies, refer to (Weaver, 1992).

5.5.4 Sampling new boreholes

A newly drilled borehole is to be sampled, either after drilling or during test pumping, preferably at the end of development or just prior to stopping the pump. Should there be an obligation to sample each individual water strike, a period of airlifting to allow any oil to be removed should precede sample collection.

Groundwater samples collected during borehole development should be collected as near as possible to the borehole. To achieve this, a clean bucket should be placed next to the borehole to collect some of the airlifted water. At no time should samples be collected from a V-notch or similar weir or after the water has flowed over the soil surface. Borehole development is discussed in more detail in the following chapter.

5.5.5 Sampling during test pumping

During test pumping, samples should be collected at the end of the test if only one sample is to be collected. It is recommended, however, that samples be collected at several intervals during testing. These intervals should be every 6 hours during a 12-hour constant discharge (CD) test, every 8 hours during a 24-hour CD test, or every 12 hours for CD tests of longer duration.

5.5.6 Sampling of existing boreholes

When any existing borehole is being re-developed or re-tested, it is imperative to sample the groundwater again. Purging the hole prior to sampling is mandatory. For the prescribed sampling methodologies, refer to Weaver (1992).

5.6 Chemical Analysis

A detailed chemical analysis of the water obtained on completion of drilling and developing a new borehole typically comprises the following parameters with reporting units mg/L unless otherwise stated: H (pH units); electrical conductivity (mS/m); potassium; sodium; calcium; magnesium; sulphate; chloride; total alkalinity; nitrate; iron; fluoride.

In order to evaluate any chemical changes that might have occurred between the time of sampling and analysis, it is necessary to measure in the field and record the EC and pH values.

The important geohydrological details that must be recorded are:

- **Water strike depth(s) (metres below datum)**
- **Blow yield of water strike(s) (L/s)**
- **SWL (depth in metres below datum). Values are positive if below surface and negative if above (artesian).**
- **EC (mS/m) and temperature of the water strike(s)**

6 GEOSITE DESIGN, DEVELOPMENT AND COMPLETION DESCRIPTORS

6.1 Introduction

Standard design procedures for geosites such as water supply and monitoring boreholes involve selecting the casing diameter and material, estimating borehole depth, selecting the length, diameter and material for the screen, determining the screen slot size and choosing the completion method. Some of this information also applies to other geosites such as dug wells, lateral collectors, drains and springs. Measuring and recording this information is therefore important, since it not only provides an as-built record of the geosite for cost certification and future trouble-shooting purposes, but also facilitates the optimisation of test pumping programmes and better informs geohydrological characterisation. Imperial units of measure to describe drill bit and casing diameter are still commonly used in the drilling industry in South Africa, and are thus included in this chapter.

6.2 Casings

Every borehole casing consists of two elements, namely solid casing and the intake (perforated) portion. Choosing the proper casing diameter for a prospective water production borehole is important because it may significantly affect the cost of borehole construction, choice of pumping equipment and operating costs. The casing must be large enough to accommodate the appropriate size pump with enough clearance for installation and efficient operation. In the case of a monitoring borehole, the diameter and casing must be large enough to accommodate the sampling pump, but not too large as this will result in an excessive amount of water that will need to be purged before collecting the water sample.

The selection of casing material is based on factors such as water quality, borehole depth and diameter, drilling equipment and drilling procedures, local regulations and cost. The different materials used in the groundwater industry are shown in Table 6.1. The most common types used in South Africa are steel and uPVC, the latter mainly in shallower boreholes and groundwater environments hosting highly corrosive water.

Table 6.1 Casing material

Descriptor
Steel
Stainless steel
UPVC (plastic)
Fibreglass
Other

6.2.1 Plain casing

The size of all steel casing in South Africa is gauged on the basis of its nominal inside diameter (ID) through which a drill bit must be able to pass with little tolerance. This implies that the outside diameter (OD) increases commensurate with an increase in wall thickness, so that specifying nominal 165 mm (ID) casing with a wall thickness of 4 mm gives an OD of 173 mm, and a wall thickness of 6 mm gives an OD of 177 mm. The standard borehole casing size used in South Africa is nominal 165 mm (6.5”) ID which, with a 4 mm side wall is identified as 173 mm (OD) casing in the casing manufacturing industry. Similarly, nominal 152 mm ID (6”) casing with a 4 mm sidewall is identified as 160 mm steel casing in the industry. Heavier duty casing, with wall thicknesses up to 10 mm, are used under increasingly onerous borehole drilling conditions.

PVC casing, by contrast, is specified according to its OD, i.e. the OD remains fixed and the ID shrinks commensurate with an increase in wall thickness. This means that specifying 140 mm (OD) uPVC casing with a 5 mm wall thickness gives an ID of 130 mm.

When recording the dimensions of the casing with which a borehole is equipped, both the inside diameter (ID) and sidewall thickness must be measured and reported in millimeters (mm).

Casing installed in a borehole should be continuous and watertight along its full length.

6.2.2 Slotted casing

Casing with slots produced by one of several methods is often used in boreholes as a screening device (refer section 6.3). Rudimentary slots may be made with a saw or cutting torch, or punched with a steel punch. Such slots are typically made on site, and important limitations thereof are the following: -

- Openings cannot be closely spaced
- Percentage open area is low
- Size of slot openings varies significantly
- Openings small enough to control fine or medium sand are difficult or impossible to produce.

Neater, cleaner and more sophisticated (efficient) slots can be made in a controlled manufacturing (factory) environment using plasma or laser cutting techniques. Such slots are much more acceptable than those made in the field. Nevertheless, slotted steel casing is not corrosion resistant, and most methods of perforation tend to hasten corrosive attack on the metal when the water is aggressive.

6.3 Screens

A borehole screen is a filtering device that serves as the intake portion of boreholes constructed mainly in unconsolidated or semi-consolidated aquifers to prevent sediment from entering the borehole and to serve as a structural retainer to support the loose geological strata. In hard rock aquifers the intake portion may consist of the uncased borehole drilled into the aquifer. Some hard rock aquifers such as sandstone may deteriorate over time because high flow rates remove cement that holds the grain together, thus causing slow collapse of the borehole wall. In other cases, certain minerals may weather faster due to exposure to the atmosphere. For example, the feldspar crystals in granitic rock disintegrate under aerobic conditions. Screens are therefore often used to protect pumps for from loosened formation particles and to stabilise the aquifer materials in many consolidated strata, especially sandstone, dolomite, limestone and some granites. The need to support unstable strata associated with highly fractured/jointed zones represents another use of screens in otherwise competent consolidated strata. The importance of a proper screening cannot be overemphasised when considering the hydraulic efficiency of a well and the long-term cost to its owner. Important screen criteria and functions include:

- Criteria
- Large percentage of open area
- Non-clogging openings
- Resistance to corrosion
- Sufficient column and collapse strength

- Functions
- Easily developed
- Minimal encrustation tendency
- Low head loss through the screen
- Minimising sand pumping in all types of aquifers.

The optimum length of screen is based on the thickness of the aquifer, available drawdown and stratified nature of the aquifer. In virtually every aquifer, certain zones (horizons) will transmit more water than others. Ideally, the borehole screen must be placed opposite those zones exhibiting the greatest hydraulic conductivity. One or more of the following techniques permit determination of the most productive layers.

Interpretation of the driller's log and comments on drilling characteristics such as fluid loss, penetration rates, etc.
Geological inspection of drill cuttings (chips) or samples. The relative transmissivity of each layer is estimated from the observed coarseness, lack of silt and clay, and thickness of the layer.
Sieve analysis of the different lithological sediment layers.
Laboratory hydraulic conductivity testing can be performed on relatively undisturbed samples that represent individual layers of the water-bearing formations.
Borehole geophysical logging techniques.

Each technique listed above provides useful information on the zones that should be exploited. Economic factors governing a drilling project will dictate the cost that can be incurred in determining most accurately the productive zones of the aquifer. Recommended screen lengths for four typical geohydrological situations are given below.

6.3.1 Homogeneous unconfined aquifer

The lower 33 to 50 % of an aquifer less than 50 m thick represents the optimum design for homogeneous unconfined aquifers. In thin aquifers, as much as 80 % of the aquifer may be screened to obtain a higher specific capacity. The screen is positioned in the lower portion of the aquifer because the upper part is dewatered during pumping. A borehole in an unconfined aquifer is therefore usually pumped such that, at maximum capacity, the pumping water level is maintained slightly above the top of the screen. Screen length selection is a compromise between specific capacity and available drawdown. The optimum drawdown is 50 % to 60 % of the unscreened zone above the top of the screen.

6.3.2 Heterogeneous unconfined aquifer

Although the same basic principles outlined above apply, the screen sections must be positioned in the most permeable layers of the lowest portions of the aquifer to maximise the available drawdown. If possible, the total screen length should be approximately 33 % of the aquifer thickness.

6.3.3 Homogeneous confined aquifer

In this type of aquifer, 80 to 90 % of the thickness of the water-bearing sediment should be screened, assuming that the pumping water level is not expected to fall below the top of the aquifer. The maximum available drawdown for boreholes in confined aquifers should be the distance from the potentiometric surface (static water level) to the top of the aquifer. Under circumstances where the available drawdown is limited, drawing the water level down below the bottom of the upper confining layer is unavoidable. When this occurs, the aquifer will respond like an unconfined aquifer during pumping. Screen lengths chosen according to these rules make it possible to obtain about 90 to 95 % of the specific capacity that could be obtained by screening the entire aquifer. Best results are obtained by centering the screen section in the aquifer.

6.3.4 Heterogeneous confined aquifer

From 80 to 90 % of the most permeable layers should be screened.

The length of casing and screens should be reported in metres, accurate to one decimal, as a depth below the ground surface. It is possible for a number of screen sections to be interspersed with plain casing in a borehole. An example of reporting under such circumstances is given in Table 6.2.

Table 6.2 Example of information recorded when casing and screens are used jointly

Descriptor	Depth Interval	
	From (m)	**To (m)**
Ccasing 1	0.0	15.5
Screen 1	15.5	27.5
Ccasing 1	27.5	37.9
Sscreen 2	37.9	49.0
Ccasing 1	49.0	55.0

When designing screens for heterogeneous formations, different slot sizes may be chosen for different sections of the borehole according to the gradation of materials in different layers. If different screen slot configurations are used at different intervals, these should be recorded. For example, the descriptor for the lower screen (Screen 2 in Table 6.2) identifies it as being different from the upper screen (Screen 1). The difference is typically described in the borehole construction record.

Screen slot openings for the same formation can differ depending on whether the borehole is naturally developed or filter packed. Either design is satisfactory and the choice for a particular borehole will depend primarily on the form of the grain size distribution curve for the aquifer materials. Coarse-grained heterogeneous formations can be developed naturally, whereas fine-grained homogeneous materials are best developed using a filter pack. Borehole screen slot openings for either method are selected from a study of sieve analysis data for samples representing the water-bearing formation. The design for slot openings (and filter pack where needed) must be based on accurate samples if maximum yields and sediment-free water is to be obtained.

In a naturally developed well, the screen slot size is selected so that most of the finer formation materials near the borehole are brought into the screen and pumped from the borehole during development. This practice results in creating a zone of graded formation materials extending up to 0.5 m outward from the screen. The increased porosity and hydraulic conductivity of the graded materials reduces the drawdown near the well during pumping. In heterogeneous sediments, the typical approach is to select a slot through which 60 % of the material will pass and 40 % will be retained. If the groundwater is corrosive or there is some doubt about the reliability of the sample, the 50 % retained size should be chosen. A conservative slot opening should be used in calcareous formations.

Parameters regarding screens that should be recorded are shown in Tables 6.3 and 6.4.

Table 6.3 Screen material

Descriptor
Steel
Stainless steel
Upvc

Table 6.4 Type of opening

Descriptor
Continuous wedge-wire slot
Machine cut slot
Machine-pressed bridge slot
Sawn slot
Torch-cut slot
Punched hole
Drilled hole

The following must be recorded:

- **Casing type**
- **Casing ID and wall thickness (mm)**
- **Screen material**
- **Screen construction**
- **Method used for making screen openings**

6.4 Filter and Gravel Packs

Filter-packed boreholes and some lateral collectors and drains are constructed with an envelope of specially graded sand or gravel that is placed around the screen to a predetermined thickness. In the case of a borehole, this takes the place of the graded zone of permeable material that is produced by the development process. Filter packs typically perform a specialist function in primary aquifers, and gravel packs are more widely used in secondary aquifers as formation stabilisers.

Commercial sand for filter packs is usually specified by the upper and lower sand size (in US mesh scale) so that 85 % of the sand retained, falls within the limit. Table 6.5 provides a list of the more common grading specifications and associated details.

Table 6.5 Filter pack characteristics

Grading Specification	85 % Size Range (mm)	Coefficient of Uniformity	Effective Size (mm)	Optimum Slot Size (mm)
4/10	4.75 to 2.00	1.47	2.48	2.0
7/16	2.80 to 1.18	1.32	1.42	1.0
12/20	1.70 to 0.85	1.31	0.90	0.8
16/30	1.19 to 0.59	1.47	0.62	0.5
25/40	0.71 to 0.42	1.28	0.46	0.3

The relevant data that needs to be recorded in regard to filter and gravel packs is listed in Table 6.6.

Table 6.6 Filter and gravel pack details

Descriptor	Comments
Bottom of filter pack	Distance from ground surface in metres
Top of filter pack	Distance from ground surface in metres
Type of filter pack material: Quartz Other	
Filter pack width (i.e. distance from the screen to the borehole wall)	Width measured in millimetres
Filter pack coefficient of uniformity	Actual measurement (should be < 2.5)
Filter pack grain size	Grain size measurement in millimetres.

The following must be described:
- **Depth to top and bottom of filter/gravel pack**
- **Nature of filter/gravel pack material**
- **Filter/gravel pack width**
- **Effective filter/gravel particle grain size**

6.4.1 Dug Well Linings

As dug wells are usually excavated by hand shovel in loose geological strata, some retaining mechanism is required. To distinguish these from casings used in borehoels and wellpoints, the term 'lining' is used. In most dug wells are lined with either stones, bricks, tiles to prevent collapse. Modrern dug wells may have other materials.

6.5 Geosite Development

6.5.1 Boreholes

Procedures designed to optimise borehole yield are included in the term "development". Development has two broad objectives.

- Mitigate the damage done to the formation by the drilling process so that the natural hydraulic properties are partly restored.
- Improve the basic physical characteristics of the aquifer near the borehole so that water will flow more freely into a borehole.

All new boreholes should be developed before being tested or put into production to promote the production of sediment-free groundwater at the highest possible specific capacity. The choice of development method(s) is largely controlled by the type of drilling rig on site, the drilling method employed, the geohydrological conditions and financial constraints.

Mechanical development.

Methods range from extremely simple to relatively complex requiring specialised tools, but share the common characteristic that all employ some physical activity generated within the borehole. There are no set rules as to which methods must be used for different aquifer types. The information presented in Table 6.7 provides an indication of the range of mechanical development methods and their application in different groundwater environments.

Table 6.7 Mechanical borehole development methods and application

Method	Equipment Required	Comments
Bailing	Cable tool rig, bailer	Also common for hand pump boreholes
Surging	Cable tool or rotary rig, surge block	Not recommended for aquifers with clays layers
Swabbing	Cable tool or rotary rig, swab	Not recommended for aquifers with clay layers
Air lifting	Air compressor	Most common method used in South Africa. Effective in a variety of environments.
Pumping	Any rig (including jetting, manual drilling) with pump	Can be used by jetting rigs or for manually drilled wells, by a power or hand operated pump.
Backwashing, air surging	Any rig with air compressor or borehole pump.	Creates a surging action without requiring surge blocks or special tools
Air lift pumping / surging	Any rig with air compressor, air lift equipment with valve	Effective for boreholes in sandstone aquifers
Surging/air lift pumping	Cable tool rig, air compressor, isolation tool	Very effective in unconsolidated aquifers; only for screened boreholes
Jetting (air)	Rotary, air compressor, jetting tool	Best with wire wrap screens; only for screened boreholes
Jetting/Air lift pumping	Rotary, mud pump, jetting tool, air compressor	Best with wire wrap screens; only for screened boreholes
Jetting (water)	Rotary, mud pump, jetting tool	Best with wire wrap screens; only for screened boreholes
Hydrofracturing	Specialised equipment incorporating an air compressor and inflatable single or double packers, amongst others.	Open/uncased boreholes penetrating conducive low-yielding secondary aquifers.

Chemical development

This activity employs a variety of chemicals. The most common additive is polyphosphate. Although less common, some aquifers may respond well to certain acid treatments which may open up fractures or dissolve cements. Acid is also sometimes used to break down organic drilling mud so as to aid mechanical development. Results are often improved if chemical methods are used in conjunction with mechanical development methods.

Polyphosphates as well as surfactants (detergents) can assist mechanical development by dispersing and separating clay particles, which are then removed more easily from the borehole. Common forms of polyphosphate are sodium acid pyrophosphate, tetrasodium pyrophosphate, sodium hexametaphosphate and sodium tripolyphosphate. These are generally supplied in crystalline form. Surfactants are used at low concentrations (250 to 500 mg/L), and enhance the dispersing efficiency of polyphosphates in removing silt and clay. Acid treatment may also be enhanced when used in conjunction with a surfactant. Caution: Sulfuric acid must never be used, since it combines with calcium to form insoluble calcium sulphate that will clog the borehole permanently.

Acid treatment is primarily effective in limestone and dolomite aquifers, or sedimentary formations that are cemented by calcium carbonate. During treatment with acid, the carbonate minerals are dissolved, thereby opening up fractures and connecting voids and fissures to increase the hydraulic conductivity in the vicinity of the borehole.

A list of chemical development additives is presented in Table 6.8. Whatever borehole development method is used, it is required that the duration of the development be recorded in hours and minutes (hh:mm).

Table 6.8 Chemical borehole development additives

Descriptor
Surfactant
Polyphosphates
Acid treatment
Other

The following must be described with respect to borehole development:

- **Method used for borehole development**
- **Duration of borehole development (hh:mm)**
- **Chemicals or chemical additives used during development.**

6.5.2 Springs

The material presented in this subsection is summarised from Pearson *et. al.* (2003). Two basic principles need to be followed when developing springs: -

Keep the spring flowing freely. Obstructions can lead to water damming up and this can result in groundwater finding easier alternative routes to the surface, causing the original spring to stop flowing.
Protect the water supply from contamination. The objective of spring development is to collect the flowing water underground to protect it from surface contamination, and store it in a reservoir. The appropriate development method depends on the type of spring.

The methods generally used to develop and protect springs in South Africa are discussed briefly in the following subsections. Pearson *et al.* (2003) provides a comprehensive discussion on spring development.

The spring box

This entails the construction of two chambers, viz. the intake chamber and the sedimentation chamber. These chambers are separated by a honeycomb wall that allows free flow of water (see Figure 6.1). The intake chamber is filled with a filter pack of graded washed stone. The floor of the intake chamber must have a slope of 1 to 2%. The sedimentation chamber is where sand particles carried in spring water can settle out of the water. A retention time of between 5 and 30 minutes should be used for the sizing of this chamber. Coarser materials require less than a minute to settle, however approximately 30 minutes is needed for silt particles. Since a scour is needed at the low point of the chamber to remove particles, the chamber floor must fall with a slope of at least 3% to the scour outlet. The outlet and overflow pipes are oversized to accommodate the maximum possible flow. A concrete roof must cover the intake chamber and the sediment chamber. A manhole must be situated in the roof of the sediment chamber to allow inspection and cleaning of this chamber.

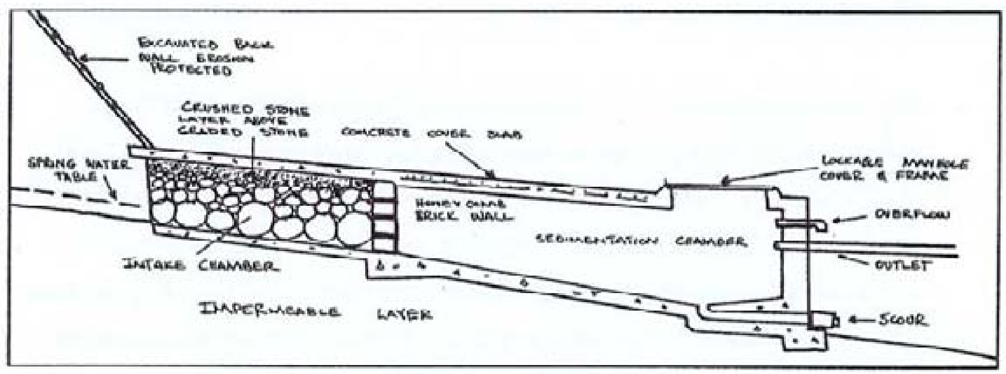


Figure 6.1 Spring box development (taken from Pearson *et al.*, 2003)

6.5.3 The spring catchment

There are two main differences between the spring catchment (Figure 6.2) and the spring box type of development.

The spring is excavated further into the hillside. After construction is complete, the ground above the intake chamber is backfilled.
The intake and sedimentation chambers are built as two separate structures, with the intake chamber located at the source.

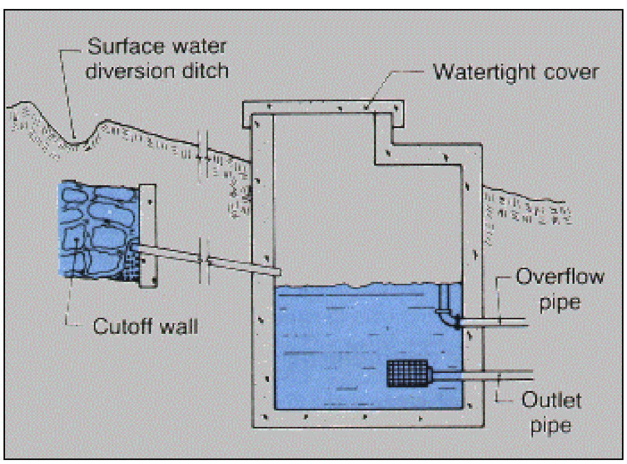
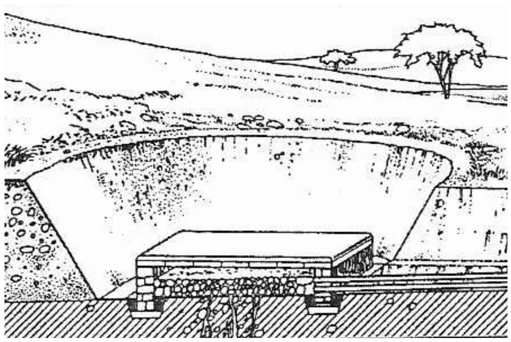


Figure 6.2 Spring catchment development (taken from Jennings, 2003)

6.5.4 Artesian spring development

Artesian spring development requires a watertight construction surrounding the source (Figure 6.3).



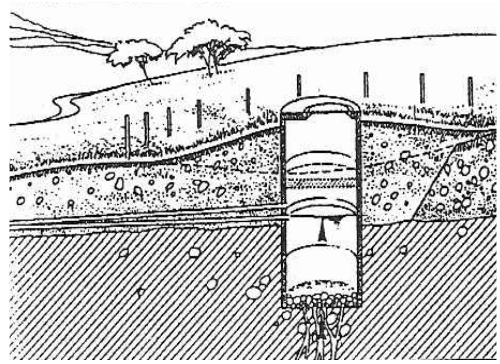


Figure 6.3 Artesian spring development (taken from Pearson *et al.*, 2003)

Table 6.9 lists the descriptors that can be used to document the information associated with the development of a spring.

Table 6.9 Spring development descriptors

Descriptor
Start and end date of spring development
Method of development: • Spring box • Spring catchment • Artesian • Other
Spring box method: • Dimensions of intake chamber • Slope of intake chamber floor • Floor material used for intake chamber • Type of filter pack used in intake chamber • Dimensions of sedimentation chamber • Slope of sedimentation chamber floor • Floor material used for sedimentation chamber • Scour, outlet and overflow pipe dimensions • Pipe material (e.g. uPVC, galvanised steel) • Position of pipes • Size and position of man hole • Distance between intake and sedimentation chamber* • Thickness of backfill*
Artesian method: • Dimensions of construction • Construction materials • Position of outlet and overflow pipes • Pipe material (eg uPVC, galvanised steel) • Outlet and overflow pipe dimensions

*Only in the case of spring catchments

7 GEOSITE AND AQUIFER TESTING DETAILS

7.1 Introduction

Test pumping is performed mainly on boreholes, and only seldom on dug wells. It is carried out to meet two main objectives:

Establish borehole yield potential, providing information on the optimum yield and hydraulic performance of individual water supply boreholes.
Establish aquifer yield potential, providing information on the hydraulic characteristics of the aquifer to determine the supply potential and sustainable yield of the groundwater system and characterise its flow pattern.

Analysis of test pumping data requires an appreciation of all the factors that can affect the drawdown. This appreciation comes mainly from a sound understanding of the aquifer, theory of groundwater movement and the practical aspects of conducting a pumping test. The analyst must be able to visualise the physical nature of the aquifer and how it deviates from the basic assumptions on which the various equations that describe the flow of groundwater under different circumstances to a pumping borehole are based. The limitations of these equations must always be kept in mind when analysing test pumping data. Difficulties experienced with analysing test pumping data, however, most commonly occur because of errors made in conducting the test or discrepancies in the recording of appropriate parameters. Test pumping standards should always be adhered to. These have been set out in the SANS (2003) document 10299-4 titled "Development, maintenance and management of groundwater resources — Part 4: Test-pumping of water boreholes".

7.2 Types of Test Pumping

Test pumping entails pumping a borehole at a known rate and recording the water level (and therefore the drawdown) in the pumped borehole as well as in any nearby observation borehole(s) at specific time intervals. Information derived from these measurements is applied in appropriate flow equations to calculate various hydraulic parameters. These parameters, together with a qualitative assessment of discharge-drawdown characteristics, are used in determining the sustainable yield of borehole(s) and the aquifer. In some cases, numerical modeling methods may also be effective in the analysis and interpretation of test pumping data. The parameters that need to be recorded and stored for the different types of pumping tests are explained in later paragraphs.

7.2.1 Step discharge (SD) test

This is often the first test carried out in a test pumping programme. It provides information on which the performance, measured in terms of hydraulic efficiency, of a borehole can be determined. It also assists in determining an appropriate pumping rate for a constant discharge test. This test is typically run for a minimum of 60 minutes per step, and a minimum of three steps is required to effect analysis of the data. Although the names 'step test' or 'step discharge test' is commonly used, technically the correct name is a 'Borehole Test'

7.2.2 Constant discharge (CD) test

This test is used to determine how much water an aquifer can yield on a long-term basis. The aquifer parameters transmissivity (T) and storativity (S) are determined from an analysis of this test data. The constant discharge test is carried out for the lengths of time given in Table 7.1 or as required by the project geohydrologist. Although the name 'constant yield test' is commonly used, technically the correct name is an 'Aquifer Test'

7.2.3 Recovery test

This entails the measurement of the recovering water level in the borehole after the pump is switched off. In the case of a step discharge test, recovery readings are collected after the last step of the test. Recovery measurements are obligatory under all circumstances of test pumping.

7.2.4 Extended step discharge test

Designed for application under circumstances where the expense of a constant discharge test is not warranted, but more information about the aquifer is needed than a step discharge test alone can provide, this test combines elements of the step discharge and the constant discharge test. The extended step discharge test is typically performed on boreholes that are intended to provide water for livestock or domestic use, or for boreholes that will be fitted with hand pumps. It can also be applied under circumstances where a lot of information is available for the aquifer and parameters only need to be verified.

7.2.5 Other tests

7.2.5.1 Interference test

This is not very common, and is carried out mainly on two or more boreholes in a well field when it is suspected that the drawdown patterns of boreholes will interfere with each other. The participating boreholes are pumped simultaneously at a known rate and the drawdown in the pumped and any observation holes is recorded.

7.2.5.2 Slug test

This is not a pumping test *per se*, and is normally performed on very low yielding boreholes. In this test a volume of water is either introduced to, removed from or displaced in the borehole, and the subsequent water level rise or decline measured/recorded and interpreted for an indication of aquifer transmissivity. Rudolph *et al* (1992) provide a detailed discussion regarding the use and interpretation of slug tests.

7.2.5.3 Calibration test

This is an abbreviated version of a step discharge test. A calibration test often validates or negates the need for further more comprehensive test pumping of whatever type.

7.3 Choice and Duration of Test

The type of test and its duration are selected to suit the level of water supply reliability required, which is a function of the water user's dependence on the borehole(s) and of the consequences (usually financial) of borehole failure (Weaver, 1995 and SANS, 2003). Thus, a borehole for watering livestock needs a much shorter duration test than a borehole for irrigation or industrial use. Table 7.1 gives recommendations regarding the type of test and its duration for various types of water use. These are minimum requirements and can be altered, if required, to suit a particular situation or to satisfy the requirements of the project geohydrologist.

Table 7.1 Types of borehole test and their minimum duration (Weaver 1995, SABS 1998)

Water Use Application	Type of Test	Duration
Livestock or domestic	Extended SD	4 x 1 hour 6 hours
Hand pump	Extended SD	4 x 1 hour 6 hours
Irrigation (Low cost consequence if failure occurs)	SD CD	4 x 1 hour 24 hours
Irrigation (High cost consequence if failure occurs)	SD CD	4 x 1 hour 48 hours or more
Engine-driven pump for rural village water supply	SD CD	4 x 1 hour 48 hours
Town/city water supply	SD CD	4 x 1 hour 72 hours or more
Factory (Water supply not critical to production)	SD CD	4 x 1 hour 48 hours
Factory (Water supply critical to production)	SD CD	4 x 1 hour 100 hours or more
Power station and similar water user	SD CD	4 x 1 hour 48 hours to 30 days
Key: CD = constant discharge test; SD = step discharge test		

Table 7.2 summarises the basic information that needs to be documented in order to characterise the type of hydraulic test.

Table 7.2 Borehole test descriptors

Descriptor
Type of test: • Constant discharge test • Recovery test • Step discharge test/Multi-rate test/Calibration test • Slug test • Interference test
Constant rate discharge and interference tests: • Distance to observation boreholes/wells • Pump inlet depth(s) • Discharge rate(s) • Time and change in water level (drawdown)
Recovery test: - Time and change in water level (recovery)
Step discharge/Multi-rate/Calibration tests: • Duration of step • Discharge rate of associated step • Number of steps • Time and change in water levels • Distance to observation boreholes/wells
Slug test:

Descriptor
• Volume of slug • Time and change in water levels

7.4 Data Collection

In order to effectively analyse the various features of a borehole, the data listed in Table 7.3 must be collected during test pumping. In addition, information pertaining to the test pumping contractor and the equipment used must also be captured. This includes the length of discharge hose used and where the water is discharged, e.g. into the veld or into a stream, etc. Further, observations such as discoloration of the water during testing, the information associated with aborted tests, etc. must also be captured.

Table 7.3 Data and associated units of measurement for a discharge test recording

Descriptor	Units of Measure
Start date and time of the test	ccyy-mm-dd and hh:mm
Water level measurement or drawdown + time or elapsed time	Meters below datum or static water level. Time interval as above or mm for elapsed time.
Rate of discharge + date and time of each measurement	Litres per second. Date and time as above.
Static water level + date and time	Metres below ground level (accurate to 2 decimals).
Depth of the borehole/dug well + date of measurement	Metres (accurate to 2 decimals).
Distance between pumped borehole/dug well and each observation borehole/well (if applicable)	Metres measured between borehole/dug well centres (accurate to 1 decimal).
Depth of pump inlet	Metres below ground level (accurate to 1 decimal).
Depth at which water was struck (already recorded)	Metres below ground level (accurate to 1 decimal).
Diameter of the borehole/dug well at surface (already recorded)	Millimetres (accurate to 3 decimals).
Diameter of the borehole/dug well at the pump inlet depth (already recorded)	Millimetres (accurate to 3 decimals).
Measurement of any rainfall that occurs during the test period	Millimetres and dates (ccyy-mm-dd)
Final recovered water level	Metres below ground level (accurate to 2 decimals).
Time after pumping stopped for the final recovered water level reading	(hh:mm)
Distance to all the respective observation boreholes and their respective referneces	Meters

7.5 Data Analysis

There are many techniques for analysing test pumping data, but these will not to be discussed here. Each of these methods has a set of conditions under which they apply. These are described in detail in Kruseman and de Ridder (1991). The FC-method (Van Tonder and Xu, 1999) is a recent spreadsheet-based technique developed locally.

Whatever the differences between the various methods, they all share the single common requirement that a proper understanding of the conceptual geohydrology is needed in order to decide which analytical method(s) is appropriate for the specific groundwater system. The ultimate objective of these analyses is to determine the aquifer transmissivity value and, if observation borehole data are available, the aquifer storage coefficient (or storativity). The method (e.g. Theis, Cooper-Jacob, FC, etc.) used and the values obtained must be recorded. Decriptors in this regard are given in Table 7.4.

Table 7.4 Test pumping data analysis results and units of measure

Descriptor	Unit of Measure
Analysis method	Name
Specific yield	%
Storage coefficient	Dimensionless
Transmissivity	m^2/day
Leakage factor	Dimensionless

Management recommendations made as a result of the test pumping data analysis are included in Chapter 9 of this document.

The following must be recorded when carrying out a pumping test:

- **Start date and time of the test (ccyy.mm.dd and hh.mm)**
- **Depth of the borehole (m)**
- **Distance to observations holes (m)**
- **Pump inlet depth (m)**
- **Groundwater features such as strike depths, fracturing**
- **Borehole diameters (mm)**
- **Static water level (m)**
- **Pumping rate (L/s)**
- **Time and drawdown**
- **Time and recovery**
- **Specific yield, transmissivity (if analysed)**
- **Data analysis method(s) applied**

8 IN-SITU GEOPHYSICAL LOGGING

Inspections carried out inside a borehole are sometimes required to obtain more detailed information about its construction and the geological/geohydrological environment. Such inspections may take the form of geophysical logging (Howard, 1990) that provides information on the various properties of the natural rock(s) intersected by a borehole. Such information typically derives from an interpretation of the geophysical data. Mechanical and visual tools (e.g. caliper arms, CCTV cameras) provide a more direct inspection method yielding information on fracture/joint zones, borehole diameter, etc. Cross-borehole correlation can provide more comprehensive information about the geohydrological makeup of a wellfield (Telford *et al.*, 1990). In addition, geophysical logging can assist in contamination studies (Daniels and Keys, 1991). If drilling mud has been used in the sinking of the borehole, then it is advisable to develop the borehole as fully as possible prior to logging. The types of geophysical logging technique, their application and the type of data that can be obtained are listed in Table 8.1.

Table 8.1 Borehole logging techniques (modified after Groundwater Consulting, 2000)

Method	Application	Data Collected	Applicable in a Cased Borehole
Caliper log	Location of collapse and fracture zones	Diameter of borehole, width of fractures	Yes
Resistivity (single point, normal, lateral)	Lithological interpretation (i.e. clay-sand contacts); water quality (TDS); porosity	**Resistivity of the formation**	No
Induction (conductivity logs)	Lithology, porosity, water quality	Conductivity of the formation	No
Spontaneous potential	Lithological contacts; permeability, water quality (formation water resistivity)	Natural electric potential	Yes
Gamma	Lithological interpretation (primarily clay-sand)	Natural radioactivity	Yes
Gamma-gamma (density)	Bulk density of formation; porosity	Backscatter radiation from source	Yes
Neutron	Total porosity under saturated conditions; lithology	Backscatter neutrons from source	Yes
Temperature	Vertical flow conditions	Temperature	Yes
Acoustic (sonic) interhole tomography	Interpretation of fracture patterns, perched water tables, quality of casing and grouting; porosity; lithology	Attenuation signal from acoustic source	Yes
CCTV/ Camera	Inspection of fractures, casing weld joints, perforations, clogging/incrustation, etc.	Video record	Yes

Every geophysical logging method has limitations and distortions and a combination of methods should be used to constrain the interpretation. The interpretation should be done by a trained geoscientist who has all relevant information at his disposal (Telford *et al.*, 1990). In terms of standard descriptors, it is required that the type(s) of method used as well as contact particulars of the person and company performing the logging be recorded.

Table 8.2 lists the more common methods.

Table 8.2 Borehole logging descriptors

Descriptor
Caliper log
Resistivity (single point, normal, lateral)
Spontaneous potential
Gamma
Gamma-gamma (density)
Neutron
Temperature
Acoustic (sonic)
CCTV/Camera
Logging company
Logging company telephone number
Person responsible for the logging
Report identification

Although the actual measurements are not stored at present, the availability of such data must be known. In future, if industry demands it, the actual data (i.e. depth and value/measurement) will be stored in electronic/digital format together with the recommendations arising from their interpretation.

The following must be recorded:

- Name and contact details of logging company
- Name and contact details of the person carrying out the logging
- Type of logging performed
- Actual depth-related measurement values – currently optional
- Relevant observations and recommendations

9 OPERATIONAL MANAGEMENT AND INSTALLED EQUIPMENT

9.1 Introduction

Ideally, an assessment of all relevant data recorded and information gleaned through various appropriate and suitable interpretations leads to recommendations regarding the sustainable utilisation and monitoring of either the borehole or the groundwater system that it exploits.

9.2 Abstraction Recommendations

The standards in this chapter address the recommendations for production pumping that are applicable to single boreholes due to be fitted with either hand pumps or motorised pumping equipment. These recommendations typically focus on suitable pumping equipment and the pump installation depth, appropriate duration of pumping (pumping or duty schedule) as hours per day required to ensure a sustainable daily abstraction and the target groundwater quality.

Borehole abstraction recommendations made without the benefit of test pumping data and analysis will have a very low level of confidence. An example of such recommendations are those based on blow yields measured during drilling operations. The scientific execution of a test pumping exercise, however, provides a wealth of information on the basis of which considered and sound recommendations regarding the responsible long term utilisation of the tested borehole and its supporting groundwater system can be made. A list of typical management recommendations and associated information is provided in Table 9.1.

Table 9.1 Production borehole operational recommendations

Descriptor	Unit of Measure
Pumping rate	m^3/d
Abstraction duration (duty cycle)	Hours per day
Recovery period (if applicable)	Hours per day
Production pump installation depth	Metres below surface
Maximum allowable water level drawdown	Metres below surface
Target water quality range (electrical conductivity)	mS/m
Extent of a borehole protection zone – up gradient	Metres from the borehole
Extent of a borehole protection zone – down gradient	Metres from the borehole

9.3 Monitoring Recommendations

It is very important to monitor the performance of a production borehole for at least a year after abstraction has started. Recommendations in this regard should also be stipulated. Typical monitoring recommendations are listed in Table 9.2.

Table 9.2 Monitoring recommendations

Descriptor	Unit of Measure
Borehole water levels (whilst pumping)	Daily/monthly/quarterly/annually
Period that monitoring is to be conducted	ccyy-mm-dd to ccyy-mm-dd
Daily abstraction rate	Yes / no
Pumping hours per day	Yes / no
Water quality (EC) and specific analysis	Specify parameters
Rainfall	Daily/monthly/quarterly/annually

The recording of actual monitoring results is discussed in Chapter 10.

9.4 Installed Equipment

An appropriate pump and associated pumping equipment is selected on the basis of the following information.

Borehole information including the depth and design (casing, screens, etc.).
Recommendations by the geohydrologist on sustainable yield, pumping duration, pumping schedule, depth of installation and expected pumping water level.
Altitude of the top of the borehole casing (mamsl).
Altitude of the location (end point) to which the water is to be pumped (mamsl).

A variety of pumps suited to specific conditions are used for pumping. These fall into the following three broad categories, based on their source of power.

- Natural energy, e.g. solar pumps and wind pumps.
- Manual energy, e.g. hand pumps, playground roundabout.
- Mechanical energy, e.g. electrical submersible pumps and positive displacement and turbine pumps driven from surface by petrol or diesel engines or electric motors.

Table 9.3 lists some of the relevant information that should be captured regarding borehole equipment and monitoring facilities.

Table 9.3 Borehole equipment and monitoring facilities

Descriptor
Installation date (ccyy-mm-dd)
Installers contact details
Installation type
Depth to pump intake (m)
Riser main material (steel, uPVC or flexible hosing)
Riser main nominal diameter (mm ID)
Type of power (see Table 9.4)
Pump motor power rating (kW)
Serial number of the pump
Suppliers contact details
Electrical meter number
Dipper tube present (Yes/No). If yes, then Dipper tube depth (m) Dipper tube nominal diameter (mm ID)
Equipped with water meter (Yes/No). If yes, then provide details regarding make, type, number, etc.

Table 9.4 provides a list of the most common pump types.

Table 9.4 Pump types

Descriptor
Positive displacement
Turbine
Submersible
Non-submersible (e.g. centrifugal)

Table 9.5 Energy source for borehole pumps

Descriptor
Electricity
Petrol/diesel
Wind
Sun
Hand

The following recommendations must be supplied to the design engineer and/or pump supplier:

- **Abstraction rate (m^3/d)**
- **Abstraction duration (hours per day)**
- **Pump installation depth**
- **Maximum allowable water level drawdown (metres below surface)**
- **Target water quality range (EC – mS/m)**
- **Extent of borehole protection zone**
- **Monitoring recommendations.**

10 GROUNDWATER MONITORING

It is envisaged that groundwater monitoring networks in South Africa will be classified on three levels (*pers comm.*, E. van Wyk, 2002).

10.1 National Monitoring (Level 1)

This level addresses the collection and analysis of groundwater data on a national scale to provide a reference/background for other measurements. The monitoring stations will be selected to represent ambient groundwater conditions that are not impacted by short-term fluctuations caused by human activity. This level of monitoring will measure the natural response of aquifers to the natural conditions over the long term and will be used for resource planning and management purposes. It will include both groundwater quantity and quality monitoring.

10.2 Catchment Monitoring (Level 2)

This level drills down to the monitoring of water resources on a catchment scale aimed at collecting appropriate data for the effective management of all relevant groundwater management units and their related water bodies. Monitoring at this level should include both quantity and quality determinations. Each Catchment Management Agency (CMA) must develop and implement a regional monitoring system for the important aquifers in the catchment, and which should be integrated with other relevant types of water resource monitoring to rationalise monitoring activities.

10.3 Local Monitoring (Level 3)

Project- and site-specific monitoring of potential human impacts on water resources and the compliance monitoring are addressed at this level. Examples of local groundwater monitoring include water quantity monitoring at individual production boreholes and water quality monitoring at point sources of pollution (e.g. waste disposal sites). Monitoring of aquifer response to abstraction and potential pollution on a local scale may be driven through conditions linked to licenses and permits. DWAF, as the central regulatory authority, will provide guidance regarding monitoring protocols and requirements, as well as audit monitoring undertaken at a local scale.

When developing a monitoring strategy, it is important that the purpose of monitoring be well defined and is communicated to those who need to support the monitoring actions. No data should be collected simply for the sake of populating databases. Monitoring can be an expensive exercise and can only have value if the information generated is useful for purposes such as the following.

- The protection, maintenance or restoration of resources.
- The protection of public health.
- The protection of ecosystem functioning.
- Quantifying the effectiveness of pollution prevention measures.
- Quantifying the effectiveness of remediation measures.
- Acting as an early warning system to avoid unnecessary future remediation.

The types of data collected during groundwater monitoring can usually be distinguished as follows.

- Data related to quantity
- Water levels (static or dynamic), flow rates, pumping rates and duration, and abstraction (daily, monthly, annually etc).

- Data related to quality
- Physical measurements (e.g. temperature, electrical conductivity)
- Chemical measurements (e.g. pH, alkalinity, species concentrations)
- Specialised measurements (e.g. stable isotope ratios).

The choice of what data to collect, particularly in the case of chemical variables where hundreds of different species could be analysed, can be:

Use-based

Select determinants which affect the fitness of the water for a particular use

Source-based

Select determinants or indicators which reflect the impact of known point and non-point sources in the area Use risk based prioritisation to select determinants which have the greatest risk of damaging human or ecosystem health

Resource-based

Select determinants that help to quantify various aspects of the behaviour of the aquifer and the relationship between these aspects.

Table 10.1 Variable monitoring parameters

Descriptor	Unit of Measure
Piezometric head (groundwater level)	Metres below ground level (positive value)
Pumping rate / injection rate	m^3/day, m^3/month, m^3/annum
Pumping durations	Hours
Precipitation over an area	Millimetres per day
Temperature	Degree Celsius
Electrical conductivity	milliSiemens/metre
PH	Unitless
Concentrations of chemical elements, ions and compounds (macro and trace elements)	Typically mg/L or μg/L
Stable and radioactive isotope concentrations	Variable, typically per mil (‰) and PMC, depending on the isotope.
Microbiological (bacteriological) variables	Variable, depending on the parameter, but typically a count per volume.

It is clear that there is a broad range of borehole monitoring data that can be collected, and it is important that the measurement units be kept consistent. Although it is not envisaged that all the data will be stored in the National Groundwater Archive (NGA), it is still important that the measurements include the date (ccyy-mm-dd) and time (hh:mm) that the different parameters were measured. In the case of laboratory-determined parameters, this will be the date and time that the water sample was collected, and not the date/time of its analysis.

11 CONCLUSION

With the many different groupings of people involved in groundwater development and utilisation, there is an associated diversity in the manner and means of recording borehole data and information.

This document provides a standardised basis for the reporting of the numerous activities, aspects and elements associated with a variety of geosites.

The advantages of using the "Standard Descriptors for Geosites" is that:

- Data acquisition strategy of DWAF will be enhanced.
- Data provided to DWAF will be standardised.
- Standardisation will facilitate the development of data capturing tools.
- Data will be more meaningful when down-loaded from the National Groundwater Archive (NGA) and thus enable improved data analysis.
- Standardisation will also facilitate the advancement of the National Groundwater Information System (NGIS) portfolio.

The challenge lies ahead for DWAF to encourage the adherence to these Standard Descriptors for Geosites and to improve the amount of data that is supplied to the National Groundwater Archive. This document provides the starting point for the meeting of the objectives of the DWAF data acquisition strategy.

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Jan Girman	DWAF
Helene Mullin	DWAF
Dziem Dziembowski	(Consultant)
Paul du Plessis	(GPM Consultants)
Phil Hobbs	(Consultant)

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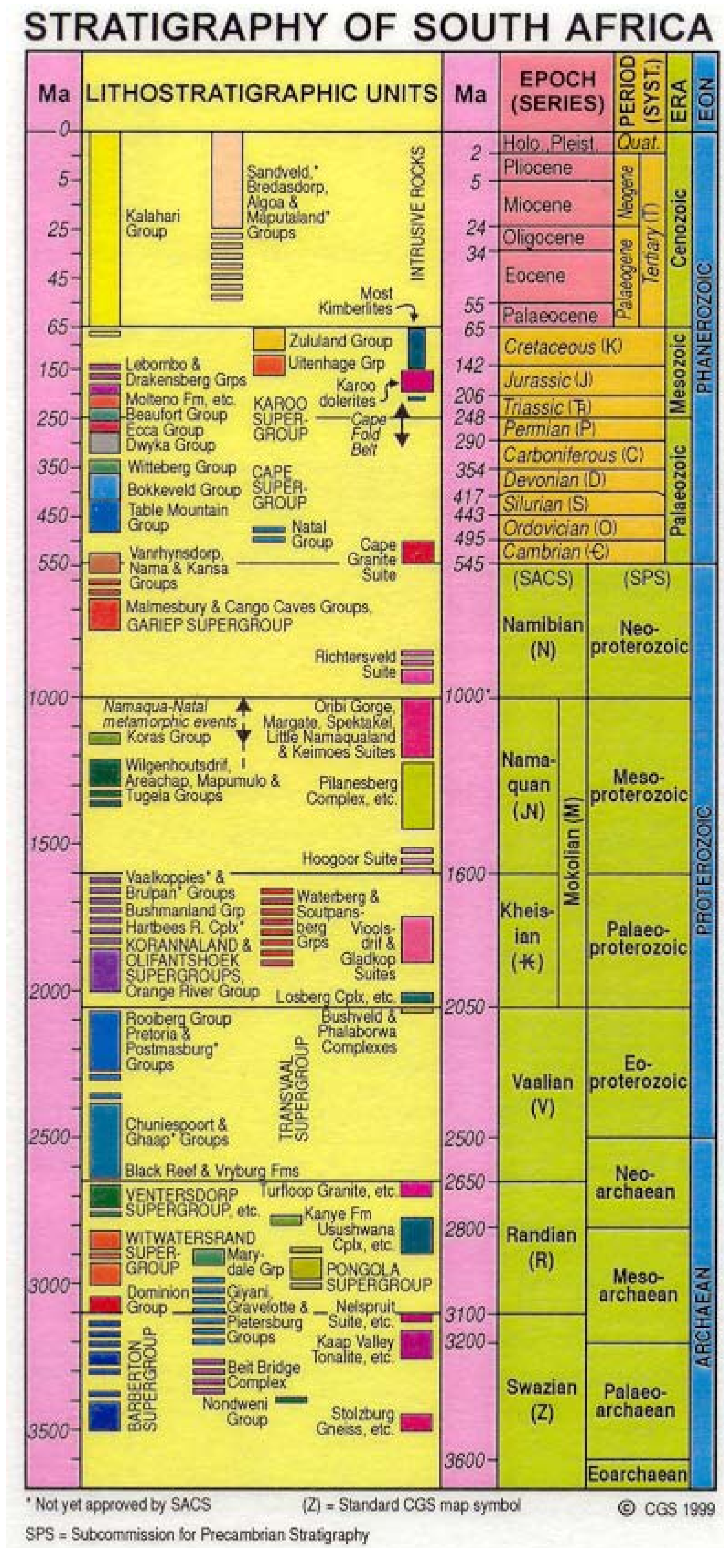
Appendix 1 – Stratigraphy of South Africa



Appendix 2 – Stratigraphic Classification: Main Categories and Unit (Rank) Terms

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STRATIGRAPHIC CLASSIFICATION: MAIN CATEGORIES AND UNIT (RANK) TERMS

Category	Unit (rank) term	Example (S. Africa)
Lithostratigraphic	Supergroup Group Subgroup Formation Member Bed Supersuite Suite Subsuite Complex	Witwatersrand West Rand Hospital Hill Parktown Observatory Contorted Rustenburg Zoetveld Bushveld
Biostratigraphic	Biozone (general) Range zones: Taxon range zone Concurrent range zone Abundance (acme) zone Assemblage zone Lineage zone Interval zone	 *Euskelosaurus* *Cistecephalus* *Lystrosaurus*
Chronostratigraphic (+ Geochronologic)	Eonothem (Eon) Erathem (Era) System (Period) Series (Epoch) Stage (Age) Chronozone (Chron)	Phanerozoic Cenozoic Tertiary Eocene Lutetian

Appendix 3 – Litho- and Chronostratigraphic units

ST = SACS approved status (AP = Approved by SACS; NY = Not yet approved; IF = Informal; NA = Not applicable - foreign country)
PUB = SACS publication status (LS = In Lithostratigraphic Series; Ca = In Catalogue; ID = Interim description (in Catalogue); IP = In press; MS = Manuscript received)
TG = Task group

Lithostratigraphy nomenclature changes periodically. An updated version of this table can be obtained from the CGS website at: http://www.geoscience.org.za/sacs/newlith.htm

CODE	LITHO NAME	RANK	LABEL	ST	PARENT NAME	RANK	CHRONO NAME	RANK	PUB
1448	Aandenk	Member	Raa	NY	Kimberley	Formation	Randian	Era	
1009	Aasvogelkop Gneiss	None	K*aa	NY	Vyfbeker Metamorphic	Suite	Kheisian	Sys	
413	Aasvoëlkop	Formation	K*as	AP	Matlabas	Subgroup	Kheisian	Sys	
408	Abbasas	Formation	K*ab	NY	Haib	Subgroup	Kheisian	Sys	
262	Abel Erasmus	Formation	Rab	AP	Wolkberg	Group	Randian	Era	MS
399	Abiekwa River	Formation	K*ai	AP	De Hoop	Subgroup	Kheisian	Sys	
1194	Abrahamskraal	Formation	Pab	AP	Adelaide	Subgroup	Permian	Sys	MS
870	Achab	Suite	N*ac	NY	*	*	Namaquan	Sys	
784	Addo	Member	Ka	AP	Sundays River	Formation	Cretaceous	Sys	
473	Adeisestad	Formation	N*ad	AP	Koras	Group	Namaquan	Sys	Ca
126	Adelaide	Subgroup	Pa	AP	Beaufort	Group	Permian	Sys	
540	Adolphspoort	Formation	Da	AP	Traka	Subgroup	Devonian	Sys	
1735	Afrikander	Formation	Raf	NY	Government	Subgroup	Randian	Era	
1729	Agatha	Formation	Rag	NY	Bivane	Subgroup	Randian	Era	
96	Aggeneys	Subgroup	K*ag	AP	Bushmanland	Group	Kheisian	Sys	
236	Alberton	Formation	Ral	AP	Klipriviersberg	Group	Randian	Era	
654	Alexander Bay	Formation	C^al	AP	*	*	Cenozoic	Era	
636	Alexandria	Formation	Ta	AP	Algoa	Group	Tertiary	Sys	LS
82	Algoa	Group	C^a	AP	*	*	Cenozoic	Era	Ca
665	Aliwal North	Formation	Qa	AP	*	*	Quaternary	Sys	
246	Allanridge	Formation	Ra	AP	Ventersdorp	Supergroup	Randian	Era	
1396	Alldays Gneiss	None	Zal	NY	Beit Bridge	Complex	Swazian	Era	MS
411	Alma	Formation	K*al	AP	Nylstroom	Subgroup	Kheisian	Sys	
390	Amam-Wes	Formation	K*am	NY	Khurisberg	Subgroup	Kheisian	Sys	
666	Amanzi	Formation	Qam	AP	*	*	Quaternary	Sys	
192	Amsterdam	Formation	Ram	AP	*	*	Randian	Era	
782	Amsterdamhoek	Member	Kam	AP	Sundays River	Formation	Cretaceous	Sys	
767	Andriesberg Conglomerate	Member	C*a	AP	Vaartwell	Formation	Cambrian	Sys	Ca
1694	Anhalt Granitoid	Suite	Za	AP	*	*	Swazian	Era	Ca
8	Areachap	Group	N*a	NY	*	*	Namaquan	Sys	
1022	Areb Gneiss	None	N*ab	AP	*	*	Namaquan	Sys	
1021	Aroams Gneiss	None	N*ar	AP	Little Namaqualand	Suite	Namaquan	Sys	
2038	Arondegas	Formation	Nar	NY	Knersvlakte	Subgroup	Namibian	Era	
47	Arribees	Group	K*a	NY	*	*	Kheisian	Sys	
653	Arries Drift	Formation	Tar	AP	*	*	Tertiary	Sys	
310	Asbestos Hills	Subgroup	Va	AP	Ghaap	Group	Vaalian	Era	
2150	Ashburton	Member	Pas	NY	Elandsvlei	Formation	Permian	Sys	
1697	Assegaai	Formation	Zas	AP	*	*	Swazian	Era	Ca
2033	Astynskloof	Formation	Nas	NY	Knersvlakte	Subgroup	Namibian	Era	
2040	Aties	Formation	Nat	NY	Gifberg	Group	Namibian	Era	
1087	Augrabies Granite/Gneiss	None	N*au	AP	*	*	Namaquan	Sys	Ca
210	Babrosco	Formation	Rba	NY	Jeppestown	Subgroup	Randian	Era	
989	Baderoukwe Granite	None	Rbd	AP	Vorster	Suite	Randian	Era	
1055	Bak River Granite	None	N*bak	NY	Eendoorn	Suite	Namaquan	Sys	
2207	Bakenskop Gneiss	None	N*bkk	NY	*	*	Namaquan	Sys	

CODE	LITHO NAME	RANK	LABEL	ST	PARENT NAME	RANK	CHRONO NAME	RANK	PUB
1109	Bakoondsvlei Granite	None	N*bv	NY	*	*	Namaquan	Sys	
575	Balfour	Formation	Pba	AP	Adelaide	Subgroup	Permian	Sys	
981	Balmoral Granite	None	Vba	AP	Lebowa Granite	Suite	Vaalian	Era	
1758	Banana Beach Gneiss	None	N*ba	AP	*	*	Namaquan	Sys	Ca
798	Bandelierkop	Complex	Zba	AP	*	*	Swazian	Era	
1757	Banke Granodiorite	None	N*ban	NY	Spektakel	Suite	Namaquan	Sys	
1051	Banks Vlei Gneiss	None	N*bav	NY	*	*	Namaquan	Sys	
1091	Bantamberg Granite	None	N*bat	NY	*	*	Namaquan	Sys	
1201	Barberskrans	Member	Pbb	AP	Balfour	Formation	Permian	Sys	
1	Barberton	Supergroup	Zb	AP	*	*	Swazian	Era	
740	Basehla	Member	K*ba	AP	Blouberg	Formation	Kheisian	Sys	
1106	Basjan Granite	None	N*bj	NY	*	*	Namaquan	Sys	
635	Bathurst	Formation	Tb	AP	Algoa	Group	Palaeogene	Sbsys	Ca
526	Baviaanskloof	Formation	Dba	AP	Nardouw	Subgroup	Devonian	Sys	LS
139	Baviaanskop	Formation	Zbv	AP	Moodies	Group	Swazian	Era	
1151	Baviaanskranz Granite	None	Vbv	AP	*	*	Vaalian	Era	MS
1163	Beacon Heights Tinguaite	None	N*bc	AP	Pilanesberg	Complex	Namaquan	Sys	
1756	Beatrix	Member	Rbe	NY	Kimberley	Formation	Randian	Era	
77	Beaufort	Group	P-TRb	AP	Karoo	Supergroup	Permian	Sys	
77	Beaufort	Group	P-TRb	AP	Karoo	Supergroup	Triassic	Sys	
2119	Beenbreek Gneiss	None	N*bn	NY	*	*	Namaquan	Sys	
797	Beit Bridge	Complex	Zbb	AP	*	*	Swazian	Era	
2172	Bellville	Formation	Tbe	NY	*	*	Cenozoic	Era	
135	Belvue Road	Formation	Zbe	AP	Fig Tree	Group	Swazian	Era	
629	Berea	Formation	Qbe	AP	*	*	Quaternary	Sys	
485	Berg River	Formation	Nbe	AP	Swartland	Subgroup	Namibian	Era	
2036	Besonderheid	Formation	Nbs	NY	Knersvlakte	Subgroup	Namibian	Era	
1047	Betadam Gabbronorite	None	N*bd	AP	*	*	Namaquan	Sys	Ca
1983	Bethel Dam Granite	None	N-C*b	AP	Cape Granite	Suite	Cambrian	Sys	Ca
1983	Bethel Dam Granite	None	N-C*b	AP	Cape Granite	Suite	Namibian	Era	Ca
368	Bethesda	Formation	N*be	AP	Areachap	Group	Namaquan	Sys	
693	Bevets Conglomerate	Member	Vbe	AP	Rooihoogte	Formation	Vaalian	Era	
1739	Beynespoort	Member	Vby	AP	Rayton	Formation	Vaalian	Era	
121	Bidouw	Subgroup	Dbi	AP	Bokkeveld	Group	Devonian	Sys	Ca
973	Bierkraal Magnetite Gabbro	None	Vbi	AP	Rustenburg Layered	Suite	Vaalian	Era	
1400	Biesiesfontein Granite	None	N*bi	NY	*	*	Namaquan	Sys	
1075	Biesiespoort Metagabbro	None	N*bs	NY	*	*	Namaquan	Sys	
50	Biesje Poort	Group	K*bi	NY	Korannaland	Supergroup	Kheisian	Sys	
2028	Biesjes Fontein	Suite	Tbf	NY	*	*	Cretaceous	Sys	
218	Bird	Member	Rbi	AP	Krugersdorp	Formation	Randian	Era	
102	Bitterfontein	Formation	Mbt	NY	Kamiesberg	Subgroup	Mokolian	Era	
164	Bivane	Subgroup	Rbv	AP	Nsuze	Group	Randian	Era	
700	Blaauwbank Shale	Member	Vbw	AP	Leeuwpoort	Formation	Vaalian	Era	
273	Black Reef	Formation	Vbr	AP	Transvaal	Supergroup	Vaalian	Era	
2117	Bladgrond South Gneiss	None	N*bls	NY	*	*	Namaquan	Sys	
2222	Blanco	None	C*bl	NY	Cape Granite	Suite	Cambrian	Sys	
1049	Blauwbosch Granite	None	N*bw	AP	*	*	Namaquan	Sys	Ca
866	Bleskop	Suite	N*bl	NY	*	*	Namaquan	Sys	
1225	Blinkberg	Member	Dbb	AP	Weltevrede	Formation	Devonian	Sys	
543	Blinkberg	Formation	Dbl	AP	Weltevrede	Subgroup	Devonian	Sys	
272	Bloempoort	Formation	Rbp	AP	Transvaal	Supergroup	Randian	Era	MS
2046	Blompoort Granite	None	N*bt	NY	Spektakel	Suite	Namaquan	Sys	
424	Blouberg	Formation	K*bl	AP	*	*	Kheisian	Sys	
761	Bloubergstrand	Member	Nbl	AP	Tygerberg	Formation	Namibian	Era	
2045	Bloukop Granite	None	N*bk	NY	Spektakel	Suite	Namaquan	Sys	
2039	Bloupoort	Formation	Nbp	NY	Gifberg	Group	Namibian	Era	
649	Bluewater Bay	Formation	C^bl	AP	*	*	Cenozoic	Era	LS
626	Bluff	Formation	Qb	AP	*	*	Quaternary	Sys	
1401	Blyvooruitzicht	Formation	Rbl	NY	Johannesburg	Subgroup	Randian	Era	
983	Bobbejaankop Granite	None	Vbb	AP	Lebowa Granite	Suite	Vaalian	Era	
731	Boegoeberg	Member	K*bg	AP	Groblershoop	Formation	Kheisian	Sys	
475	Boegoeberg Dam	Formation	K*bb	NY	Olifantshoek	Supergroup	Kheisian	Sys	

CODE	LITHO NAME	RANK	LABEL	ST	PARENT NAME	RANK	CHRONO NAME	RANK	PUB
2054	Boegoekom	Formation	Mbm	NY	Kamiesberg	Subgroup	Mokolian	Era	
406	Boerputs	Formation	K*be	NY	Haib	Subgroup	Kheisian	Sys	
912	Boesmanskop Syenite	None	Zbo	AP	*	*	Swazian	Era	
345	Bok-Se-Puts	Formation	K*bp	NY	Koelmanskop Metamorphic	Suite	Kheisian	Sys	
72	Bokkeveld	Group	Db	AP	Cape	Supergroup	Devonian	Sys	Ca
112	Boland	Subgroup	Nb	AP	Malmesbury	Group	Namibian	Era	
160	Bomvu	Formation	Rbm	AP	Nsuze	Group	Randian	Era	
204	Bonanza	Formation	Rbn	NY	Government	Subgroup	Randian	Era	
1781	Bongaspoort	Formation	Rbg	NY	Nkoneni	Subgroup	Randian	Era	
464	Boom River	Formation	N*bm	AP	Koras	Group	Namaquan	Sys	Ca
704	Boomplaas	Formation	Vbp	AP	Schmidtsdrif	Subgroup	Vaalian	Era	
226	Booysens	Formation	Rbo	AP	Johannesburg	Subgroup	Randian	Era	
441	Bope	Formation	N*bp	AP	Mfongosi	Group	Namaquan	Sys	
533	Boplaas	Formation	Dbo	AP	Ceres	Subgroup	Devonian	Sys	LS
601	Bosbokpoort	Formation	TRbo	AP	Karoo	Supergroup	Triassic	Sys	
699	Boschoffsberg Quartzite	Member	Vbs	AP	Leeuwpoort	Formation	Vaalian	Era	
283	Boshoek	Formation	Vbo	AP	Pretoria	Group	Vaalian	Era	
338	Bossiekom	Formation	K*bo	NY	Kamiesberg	Subgroup	Kheisian	Sys	
465	Bossienek	Formation	N*bo	AP	Koras	Group	Namaquan	Sys	Ca
2168	Botterberg Granodiorite	None	N/C*bo	NY	Cape Granite	Suite	Cambrian	Sys	
2168	Botterberg Granodiorite	None	N/C*bo	NY	Cape Granite	Suite	Namibian	Era	
245	Bothaville	Formation	Rbt	AP	Ventersdorp	Supergroup	Randian	Era	
1036	Boudbytkop Syenite	None	N*by	NY	*	*	Namaquan	Sys	
1058	Boven Rugzeer Granite	None	N*bg	NY	Keimoes	Suite	Namaquan	Sys	
696	Boven Shale	Member	Vbn	AP	Silverton	Formation	Vaalian	Era	
1038	Brakbos Biotite Granite	None	N*bb	AP	Keimoes	Suite	Namaquan	Sys	
765	Brakkerivier	Member	Nbk	AP	Groenefontein	Formation	Namibian	Era	Ca
854	Brakwater Metamorphic	Suite	K*br	NY	*	*	Kheisian	Sys	
1018	Brandewynsbank Gneiss	None	K*bw	AP	Gladkop	Suite	Kheisian	Sys	
1680	Brandkop	Subgroup	C*b	NY	Vanrhynsdorp	Group	Cambrian	Sys	
1353	Brandwacht	Formation	Nbr	AP	Boland	Subgroup	Namibian	Era	
2019	Brazil Granite	None	N*bz	NY	Goraap	Suite	Namaquan	Sys	
509	Breckhorn	Formation	Nbh	AP	Fish River	Subgroup	Namibian	Era	
83	Bredasdorp	Group	C^b	AP	*	*	Cenozoic	Era	Ca
616	Brenton	Formation	J-Kbr	AP	*	*	Cretaceous	Sys	
616	Brenton	Formation	J-Kbr	AP	*	*	Jurassic	Sys	
1984	Bretagne Granite	None	C*br	AP	Cape Granite	Suite	Cambrian	Sys	Ca
482	Bridgetown	Formation	Nbi	AP	Malmesbury	Group	Namibian	Era	
774	Britskraal	Member	Pbr	AP	Waterford	Formation	Permian	Sys	Ca
198	Brixton	Formation	Rbr	AP	Hospital Hill	Subgroup	Randian	Era	
324	Brulkolk	Formation	K*bk	NY	*	*	Kheisian	Sys	
52	Brulpan	Group	K*bu	NY	*	*	Kheisian	Sys	
320	Brulsand	Subgroup	K*bs	AP	Volop	Group	Kheisian	Sys	
1059	Brussel Granite	None	N*br	NY	Keimoes	Suite	Namaquan	Sys	
658	Budin	Formation	Tbu	AP	Kalahari	Group	Tertiary	Sys	
1740	Buffels River	Member	Pbu	AP	Collingham	Formation	Permian	Sys	LS
1759	Buffels River Granite	None	N*bf	NY	Little Namaqualand	Suite	Namaquan	Sys	
37	Buffelsfontein	Group	Rb	AP	Transvaal	Supergroup	Randian	Era	
613	Buffelskloof	Formation	Kb	NY	Uitenhage	Group	Cretaceous	Sys	
1672	Buffelskraal	Complex	N*bu	NY	*	*	Namaquan	Sys	
1123	Buhleni Gneiss	None	N*bh	AP	*	*	Namaquan	Sys	
924	Bulai Gneiss	None	Rbu	AP	Beit Bridge	Complex	Randian	Era	
811	Bulls Run	Complex	N*b	AP	*	*	Namaquan	Sys	Ca
833	Bumbeni	Complex	Jb	AP	*	*	Jurassic	Sys	
577	Burgersdorp	Formation	TRb	AP	Tarkastad	Subgroup	Triassic	Sys	Ca
2220	Burtons Puts Granite	None	N*bur	NY	*	*	Namaquan	Sys	
54	Bushmanland	Group	K*b	AP	*	*	Kheisian	Sys	
806	Bushveld	Complex	Vb	AP	*	*	Vaalian	Era	
2200	Button's Kop	Member	Rbk	NY	Selati	Formation	Randian	Era	
2123	Bysteek	Formation	K*by	NY	Arribees	Group	Kheisian	Sys	
380	Cammas	Formation	K*ca	NY	Pella	Subgroup	Kheisian	Sys	
1685	Campbell Rand	Subgroup	Vca	NY	Ghaap	Group	Vaalian	Era	
1985	Cango Caves	Group	Nc	AP	*	*	Namibian	Era	Ca

CODE	LITHO NAME	RANK	LABEL	ST	PARENT NAME	RANK	CHRONO NAME	RANK	PUB
12	Cape	Supergroup	O-Cc	AP	*	*	Carboniferous	Sys	
12	Cape	Supergroup	O-Cc	AP	*	*	Devonian	Sys	
12	Cape	Supergroup	O-Cc	AP	*	*	Ordovician	Sys	
12	Cape	Supergroup	O-Cc	AP	*	*	Silurian	Sys	
2174	Cape Columbine Granite	None	C*cc	AP	Cape Granite	Suite	Cambrian	Sys	
652	Cape Flats	Formation	Qc	AP	*	*	Quaternary	Sys	
887	Cape Granite	Suite	N-C*c	AP	*	*	Cambrian	Sys	
887	Cape Granite	Suite	N-C*c	AP	*	*	Namibian	Era	
2084	Cape Peninsula Pluton	Pluton	N-C*cp	IF	Cape Granite	Suite	Cambrian	Sys	
2084	Cape Peninsula Pluton	Pluton	N-C*cp	IF	Cape Granite	Suite	Namibian	Era	
677	Cascade	Member	Rca	AP	Ntombe	Formation	Randian	Era	
786	Cave Rock Calcarenite	Member	Qca	AP	Bluff	Formation	Pleistocene	Ser	
522	Cedarberg	Formation	Oc	AP	Table Mountain	Group	Ordovician	Sys	
29	Central Rand	Group	Rc	AP	Witwatersrand	Supergroup	Randian	Era	
120	Ceres	Subgroup	Dc	AP	Bokkeveld	Group	Devonian	Sys	Ca
1170	Chakise Foyaiite	None	N*ch	NY	Pilanesberg	Complex	Namaquan	Sys	
163	Chobeni	Formation	Rch	AP	Nsuze	Group	Randian	Era	
463	Christiana	Formation	N*c	AP	Koras	Group	Namaquan	Sys	Ca
39	Chuniespoort	Group	Vch	AP	Transvaal	Supergroup	Vaalian	Era	
1184	Citruspoort Granite	None	N/C*c	NY	Cape Granite	Suite	Cambrian	Sys	MS
1184	Citruspoort Granite	None	N/C*c	NY	Cape Granite	Suite	Namibian	Era	MS
952	Clapham Bronzitite	None	Vcp	AP	Croydon	Subsuite	Vaalian	Era	
586	Clarens	Formation	Jc	AP	Karoo	Supergroup	Jurassic	Sys	MS
705	Clearwater	Formation	Vcl	NY	Schmidtsdrif	Subgroup	Vaalian	Era	
415	Cleremont	Formation	K*c	AP	Kransberg	Subgroup	Kheisian	Sys	
137	Clutha	Formation	Zc	AP	Moodies	Group	Swazian	Era	
904	Cnydas	Subsuite	N*cn	NY	Keimoes	Suite	Namaquan	Sys	
1093	Coboop Granite/Gneiss	None	K*cb	NY	*	*	Kheisian	Sys	
608	Coerney	Formation	Jco	AP	Suurberg	Group	Jurassic	Sys	Ca
781	Colchester Shale	Member	Jcl	AP	Kirkwood	Formation	Jurassic	Sys	
560	Collingham	Formation	Pc	AP	Ecca	Group	Permian	Sys	LS
346	Collinskop	Formation	K*co	NY	Koelmanskop Metamorphic	Suite	Kheisian	Sys	
1027	Colston Granite	None	N*co	AP	Keimoes	Suite	Namaquan	Sys	Ca
1695	Commondale	Formation	Zco	AP	*	*	Swazian	Era	Ca
1042	Concordia Granite	None	N*cc	AP	Spektakel	Suite	Namaquan	Sys	
1686	Constantia	Suite	Rcn	NY	*	*	Randian	Era	
790	Contorted	Bed	Rct	AP	Parktown	Formation	Randian	Era	
606	Cooeyana	Formation	Jcy	AP	*	*	Jurassic	Sys	
668	Cornelia	Formation	Qco	AP	*	*	Quaternary	Sys	
202	Coronation	Formation	Rco	AP	Government	Subgroup	Randian	Era	
1290	Critical	Zone	Vc	IF	Rustenburg Layered	Suite	Vaalian	Era	
207	Crown	Formation	Rcr	AP	Jeppestown	Subgroup	Randian	Era	
896	Croydon	Subsuite	Vcr	NY	Rustenburg Layered	Suite	Vaalian	Era	
926	Cunning Moor Tonalite	None	Rcu	AP	*	*	Randian	Era	Ca
1052	Curries Camp Gneiss	None	N*cu	NY	*	*	Namaquan	Sys	
1317	Cyferfontein	Formation	Vcy	AP	Makeckaan	Subgroup	Vaalian	Era	Ca
378	Dabenoris	Formation	K*db	NY	Pella	Subgroup	Kheisian	Sys	
1056	Daberas Granodiorite	None	N*da	NY	Eendoorn	Suite	Namaquan	Sys	
1726	Dabie River	Formation	Ndr	NY	Hilda	Subgroup	Namibian	Era	IP
2007	Dabis	Formation	Nd	AP	Kuibis	Subgroup	Namibian	Era	
361	Dagbreek	Formation	K*da	AP	Vaalkoppies	Group	Kheisian	Sys	
1200	Daggaboersnek	Member	Pd	AP	Balfour	Formation	Permian	Sys	
911	Dalmein Granodiorite	None	Zda	AP	*	*	Swazian	Era	
300	Damwal	Formation	Vdm	AP	Rooiberg	Group	Vaalian	Era	
711	Daniëlskuil	Formation	Vd	AP	Asbestos Hills	Subgroup	Vaalian	Era	
2089	Darling Batholith	Batholith	N-C*d	IF	Cape Granite	Suite	Cambrian	Sys	
2089	Darling Batholith	Batholith	N-C*d	IF	Cape Granite	Suite	Namibian	Era	
287	Daspoort	Formation	Vdp	AP	Pretoria	Group	Vaalian	Era	
1183	Dassen Heuwel Aplogranite	None	N/C*d	NY	Cape Granite	Suite	Cambrian	Sys	MS
1183	Dassen Heuwel Aplogranite	None	N/C*d	NY	Cape Granite	Suite	Namibian	Era	MS
1751	Dassenhoek	Member	Oda	AP	Durban	Formation	Ordovician	Sys	LS

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2171	Dassen Island Granite	None	N/C*di	NY	Cape Granite	Suite	Cambrian	Sys	
2171	Dassen Island Granite	None	N/C*di	NY	Cape Granite	Suite	Namibian	Era	
1105	De Bakken Granite	None	N*db	NY	*	*	Namaquan	Sys	
1006	De Banken Gneiss	None	K*de	NY	Brakwater Metamorphic	Suite	Kheisian	Sys	
2120	De Bome Gneiss	None	K*do	NY	Koelmanskop Metamorphic	Suite	Kheisian	Sys	
107	De Hoop	Subgroup	K*dh	AP	Orange River	Group	Kheisian	Sys	
641	De Hoopvlei	Formation	Td	AP	Bredasdorp	Group	Pliocene	Ser	LS
1696	De Kraalen	Formation	Zd	AP	*	*	Swazian	Era	Ca
48	De Kruis	Group	K*dk	NY	*	*	Kheisian	Sys	
1784	Delfkom	Formation	Rdf	NY	Odwaleni	Subgroup	Randian	Era	
271	Dennilton	Formation	Rde	AP	*	*	Randian	Era	MS
679	Denny Dalton Conglomerate	Member	Rdd	AP	Sinqeni	Formation	Randian	Era	
1154	Derdepoort Carbonatite	None	N*de	AP	Pienaars River	Complex	Namaquan	Sys	
2196	Diazville	Member	Tdi	NY	Langebaan	Formation	Pliocene	Ser	
2018	Dikgat Granite	None	N*dk	NY	Goraap	Suite	Namaquan	Sys	
1121	Dimane Granite	None	N*dm	AP	*	*	Namaquan	Sys	
436	Dinuntuli	Formation	N*di	AP	Mfongosi	Group	Namaquan	Sys	
552	Dirkskraal	Formation	Cd	AP	Kommadagga	Subgroup	Carboniferous	Sys	
169	Dlabe	Formation	Rdl	AP	Nsuze	Group	Randian	Era	
432	Dlolwana	Formation	N*dl	AP	Ntingwe	Group	Namaquan	Sys	
2034	Dolkraals	Formation	Ndo	NY	Knersvlakte	Subgroup	Namibian	Era	
27	Dominion	Group	Rd	AP	*	*	Randian	Era	
445	Dondwana	Formation	N*d	AP	Tugela	Group	Namaquan	Sys	
1054	Donkieboud Granite	None	N*do	NY	Eendoorn	Suite	Namaquan	Sys	
89	Doornfontein	Subgroup	Rdo	AP	Marydale	Group	Randian	Era	
918	Doornhoek Trondhjemite	None	Zdo	AP	*	*	Swazian	Era	Ca
227	Doornkop Quartzite	Member	Rdk	AP	Booysens	Formation	Randian	Era	
796	Doradale	Formation	Vdo	AP	Koegas	Subgroup	Vaalian	Era	
925	Draghoender Granite/Gneiss	None	Rdr	NY	*	*	Randian	Era	
587	Drakensberg	Group	Jdr	AP	Karoo	Supergroup	Jurassic	Sys	
341	Dreyer's Put	Formation	K*dy	NY	Vyfbeker Metamorphic	Suite	Kheisian	Sys	
339	Driehoek	Formation	K*di	NY	Vyfbeker Metamorphic	Suite	Kheisian	Sys	
583	Driekoppen	Formation	TRd	NY	Tarkastad	Subgroup	Triassic	Sys	
46	Droëboom	Group	K*d	NY	*	*	Kheisian	Sys	
327	Droëgrond	Formation	K*dr	NY	Droëboom	Group	Kheisian	Sys	
2043	Droëkraal Amphibolite	None	N*dr	NY	*	*	Namaquan	Sys	
975	Drummondlea Harzburgite-Chromitite	None	Vdr	NY	Zoetveld	Subsuite	Vaalian	Era	MS
898	Dsjate	Subsuite	Vdj	NY	Rustenburg Layered	Suite	Vaalian	Era	
280	Duitschland	Formation	Vdu	AP	Chuniespoort	Group	Vaalian	Era	
296	Dullstroom	Formation	Vdl	AP	Pretoria	Group	Vaalian	Era	
446	Dulumbe	Formation	N*du	AP	Tugela	Group	Namaquan	Sys	
1723	Durban	Formation	Od	AP	Natal	Group	Ordovician	Sys	LS
1062	Dwaalgees Granite	None	N*dw	NY	Keimoes	Suite	Namaquan	Sys	
285	Dwaalheuwel	Formation	Vdw	AP	Pretoria	Group	Vaalian	Era	LS
1683	Dwaalhoek	Subgroup	Rdw	NY	Mozaan	Group	Randian	Era	
2143	Dwalile	Formation	Zdw	NA	*	*	Swazian	Era	
897	Dwars River	Subsuite	Vds	NY	Rustenburg Layered	Suite	Vaalian	Era	
1673	Dwarsfontein	Complex	K*dw	NY	*	*	Kheisian	Sys	
75	Dwyka	Group	C-Pd	AP	Karoo	Supergroup	Carboniferous	Sys	Ca
75	Dwyka	Group	C-Pd	AP	Karoo	Supergroup	Permian	Sys	Ca
1083	Dyasons Klip Gneiss	None	N*dy	NY	*	*	Namaquan	Sys	
689	Earls Court	Member	Rea	NY	Kimberley	Formation	Randian	Era	
76	Ecca	Group	Pe	AP	Karoo	Supergroup	Permian	Sys	
277	Eccles	Formation	Ve	AP	Malmani	Subgroup	Vaalian	Era	
659	Eden	Formation	Te	AP	Kalahari	Group	Tertiary	Sys	
240	Edenville	Formation	Red	AP	Klipriviersberg	Group	Randian	Era	

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864	Eendoorn	Suite	N*ee	NY	*	*	Namaquan	Sys	
1720	Eendragtpan	Formation	TRee	NY	Karoo	Supergroup	Triassic	Sys	
966	Eerlyk Bronzitite	None	Vee	AP	Vlakfontein	Subsuite	Vaalian	Era	
149	Eersteling	Formation	Ze	AP	Pietersburg	Group	Swazian	Era	
370	Eierdoppan	Formation	N*ei	AP	Areachap	Group	Namaquan	Sys	
852	Eiland	Suite	Rei	NY	*	*	Randian	Era	
1202	Elandsberg	Member	Pel	AP	Balfour	Formation	Permian	Sys	
2205	Elandsfontyn	Formation	Tel	NY	Sandveld	Group	Miocene	Ser	
1213	Elandslaagte	Formation	Rel	NY	Government	Subgroup	Randian	Era	
1986	Elandsvlei	Formation	C-Pe	NY	Dwyka	Group	Carboniferous	Sys	MS
1986	Elandsvlei	Formation	C-Pe	NY	Dwyka	Group	Permian	Sys	MS
723	Ellie's Rust	Formation	K*e	AP	Matsap	Subgroup	Kheisian	Sys	
585	Elliot	Formation	TRe	AP	Karoo	Supergroup	Triassic	Sys	
229	Elsburg	Formation	Re	AP	Turffontein	Subgroup	Randian	Era	
1057	Elsie Se Gorra Granite	None	N*el	NY	Keimoes	Suite	Namaquan	Sys	
588	Emakwezini	Formation	Pem	AP	Beaufort	Group	Permian	Sys	
836	Empangeni Metamorphic	Suite	Zem	NY	*	*	Swazian	Era	
450	Endlovini	Formation	N*en	NY	Tugela	Group	Namaquan	Sys	
610	Enon	Formation	Je	AP	Uitenhage	Group	Jurassic	Sys	
788	Enqhura	Member	Qen	AP	Amanzi	Formation	Pleistocene	Ser	
1003	Entabeni Granite	None	Ven	NY	*	*	Vaalian	Era	
877	Equeefa	Suite	N*e	AP	*	*	Namaquan	Sys	Ca
553	Eshowe	Member	Oe	AP	Durban	Formation	Ordovician	Sys	LS
469	Ezelfontein	Formation	N*ez	AP	Koras	Group	Namaquan	Sys	Ca
708	Fairfield	Formation	Vfa	AP	Campbell Rand	Subgroup	Vaalian	Era	
787	False Bay Coral Limestone	Member	Qfa	AP	Bluff	Formation	Quaternary	Sys	
604	Fenda	Formation	Jf	AP	Bumbeni	Complex	Jurassic	Sys	
154	Ferndale	Formation	Zfe	AP	Kraaipan	Group	Swazian	Era	
17	Fig Tree	Group	Zf	AP	Barberton	Supergroup	Swazian	Era	
118	Fish River	Subgroup	C*f	AP	Nama	Group	Cambrian	Sys	
512	Flaminkberg	Formation	Nfl	AP	Vanrhynsdorp	Group	Namibian	Era	LS
664	Florisbad	Formation	Qf	AP	*	*	Pleistocene	Ser	
547	Floriskraal	Formation	Cf	AP	Lake Mentz	Subgroup	Carboniferous	Sys	
562	Fort Brown	Formation	Pf	AP	Ecca	Group	Permian	Sys	
484	Franschhoek	Formation	Nfr	AP	Malmesbury	Group	Namibian	Era	
1155	Franspoort Foyaite	None	N*fr	AP	Pienaars River	Complex	Namaquan	Sys	
838	Free State Diorite	Suite	Rf	AP	Rooiwater	Complex	Randian	Era	
1034	Friersdale Charnockite	None	N*f	AP	Keimoes	Suite	Namaquan	Sys	
598	Fripp	Formation	Pfr	AP	Karoo	Supergroup	Permian	Sys	
278	Frisco	Formation	Vfr	AP	Malmani	Subgroup	Vaalian	Era	
722	Fuller	Formation	K*fu	AP	Matsap	Subgroup	Kheisian	Sys	
429	Fundudzi	Formation	K*f	AP	Soutpansberg	Group	Kheisian	Sys	
2024	Gaarseep Gneiss	None	K*gs	NY	Vioolsdrif	Suite	Kheisian	Sys	
2214	Gabaip Granite	None	N*gb	NY	*	*	Namaquan	Sys	
1782	Gabela	Formation	Rgb	NY	Nkoneni	Subgroup	Randian	Era	
990	Gaborone Granite	Suite	Rga	AP	*	*	Randian	Era	
2103	Gais	Member	Ngs	NY	Grootderm	Formation	Namibian	Era	IP
2213	Galputs Gneiss	None	N*gu	NY	*	*	Namaquan	Sys	
312	Gamagara	Formation	Vgm	AP	Olifantshoek	Supergroup	Vaalian	Era	
529	Gamka	Formation	Dga	AP	Ceres	Subgroup	Devonian	Sys	LS
894	Gamoep Melilitite	Suite	Tga	AP	*	*	Palaeocene	Ser	
792	Gamohaan	Formation	Vga	AP	Campbell Rand	Subgroup	Vaalian	Era	
375	Gams	Formation	K*ga	AP	Aggeneys	Subgroup	Kheisian	Sys	
67	Gamtoos	Group	Nga	AP	*	*	Namibian	Era	Ca
2037	Gannabos	Formation	Ngb	NY	Knersvlakte	Subgroup	Namibian	Era	
889	Gannakouriep	Suite	Ngn	AP	*	*	Namibian	Era	
357	Ganzenmond	Formation	K*gz	NY	Biesje Poort	Group	Kheisian	Sys	
2125	Gareskop	Suite	N*gs	NY	*	*	Namaquan	Sys	
692	Garfield	Member	Rgr	AP	Rietgat	Formation	Randian	Era	
832	Gariep	Supergroup	Ng	AP	*	*	Namibian	Era	IP
453	Gazeni	Formation	N*ga	AP	Tugela	Group	Namaquan	Sys	
1208	Geelbeksdam	Member	Vge	AP	Vryburg	Formation	Vaalian	Era	LS
86	Geluk	Subgroup	Zge	AP	Onverwacht	Group	Swazian	Era	

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1071	Gemsbokbult Granite	None	N*ge	NY	Keimoes	Suite	Namaquan	Sys	
2208	Gemsbokvlakte Gneiss	None	N*gv	NY	*	*	Namaquan	Sys	
2097	George Batholith	Batholith	N-C*g	IF	Cape Granite	Suite	Cambrian	Sys	
2097	George Batholith	Batholith	N-C*g	IF	Cape Granite	Suite	Namibian	Era	
376	Geselskapbank	Formation	K*ge	AP	*	*	Kheisian	Sys	Ca
2203	Geyser Granite	None	Rgy	AP	*	*	Randian	Era	
495	Gezwinds Kraal	Formation	C*g	AP	Kansa	Group	Cambrian	Sys	Ca
1678	Ghaap	Group	Vg	NY	Transvaal	Supergroup	Vaalian	Era	
1760	Gif Berg Granite	None	N*gi	NY	Keimoes	Suite	Namaquan	Sys	
511	Gifberg	Group	Ngi	NY	Gariep	Supergroup	Namibian	Era	
20	Giyani	Group	Zgi	AP	*	*	Swazian	Era	
858	Gladkop	Suite	K*gk	AP	*	*	Kheisian	Sys	
760	Glen Heatlie	Member	Ngl	AP	Porterville	Formation	Namibian	Era	
724	Glen Lyon	Formation	K*gl	AP	Matsap	Subgroup	Kheisian	Sys	
1136	Glenmore Granite	None	N*gl	AP	*	*	Namaquan	Sys	Ca
816	Glenover Carbonatite	Complex	N*g	AP	*	*	Namaquan	Sys	
305	Glentig	Formation	Vgl	AP	Transvaal	Supergroup	Vaalian	Era	
681	Gobosha Dacite	Member	Rgs	AP	Amsterdam	Formation	Randian	Era	
260	Godwan	Formation	Rgo	AP	Transvaal	Supergroup	Randian	Era	
359	Goede Hoop	Formation	K*gh	AP	Korannaland	Supergroup	Kheisian	Sys	
1719	Goedgedacht	Formation	Pgo	NY	Karoo	Supergroup	Permian	Sys	
242	Goedgenoeg	Formation	Rgg	NY	Platberg	Group	Randian	Era	
153	Gold Ridge	Formation	Zgl	AP	Kraaipan	Group	Swazian	Era	
868	Goodhouse	Subsuite	K*gd	NY	Vioolsdrif	Suite	Kheisian	Sys	
1688	Goraap	Suite	N*go	NY	*	*	Kheisian	Sys	
661	Gordonia	Formation	Qg	AP	Kalahari	Group	Quaternary	Sys	
523	Goudini	Formation	Sg	AP	Nardouw	Subgroup	Silurian	Sys	LS
1674	Goudini	Complex	N*go	NY	*	*	Namaquan	Sys	
921	Goudplaats Gneiss	None	Zgo	NY	*	*	Swazian	Era	
1031	Gouskop Granite	None	N*gk	NY	Keimoes	Suite	Namaquan	Sys	
91	Government	Subgroup	Rg	AP	West Rand	Group	Randian	Era	
519	Graafwater	Formation	Og	AP	Table Mountain	Group	Ordovician	Sys	LS
655	Grahamstown	Formation	Tg	AP	*	*	Tertiary	Sys	
673	Granville Grove Oolite	Bed	Zgg	AP	Sheba	Formation	Swazian	Era	
49	Grappies	Group	K*g	NY	*	*	Kheisian	Sys	
1987	Graskop Granite	None	N/C*g	AP	Cape Granite	Suite	Cambrian	Sys	Ca
1987	Graskop Granite	None	N/C*g	AP	Cape Granite	Suite	Namibian	Era	Ca
977	Grasvally Norite-Anorthosite	None	Vgr	NY	Rustenburg Layered	Suite	Vaalian	Era	
19	Gravelotte	Group	Zg	AP	*	*	Swazian	Era	
1988	Greenlands	Formation	Zgr	AP	*	*	Swazian	Era	Ca
1721	Greenwich	Formation	TRg	NY	Karoo	Supergroup	Triassic	Sys	
2094	Greyton Pluton	Pluton	N-C*gr	IF	Cape Granite	Suite	Cambrian	Sys	
2094	Greyton Pluton	Pluton	N-C*gr	IF	Cape Granite	Suite	Namibian	Era	
365	Groblershoop	Formation	K*gr	AP	Brulpan	Group	Kheisian	Sys	
2026	Groendoring	Formation	K*gn	NY	Khurisberg	Subgroup	Kheisian	Sys	
491	Groenefontein	Formation	Ngf	AP	Cango Caves	Group	Namibian	Era	Ca
968	Groenfontein Harzburgite	None	Vgf	AP	Vlakfontein	Subsuite	Vaalian	Era	
733	Groot Drink	Member	N*gr	NY	Zonderhuis	Formation	Namaquan	Sys	
2202	Groot-Letaba Gneiss	None	Rgl	NY	*	*	Randian	Era	
884	Grootderm	Formation	Ngr	AP	Gariep	Supergroup	Namibian	Era	IP
1607	Grootegeluk	Formation	Pgr	NY	Karoo	Supergroup	Permian	Sys	
734	Groothoek Mudstone	Member	K*gt	AP	Aasvoëlkop	Formation	Kheisian	Sys	
98	Guadom	Subgroup	K*gu	AP	Bushmanland	Group	Kheisian	Sys	
13	Gumbu	Group	Zgu	AP	Beit Bridge	Complex	Swazian	Era	
1730	Gumchavib	Formation	Ngu	NY	Stinkfontein	Subgroup	Namibian	Era	
528	Gydo	Formation	Dg	AP	Ceres	Subgroup	Devonian	Sys	LS
1232	Haakdoorn	Formation	K*hk	NY	Brakwater Metamorphic	Suite	Kheisian	Sys	
1156	Haakdoornfontein Syenite	None	N*ha	AP	Pienaars River	Complex	Namaquan	Sys	
108	Haib	Subgroup	K*hb	AP	Orange River	Group	Kheisian	Sys	
1122	Halambu Gneiss	None	N*h	AP	*	*	Namaquan	Sys	

CODE	LITHO NAME	RANK	LABEL	ST	PARENT NAME	RANK	CHRONO NAME	RANK	PUB
919	Halfway House Granite	None	Zhh	AP	*	*	Swazian	Era	
685	Hamberg Quartzite	Member	Rhm	AP	Promise	Formation	Randian	Era	
267	Hampton	Formation	Rhp	AP	Buffelsfontein	Group	Randian	Era	
2044	Hangsfontein Granite	None	N*hf	NY	Spektakel	Suite	Namaquan	Sys	
1115	Haramoep Gneiss	None	K*hr	NY	*	*	Kheisian	Sys	
1219	Hardeberg Granodiorite	None	N*hr	NY	*	*	Namaquan	Sys	
2017	Hardevlakte Granite	None	N*hv	NY	Korridor	Suite	Namaquan	Sys	
1215	Harmony	Member	Rhn	NY	Krugersdorp	Formation	Randian	Era	
992	Harmony Granite	None	Rha	AP	*	*	Randian	Era	
777	Harrismith	Member	TRh	NY	Normandien	Formation	Triassic	Sys	
807	Hartbees River	Complex	K*h	NY	*	*	Kheisian	Sys	
1069	Hartebeest Pan Granite	None	N*ht	NY	Keimoes	Suite	Namaquan	Sys	
318	Hartley	Formation	K*ha	AP	Olifantshoek	Supergroup	Kheisian	Sys	
920	Hebron Granodiorite	None	Zhe	NY	*	*	Swazian	Era	
1211	Hedley Plains	Formation	K*hp	NY	Jacomyns Pan	Group	Kheisian	Sys	
404	Heiroigas	Formation	K*he	NY	Haib	Subgroup	Kheisian	Sys	
284	Hekpoort	Formation	Vh	AP	Pretoria	Group	Vaalian	Era	
2092	Hermanus Pluton	Pluton	N-C*h	IF	Cape Granite	Suite	Cambrian	Sys	
2092	Hermanus Pluton	Pluton	N-C*h	IF	Cape Granite	Suite	Namibian	Era	
531	Hex River	Formation	Dh	AP	Ceres	Subgroup	Devonian	Sys	LS
1234	Heynskop	Formation	Vhe	NY	Koegas	Subgroup	Vaalian	Era	
1779	Highbury Pegmatite	None	N*hi	AP	Margate Granite	Suite	Namaquan	Sys	Ca
883	Hilda	Subgroup	Nh	AP	Port Nolloth	Group	Namibian	Era	IP
841	Hlagothi	Suite	Rhg	NY	*	*	Randian	Era	MS
1731	Hlashana	Formation	Rhs	AP	Mozaan	Group	Randian	Era	
166	Hlathini	Formation	Rht	AP	Nsuze	Group	Randian	Era	Ca
2138	Hlatikulu Granite	None	Rhk	NA	*	*	Randian	Era	
843	Hlelo Granite	Suite	Rhl	AP	Usushwana	Complex	Randian	Era	
810	Hlobane	Complex	N*hl	AP	*	*	Namaquan	Sys	
933	Hoed Granite	None	Rho	AP	Mashishimale	Suite	Randian	Era	
1197	Hoedemaker	Member	Ph	NY	Teekloof	Formation	Permian	Sys	
2178	Hoedjiespunt Granite	None	N*he	NY	Cape Granite	Suite	Namibian	Era	
886	Holgat	Formation	Nho	AP	Port Nolloth	Group	Namibian	Era	IP
97	Hom	Subgroup	K*ho	AP	Bushmanland	Group	Kheisian	Sys	
504	Homtini	Formation	Nhm	AP	Kaaimans	Group	Namibian	Era	
131	Hooggenoeg	Formation	Zh	AP	Geluk	Subgroup	Swazian	Era	
860	Hoogoor	Suite	K*hg	AP	*	*	Kheisian	Sys	
90	Hospital Hill	Subgroup	Rh	AP	West Rand	Group	Randian	Era	
720	Hotazel	Formation	Vhz	AP	Voëlwater	Subgroup	Vaalian	Era	
381	Hotson	Formation	K*ht	AP	Nab	Subgroup	Kheisian	Sys	LS
927	Hout River Gneiss	None	Rhr	NY	*	*	Randian	Era	
295	Houtenbek	Formation	Vho	AP	Pretoria	Group	Vaalian	Era	
936	Hugomond Granite	None	Rhu	AP	*	*	Randian	Era	
342	Hugosput	Formation	K*hu	NY	Vyfbeker Metamorphic	Suite	Kheisian	Sys	
492	Huis Rivier	Formation	Nhu	AP	Cango Caves	Group	Namibian	Era	LS
1144	Humberdale Granite	None	N*hu	AP	*	*	Namaquan	Sys	Ca
2008	Huns Limestone	Member	Nhn	AP	Urusis	Formation	Namibian	Era	
2193	Hytkoras	Formation	K*hy	NY	Kamiesberg	Subgroup	Kheisian	Sys	
620	Igoda	Formation	Ki	AP	*	*	Cretaceous	Sys	
615	Infanta	Formation	J-Ki	AP	*	*	Cretaceous	Sys	
615	Infanta	Formation	J-Ki	AP	*	*	Jurassic	Sys	
1147	Ingwe Granodiorite	None	N*ig	AP	*	*	Namaquan	Sys	Ca
909	Inlandsee Leucogranofels/Gneiss	None	Zi	NY	*	*	Swazian	Era	
459	Intuze	Formation	N*i	AP	Matigulu	Group	Namaquan	Sys	
962	Ironstone Magnetite Gabbro	None	Vi	AP	Roossenekal	Subsuite	Vaalian	Era	
594	Irrigasie	Formation	P-TRi	AP	Karoo	Supergroup	Permian	Sys	
594	Irrigasie	Formation	P-TRi	AP	Karoo	Supergroup	Triassic	Sys	
2148	Isipingo	Formation	Qi	NY	Maputuland	Group	Pleistocene	Ser	
344	Jacomyns Pan	Group	K*j	NY	*	*	Kheisian	Sys	
954	Jagdlust Harzburgite	None	Vj	AP	Croydon	Subsuite	Vaalian	Era	
2056	Jakkalsfontein	Formation	Mja	NY	Kamiesberg	Subgroup	Mokolian	Era	

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2047	Jakkalshoek Granite	None	N*jk	NY	Spektakel	Suite	Namaquan	Sys	
371	Jannelsepan	Formation	N*j	NY	Areachap	Group	Namaquan	Sys	
238	Jeannette	Formation	Rje	AP	Klipriviersberg	Group	Randian	Era	
92	Jeppestown	Subgroup	Rj	AP	West Rand	Group	Randian	Era	
1399	Jerome Granite	None	Rjr	NY	*	*	Randian	Era	
2048	Jobs Kraal Charnockite	None	N*jo	NY	*	*	Namaquan	Sys	
138	Joe's Luck	Formation	Zj	AP	Moodies	Group	Swazian	Era	
93	Johannesburg	Subgroup	Rjo	AP	Central Rand	Group	Randian	Era	
214	Johnstone	Member	Rjh	AP	Randfontein	Formation	Randian	Era	
592	Jozini	Formation	Jj	AP	Lebombo	Group	Jurassic	Sys	
388	K'oumoesk'naap	Formation	K*kom	NY	Khurisberg	Subgroup	Kheisian	Sys	
66	Kaaimans	Group	Nk	AP	*	*	Namibian	Era	
483	Kaaimansgat	Formation	Nkm	AP	Malmesbury	Group	Namibian	Era	
507	Kaan	Formation	Nka	NY	Gamtoos	Group	Namibian	Era	
916	Kaap Valley Tonalite	None	Zkv	AP	*	*	Swazian	Era	Ca
379	Kabas	Formation	K*ks	NY	Pella	Subgroup	Kheisian	Sys	
1092	Kabis Granite	None	N*ki	NY	Little Namaqualand	Suite	Namaquan	Sys	
1227	Kaboom	Formation	K*kb	NY	*	*	Kheisian	Sys	
817	Kaffirskraal	Complex	K*kf	AP	*	*	Kheisian	Sys	
758	Kaigas	Formation	Nki	AP	Port Nolloth	Group	Namibian	Era	IP
1086	Kakamas Suid Gneiss	None	N*ku	NY	*	*	Namaquan	Sys	
84	Kalahari	Group	C^k	AP	*	*	Cenozoic	Era	
2035	Kalk Gat	Formation	Nkg	NY	Knersvlakte	Subgroup	Namibian	Era	
1910	Kalkkloof	Complex	Zka	NY	*	*	Swazian	Era	
1187	Kalkkop Breccia	None		NY	*	*	Phanerozoic	Eon	
474	Kalkpunt	Formation	N*ka	AP	Koras	Group	Namaquan	Sys	Ca
1209	Kalkput	Member	Vkk	AP	Vryburg	Formation	Vaalian	Era	LS
2215	Kalkvlei Granite	None	N*kav	NY	*	*	Namaquan	Sys	
1046	Kalkwerf Gneiss	None	N*kl	NY	*	*	Namaquan	Sys	
323	Kameel Puts	Formation	K*kp	NY	*	*	Kheisian	Sys	
241	Kameeldoorns	Formation	Rka	AP	Platberg	Group	Randian	Era	
1206	Kameelfontein	Formation	Vka	NY	Koegas	Subgroup	Vaalian	Era	
2104	Kamiesberg	Subgroup	Mk	NY	Bushmanland	Group	Mokolian	Era	
1761	Kamieskroon Gneiss	None	N*km	NY	*	*	Namaquan	Sys	
387	Kangnas	Formation	K*ka	AP	Khurisberg	Subgroup	Kheisian	Sys	Ca
791	Kanguru	Member	Vkg	AP	Reivilo	Formation	Vaalian	Era	
1029	Kanoneiland Granite	None	N*kn	NY	Keimoes	Suite	Namaquan	Sys	
115	Kansa	Group	C*ka	AP	*	*	Cambrian	Sys	Ca
1192	Kanye	Formation	Rkn	NY	*	*	Randian	Era	
769	Kareedouw Sandstone	Member	Dkr	AP	Baviaanskloof	Formation	Devonian	Sys	LS
2098	Karelskraal	Member	Pka	NY	Abrahamskraal	Formation	Permian	Sys	
539	Karies	Formation	Dk	AP	Traka	Subgroup	Devonian	Sys	
2042	Karoetjes Kop	Formation	Nkr	NY	Gariep	Supergroup	Namibian	Era	
9	Karoo	Supergroup	C-Jk	AP	*	*	Carboniferous	Sys	
9	Karoo	Supergroup	C-Jk	AP	*	*	Jurassic	Sys	
9	Karoo	Supergroup	C-Jk	AP	*	*	Permian	Sys	
9	Karoo	Supergroup	C-Jk	AP	*	*	Triassic	Sys	
891	Karoo Dolerite	Suite	Jd	NY	*	*	Jurassic	Sys	
538	Karoopoort	Formation	Dka	AP	Bidouw	Subgroup	Devonian	Sys	
576	Katberg	Formation	TRk	AP	Tarkastad	Subgroup	Triassic	Sys	MS
2149	Kayeni	Member	Cka	NY	Elandsvlei	Formation	Carboniferous	Sys	
1026	Keboes Granite	None	N*kb	NY	Keimoes	Suite	Namaquan	Sys	
847	Kees Zyn Doorns Syenite	Suite	Rke	NY	*	*	Randian	Era	
2004	Keesenbosch Diorite	None	Nke	NY	*	*	Namibian	Era	
861	Keimoes	Suite	N*ke	AP	*	*	Namaquan	Sys	
1011	Kenhardt Migmatite	None	K*ke	NY	Vyfbeker Metamorphic	Suite	Kheisian	Sys	
1786	Khiphunyawa	Formation	Rkh	NY	Odwaleni	Subgroup	Randian	Era	
456	Khomo	Formation	N*kh	AP	Tugela	Group	Namaquan	Sys	
2025	Khoromus Gneiss	None	K*km	NY	Vioolsdrif	Suite	Kheisian	Sys	
155	Khunwana	Formation	Zkh	AP	Kraaipan	Group	Swazian	Era	
105	Khurisberg	Subgroup	K*kh	AP	Bushmanland	Group	Kheisian	Sys	
228	Kimberley	Formation	Rki	AP	Turffontein	Subgroup	Randian	Era	

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2206	Kimberley Kimberlite	Suite	Kki	NY	*	*	Cretaceous	Sys	
646	Kinkelbos	Formation	C^ki	AP	*	*	Cenozoic	Era	LS
611	Kirkwood	Formation	J-Kk	AP	Uitenhage	Group	Cretaceous	Sys	
611	Kirkwood	Formation	J-Kk	AP	Uitenhage	Group	Jurassic	Sys	
694	Klapperkop Quartzite	Member	Vkp	AP	Timeball Hill	Formation	Vaalian	Era	
643	Klein Brak	Formation	Qk	AP	Bredasdorp	Group	Pleistocene	Ser	LS
1715	Klein Naute	Formation	Vke	NY	Campbell Rand	Subgroup	Vaalian	Era	
1067	Klein Van Wykspan Granite	None	N*kv	NY	Keimoes	Suite	Namaquan	Sys	
903	Kleinbegin	Subsuite	N*kle	NY	Keimoes	Suite	Namaquan	Sys	
1181	Kleinfontein Granite	None	C*kf	NY	Cape Granite	Suite	Cambrian	Sys	
506	Kleinrivier	Formation	Nkl	NY	Gamtoos	Group	Namibian	Era	
1053	Klip Bakken Gneiss	None	N*klb	NY	*	*	Namaquan	Sys	
1025	Klip Koppies Granite	None	N*klk	NY	Keimoes	Suite	Namaquan	Sys	
514	Klipbak	Formation	C*kl	NY	Brandkop	Subgroup	Cambrian	Sys	
536	Klipbokkop	Formation	Dkl	AP	Bidouw	Subgroup	Devonian	Sys	
1158	Klipdrift Syenite	None	N*kld	AP	Pienaars River	Complex	Namaquan	Sys	
1708	Klipfonteinheuwel	Formation	Vkf	NY	Campbell Rand	Subgroup	Vaalian	Era	
68	Klipheuwel	Group	C*k	AP	*	*	Cambrian	Sys	
1762	Kliphoek Granite	None	N*klh	NY	Spektakel	Suite	Namaquan	Sys	
984	Klipkloof Granite	None	Vki	AP	Lebowa Granite	Suite	Vaalian	Era	
1032	Klipkraal Granite	None	N*kli	NY	Keimoes	Suite	Namaquan	Sys	
395	Klipneus	Formation	K*kl	AP	Orange River	Group	Kheisian	Sys	
1711	Klippan	Formation	Vkl	NY	Campbell Rand	Subgroup	Vaalian	Era	
486	Klipplaat	Formation	Nkp	AP	Swartland	Subgroup	Namibian	Era	
1765	Kliprand Charnockite	None	N*klr	NY	Little Namaqualand	Suite	Namaquan	Sys	
30	Klipriviersberg	Group	Rk	AP	Ventersdorp	Supergroup	Randian	Era	
326	Klipvlei	Formation	K*kv	NY	Droëboom	Group	Kheisian	Sys	
87	Klipwal	Subgroup	Rkl	NY	Mozaan	Group	Randian	Era	
600	Klopperfontein	Formation	TRkl	AP	Karoo	Supergroup	Triassic	Sys	
1157	Kloppersbos Foyaite	None	N*klo	AP	Pienaars River	Complex	Namaquan	Sys	
513	Knersvlakte	Subgroup	Nkn	AP	Vanrhynsdorp	Group	Namibian	Era	
632	Knysna	Formation	Tk	AP	*	*	Miocene	Ser	LS
1737	Koedoeslaagte	Formation	Rko	NY	Jeppestown	Subgroup	Randian	Era	
1352	Koedoesrand	Formation	Vkd	NY	*	*	Vaalian	Era	
311	Koegas	Subgroup	Vk	AP	Ghaap	Group	Vaalian	Era	
2029	Koegel Fontein	Complex	Kk	NY	*	*	Cretaceous	Sys	
1117	Koeipoort Granite	None	K*kop	NY	*	*	Kheisian	Sys	
350	Koekoepkop	Formation	K*kok	NY	*	*	Kheisian	Sys	
856	Koelmanskop Metamorphic	Suite	K*kol	NY	Hartbees River	Complex	Kheisian	Sys	
2122	Koenap	Formation	K*kn	NY	Arribees	Group	Kheisian	Sys	
385	Koeris	Formation	K*koe	NY	Zuurwater	Subgroup	Kheisian	Sys	MS
1102	Koesie Se Dam Tonalite	None	N*ks	AP	T'Oubep	Suite	Namaquan	Sys	Ca
1712	Kogelbeen	Formation	Vko	NY	Campbell Rand	Subgroup	Vaalian	Era	
331	Kokerberg	Formation	K*ko	AP	De Kruis	Group	Kheisian	Sys	
964	Kolobeng Norite	None	Vkb	AP	Rustenburg Layered	Suite	Vaalian	Era	
130	Komati	Formation	Zko	AP	Tjakastad	Subgroup	Swazian	Era	
892	Komatipoort	Suite	Jk	NY	*	*	Jurassic	Sys	
763	Kombuis	Member	Nko	AP	Matjies River	Formation	Namibian	Era	LS
125	Kommadagga	Subgroup	Ck	AP	Witteberg	Group	Carboniferous	Sys	
2111	Konkonsies Granite	None	N*kon	NY	*	*	Namaquan	Sys	
1020	Konkyp Gneiss	None	N*ky	AP	Little Namaqualand	Suite	Namaquan	Sys	
1111	Kontorogab Gneiss	None	K*kon	NY	*	*	Kheisian	Sys	
400	Kook River	Formation	K*kor	AP	De Hoop	Subgroup	Kheisian	Sys	
568	Kookfontein	Formation	Pkk	NY	Ecca	Group	Permian	Sys	
573	Koonap	Formation	Pk	AP	Adelaide	Subgroup	Permian	Sys	
1659	Koornplaats	Member	Pkr	NY	Abrahamskraal	Formation	Permian	Sys	
2216	Koos Vlei Granite	None	K*koo	Y	*	*	Namaquan	Sys	
863	Koperberg	Suite	N*ko	AP	*	*	Namaquan	Sys	
7	Korannaland	Supergroup	K*k	AP	*	*	Kheisian	Sys	
63	Koras	Group	N*k	AP	*	*	Namaquan	Sys	Ca
818	Koringkoppies	Complex	K*kog	AP	*	*	Kheisian	Sys	
1687	Korridor	Suite	N*kd	NY	*	*	Namaquan	Sys	

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2146	Kosi Bay	Formation	Qko	NY	Maputuland	Group	Pleistocene	Ser	
1787	Kosies	Formation	K*kos	NY	Khurisberg	Subgroup	Kheisian	Sys	
1119	Kotongweni Tonalite	None	N*kg	AP	*	*	Namaquan	Sys	
384	Kouboom	Formation	K*kob	NY	Zuurwater	Subgroup	Kheisian	Sys	
1014	Kourop Migmatite	None	K*kou	NY	Koelmanskop Metamorphic	Suite	Kheisian	Sys	
22	Kraaipan	Group	Zk	AP	*	*	Swazian	Era	
2195	Kraal Bay	Member	Qkr	NY	Langebaan	Formation	Quaternary	Sys	
2219	Kraalbosch Vlei Granite	None	N*kc	NY	*	*	Namaquan	Sys	
1764	Kraalkop Quartz Diorite	None	N*kk	AP	Keimoes	Suite	Namaquan	Sys	Ca
337	Kraandraai	Formation	K*kd	NY	Kamiesberg	Subgroup	Kheisian	Sys	
111	Kransberg	Subgroup	K*kr	AP	Waterberg	Group	Kheisian	Sys	
1749	Kranskloof	Member	Ok	AP	Durban	Formation	Ordovician	Sys	LS
1107	Krom Puts Granite	None	N*kp	NY	*	*	Namaquan	Sys	
132	Kromberg	Formation	Zkr	AP	Geluk	Subgroup	Swazian	Era	
669	Kromdraai	Formation	C^kr	AP	*	*	Cenozoic	Era	
965	Kroondal Norite	None	Vkr	NY	Vlakfontein	Subsuite	Vaalian	Era	
219	Krugersdorp	Formation	Rkr	AP	Johannesburg	Subgroup	Randian	Era	
819	Kruidfontein Carbonatite	Complex	N*kr	AP	*	*	Namaquan	Sys	
401	Kuams River	Formation	K*ku	AP	De Hoop	Subgroup	Kheisian	Sys	
2145	Kuboos Pluton	Pluton	C*ku	IF	Kuboos-Bremen	Suite	Cambrian	Sys	
1689	Kuboos-Bremen	Suite	N-C*k	NY	*	*	Cambrian	Sys	
1689	Kuboos-Bremen	Suite	N-C*k	NY	*	*	Namibian	Era	
647	Kudus Kloof	Formation	C^ku	AP	*	*	Cenozoic	Era	Ca
116	Kuibis	Subgroup	Nku	AP	Nama	Group	Namibian	Era	
2085	Kuilsrivier-Helderberg Batholith	Batholith	N-C*kh	IF	Cape Granite	Suite	Cambrian	Sys	
2085	Kuilsrivier-Helderberg Batholith	Batholith	N-C*kh	IF	Cape Granite	Suite	Namibian	Era	
710	Kuruman	Formation	Vku	AP	Asbestos Hills	Subgroup	Vaalian	Era	
302	Kwaggasnek	Formation	Vkn	AP	Rooiberg	Group	Vaalian	Era	
2016	Kwakanab	Member	Nkk	NY	Lekkersing	Formation	Namibian	Era	
1709	Kwanous	Subgroup	Nkw	NY	Vanrhynsdorp	Group	Namibian	Era	
1304	Kwarriehoek	Formation	Vkw	AP	Makeckaan	Subgroup	Vaalian	Era	Ca
1041	Kweekfontein Granite	None	N*kf	AP	Korridor	Suite	Namaquan	Sys	
546	Kweekvlei	Formation	Ckw	AP	Lake Mentz	Subgroup	Carboniferous	Sys	
1099	Kwessiedam Granite	None	N*kw	AP	T'Oubep	Suite	Namaquan	Sys	Ca
1763	Kwetta Granite	None	Rkw	NY	*	*	Randian	Era	
143	La France	Formation	Zlf	AP	Gravelotte	Group	Swazian	Era	
1989	Laborie Granite	None	C*l	AP	Cape Granite	Suite	Cambrian	Sys	Ca
564	Laingsburg	Formation	Pl	AP	Ecca	Group	Permian	Sys	LS
124	Lake Mentz	Subgroup	Cl	AP	Witteberg	Group	Carboniferous	Sys	
292	Lakenvalei	Formation	Vla	AP	Pretoria	Group	Vaalian	Era	
1188	Lamberts Bay Breccia - Basalt	None		NY	*	*	Phanerozoic	Eon	
1990	Lammershoek Granite	None	N/C*l	AP	Cape Granite	Suite	Cambrian	Sys	Ca
1990	Lammershoek Granite	None	N/C*l	AP	Cape Granite	Suite	Namibian	Era	Ca
2051	Landplaas Gneiss	None	N*lp	NY	Little Namaqualand	Suite	Namaquan	Sys	
869	Lange Kolk	Suite	N*ln	NY	*	*	Namaquan	Sys	
1330	Langebaan	Formation	Ql	AP	Sandveld	Group	Quaternary	Sys	MS
182	Langfontein	Formation	Rla	NY	Ozwana	Subgroup	Randian	Era	
2198	Langkrans	Formation	Rln	NY	*	*	Randian	Era	
1040	Lat River Granite	None	N*la	AP	*	*	Namaquan	Sys	
982	Lease Granite	None	Vls	AP	Lebowa Granite	Suite	Vaalian	Era	
78	Lebombo	Group	Jl	AP	Karoo	Supergroup	Jurassic	Sys	MS
851	Lebowa Granite	Suite	Vle	AP	Bushveld	Complex	Vaalian	Era	
1164	Ledig Foyaite	None	N*lg	AP	Pilanesberg	Complex	Namaquan	Sys	
373	Leerkrans	Formation	N*lr	AP	Wilgenhoutsdrif	Group	Namaquan	Sys	
472	Leeuwdraai	Formation	N*ld	AP	Koras	Group	Namaquan	Sys	Ca
880	Leeuwfontein	Suite	N*lf	AP	Pienaars River	Complex	Namaquan	Sys	
1159	Leeuwkraal Phonolite	None	N*lk	AP	Pienaars River	Complex	Namaquan	Sys	
297	Leeuwpoort	Formation	Vlw	AP	Pretoria	Group	Vaalian	Era	
1128	Leisure Bay	Formation	N*le	AP	Mzimkulu	Group	Namaquan	Sys	Ca
2211	Lekkerdrink Gneiss	None	K*ld	NY	*	*	Namaquan	Sys	

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914	Lekkerloop Granite	None	Zle	NY	*	*	Swazian	Era	
756	Lekkersing	Formation	Nl	AP	Stinkfontein	Subgroup	Namibian	Era	IP
934	Lekkersmaak Granite	None	Rle	AP	Vorster	Suite	Randian	Era	
1991	Lemoenkloof Granite	None	N/C*le	AP	Cape Granite	Suite	Cambrian	Sys	Ca
1991	Lemoenkloof Granite	None	N/C*le	AP	Cape Granite	Suite	Namibian	Era	Ca
391	Lemoenpoort	Formation	K*le	NY	Khurisberg	Subgroup	Kheisian	Sys	
959	Leolo Mountain Gabbro-Norite	None	Vll	AP	Dsjate	Subsuite	Vaalian	Era	
2201	Leshareng Porphyry	None	Vlh	NY	Bushveld	Complex	Vaalian	Era	
591	Letaba	Formation	Jle	AP	Lebombo	Group	Jurassic	Sys	
142	Leydsdorp	Formation	Zl	AP	Gravelotte	Group	Swazian	Era	
1060	Liefdood Granite	None	N*li	NY	Keimoes	Suite	Namaquan	Sys	
932	Lillie Granite	None	Rll	AP	Mashishimale	Suite	Randian	Era	
709	Lime Acres	Member	Vli	NY	Kogelbeen	Formation	Vaalian	Era	
505	Lime Bank	Formation	Nli	NY	Gamtoos	Group	Namibian	Era	
820	Lindeques Drift	Complex	K*li	AP	*	*	Kheisian	Sys	
1722	Lisbon	Formation	TRl	NY	Karoo	Supergroup	Triassic	Sys	
859	Little Namaqualand	Suite	N*l	AP	*	*	Namaquan	Sys	
216	Livingstone Conglomerate	Member	Rli	AP	Randfontein	Formation	Randian	Era	
2194	Lonely	Formation	Qlo	NY	Kalahari	Group	Quaternary	Sys	
328	Longsiekvlei	Formation	K*lo	NY	Droëboom	Group	Kheisian	Sys	
239	Loraine	Formation	Rlo	AP	Klipriviersberg	Group	Randian	Era	
821	Losberg	Complex	K*l	AP	*	*	Kheisian	Sys	
304	Loskop	Formation	Vlo	AP	Transvaal	Supergroup	Vaalian	Era	
2058	Louisrus	Formation	Mlr	NY	Kamiesberg	Subgroup	Mokolian	Era	
1024	Louisvale Granite	None	N*lo	NY	Keimoes	Suite	Namaquan	Sys	
1289	Lower	Zone	Vl	IF	Rustenburg Layered	Suite	Vaalian	Era	
158	Lubana	Formation	Zlu	NY	Empangeni Metamorphic	Suite	Swazian	Era	
186	Lubanjana	Formation	Rlb	NY	Klipwal	Subgroup	Randian	Era	
317	Lucknow	Formation	K*lu	AP	Olifantshoek	Supergroup	Kheisian	Sys	
217	Luipaardsvlei	Formation	Rl	AP	Johannesburg	Subgroup	Randian	Era	
963	Luipershoek Olivine Diorite	None	Vlu	AP	Roossenekal	Subsuite	Vaalian	Era	
752	Lukin Quartzite	Member	K*lk	AP	Nzhelele	Formation	Kheisian	Sys	
929	Lunsklip Granite	None	Rlu	AP	Mashashane	Suite	Randian	Era	IP
1050	Lutzputs Gneiss	None	N*lu	NY	*	*	Namaquan	Sys	
698	Lydenburg Shale	Member	Vld	AP	Silverton	Formation	Vaalian	Era	
276	Lyttelton	Formation	Vly	AP	Malmani	Subgroup	Vaalian	Era	
1185	Maalgaten Granite	None	C*ma	NY	Cape Granite	Suite	Cambrian	Sys	
167	Mabaleni	Formation	Rml	AP	Nsuze	Group	Randian	Era	Ca
425	Mabiligwe	Formation	K*ma	AP	Soutpansberg	Group	Kheisian	Sys	
265	Mabin	Formation	Rmb	AP	Wolkberg	Group	Randian	Era	MS
145	Mac Kop	Formation	Zmc	AP	Gravelotte	Group	Swazian	Era	
812	Macala	Complex	N*mac	AP	*	*	Namaquan	Sys	
1767	Macetse Granite	None	Rmc	AP	*	*	Randian	Era	
697	Machadodorp	Member	Vmc	AP	Silverton	Formation	Vaalian	Era	
1002	Madiapala Syenite	None	Zmp	NY	Beit Bridge	Complex	Swazian	Era	
676	Madola Shale	Member	Rmad	AP	Sinqeni	Formation	Randian	Era	
596	Madzaringwe	Formation	Pma	AP	Karoo	Supergroup	Permian	Sys	
289	Magaliesberg	Formation	Vmg	AP	Pretoria	Group	Vaalian	Era	
961	Magnet Heights Gabbronorite	None	Vmh	AP	Roossenekal	Subsuite	Vaalian	Era	
1698	Magongolozi	Formation	Zmg	AP	Nondweni	Group	Swazian	Era	Ca
517	Magrug	Formation	C*m	NY	Klipheuwel	Group	Cambrian	Sys	
1766	Mahamba Gneiss	None	Zmb	NY	*	*	Swazian	Era	
1145	Mahlongwa Granite	None	N*mah	AP	*	*	Namaquan	Sys	Ca
212	Main	Formation	Rma	AP	Johannesburg	Subgroup	Randian	Era	
1291	Main	Zone	Vm	IF	Rustenburg Layered	Suite	Vaalian	Era	
670	Makapansgat	Formation	C^ma	AP	*	*	Cenozoic	Era	
434	Makasana	Formation	N*mak	AP	Ntingwe	Group	Namaquan	Sys	
621	Makatini	Formation	Kma	AP	Zululand	Group	Cretaceous	Sys	
299	Makeckaan	Subgroup	Vmk	AP	Pretoria	Group	Vaalian	Era	Ca

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419	Makgabeng	Formation	K*mk	AP	Matlabas	Subgroup	Kheisian	Sys	
313	Makganyene	Formation	Vmy	AP	Postmasburg	Group	Vaalian	Era	LS
967	Makgope Bronzitite	None	Vmz	AP	Vlakfontein	Subsuite	Vaalian	Era	
987	Makhutso Granite	None	Vmu	AP	Lebowa Granite	Suite	Vaalian	Era	
922	Makhutswi Gneiss	None	Zmk	AP	*	*	Swazian	Era	
243	Makwassie	Formation	Rmk	AP	Platberg	Group	Randian	Era	
14	Malala Drift	Group	Zma	AP	Beit Bridge	Complex	Swazian	Era	
95	Malmani	Subgroup	Vma	AP	Chuniespoort	Group	Vaalian	Era	
64	Malmesbury	Group	Nm	AP	*	*	Namibian	Era	
2088	Malmesbury Batholith	Batholith	N-C*m	IF	Cape Granite	Suite	Cambrian	Sys	Ca
2088	Malmesbury Batholith	Batholith	N-C*m	IF	Cape Granite	Suite	Namibian	Era	Ca
624	Malvernia	Formation	Kml	AP	*	*	Cretaceous	Sys	
814	Mambulu	Complex	N*mam	AP	*	*	Namaquan	Sys	
741	Manaka Arkose	Member	K*mn	AP	Blouberg	Formation	Kheisian	Sys	
187	Mandeva	Formation	Rman	AP	Klipwal	Subgroup	Randian	Era	
174	Mankane	Formation	Rmn	AP	Nsuze	Group	Randian	Era	
1165	Mankwe	Formation	N*man	AP	Pilanesberg	Complex	Namaquan	Sys	
176	Mantonga	Formation	Rmg	AP	Nsuze	Group	Randian	Era	
444	Manyane	Formation	N*may	AP	Tugela	Group	Namaquan	Sys	
433	Manzawayo	Formation	N*maa	AP	Ntingwe	Group	Namaquan	Sys	
316	Mapedi	Formation	K*mp	AP	Olifantshoek	Supergroup	Kheisian	Sys	
978	Mapela Gabbro-Norite	None	Vme	NY	Rustenburg Layered	Suite	Vaalian	Era	
960	Mapoch Gabbronorite	None	Vmp	AP	Dsjate	Subsuite	Vaalian	Era	
872	Mapumulo	Group	N*m	AP	*	*	Namaquan	Sys	Ca
1676	Maputaland	Group	C^m	NY	*	*	Cenozoic	Era	
211	Maraisburg	Formation	Rmr	AP	Johannesburg	Subgroup	Randian	Era	
993	Maranda Granite	None	Rmar	NY	*	*	Randian	Era	
1126	Marble Delta	Formation	N*mad	AP	Mzimkulu	Group	Namaquan	Sys	Ca
873	Margate Granite	Suite	N*ma	AP	*	*	Namaquan	Sys	Ca
2002	Marginal	Zone	Vmr	IF	Rustenburg Layered	Suite	Vaalian	Era	
1724	Mariannhill	Formation	Om	AP	Natal	Group	Ordovician	Sys	LS
737	Marken Conglomerate	Member	K*mr	AP	Mogalakwena	Formation	Kheisian	Sys	
715	Marthaspoort	Member	Vms	AP	Gamagara	Formation	Vaalian	Era	
631	Martindale	Formation	Tm	AP	*	*	Tertiary	Sys	
26	Marydale	Group	Rmy	AP	*	*	Randian	Era	
845	Mashashane	Suite	Rmh	AP	*	*	Randian	Era	IP
846	Mashishimale	Suite	Rmas	AP	*	*	Randian	Era	
630	Masotcheni	Formation	Qm	AP	*	*	Quaternary	Sys	
178	Maswili	Formation	Rmsw	NY	Nsuze	Group	Randian	Era	
971	Mathlagame Norite-Anorthosite	None	Vmt	AP	Schilpadnest	Subsuite	Vaalian	Era	
1124	Mati Granite	None	N*mat	AP	*	*	Namaquan	Sys	
62	Matigulu	Group	N*mag	NY	*	*	Namaquan	Sys	
438	Matigwe	Formation	N*maw	AP	Mfongosi	Group	Namaquan	Sys	
490	Matjies River	Formation	Nma	AP	Cango Caves	Group	Namibian	Era	LS
1791	Matjiesfontein Chert	Bed	Pmt	AP	Collingham	Formation	Permian	Sys	LS
110	Matlabas	Subgroup	K*mb	AP	Waterberg	Group	Kheisian	Sys	
994	Matlala Granite	None	Vml	AP	*	*	Vaalian	Era	
937	Matok Granite	None	Rmt	AP	*	*	Randian	Era	
319	Matsap	Subgroup	K*m	AP	Volop	Group	Kheisian	Sys	
1770	Matshempondo Peridotite	None	Zms	AP	*	*	Swazian	Era	Ca
439	Mazula	Formation	N*maz	AP	Mfongosi	Group	Namaquan	Sys	
1771	Mbizana Microgranite	None	N*mb	AP	*	*	Namaquan	Sys	Ca
1992	Mbizane	Formation	Pmb	AP	Dwyka	Group	Permian	Sys	LS
617	Mbotyi	Formation	Kmb	AP	*	*	Cretaceous	Sys	
171	Mdlelanga	Formation	Rmd	AP	Nsuze	Group	Randian	Era	
995	Meinhardskraal Granite	None	Rmi	AP	*	*	Randian	Era	
2170	Melkboomfontein Granite	None	Rmel	NY	*	*	Randian	Era	
1752	Melmoth	Member	Ome	AP	Durban	Formation	Ordovician	Sys	LS
996	Meriri Granite	None	Rme	AP	*	*	Randian	Era	
1768	Mesklip Granite	None	N*me	NY	Little Namaqualand	Suite	Namaquan	Sys	
834	Messina	Suite	Zme	AP	Beit Bridge	Complex	Swazian	Era	

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60	Mfongosi	Group	N*mf	AP	*	*	Namaquan	Sys	
156	Mhlatuze	Formation	Zmh	NY	*	*	Swazian	Era	
574	Middleton	Formation	Pm	AP	Adelaide	Subgroup	Permian	Sys	
597	Mikambeni	Formation	Pmi	AP	Karoo	Supergroup	Permian	Sys	
549	Miller	Formation	Cm	AP	Kommadagga	Subgroup	Carboniferous	Sys	
2204	Milnerton	Formation	Qmi	NY	*	*	Pleistocene	Ser	
609	Mimosa	Formation	Jmi	AP	Suurberg	Group	Jurassic	Sys	Ca
1094	Mission Granite/Gneiss	None	N*ms	NY	*	*	Namaquan	Sys	
183	Mkaya	Formation	Rmka	NY	Klipwal	Subgroup	Randian	Era	
876	Mkomazi Gneiss	None	N*mk	AP	*	*	Namaquan	Sys	Ca
1120	Mkondeni Diorite	None	N*mn	NY	*	*	Namaquan	Sys	
184	Mkuzane	Formation	Rmz	NY	Ozwana	Subgroup	Randian	Era	
815	Mlalazi	Complex	N*ml	AP	*	*	Namaquan	Sys	
2141	Mliba Granodiorite	None	Zmi	NA	*	*	Swazian	Era	
743	Mmallebogos Grit	Member	K*mm	AP	Blouberg	Formation	Kheisian	Sys	
618	Mngazana	Formation	Kmn	AP	*	*	Cretaceous	Sys	
190	Modderfontein	Formation	Rmf	AP	Doornfontein	Subgroup	Randian	Era	
1769	Modderfontein Granite/Gneiss	None	N*md	NY	Little Namaqualand	Suite	Namaquan	Sys	
336	Moddergat Gneiss	None	K*md	NY	*	*	Kheisian	Sys	
1182	Modderkloof Granodiorite	None	N/C*md	NY	Cape Granite	Suite	Cambrian	Sys	
1182	Modderkloof Granodiorite	None	N/C*md	NY	Cape Granite	Suite	Namibian	Era	
803	Modipe	Complex	Zmo	AP	*	*	Swazian	Era	
420	Mogalakwena	Formation	K*mo	AP	Kransberg	Subgroup	Kheisian	Sys	
882	Mogashoa	Suite	N*mo	AP	*	*	Namaquan	Sys	
660	Mokalanen	Formation	C^mo	NY	Kalahari	Group	Cenozoic	Era	
980	Molendraai Magnetite Gabbro	None	Vmn	NY	Rustenburg Layered	Suite	Vaalian	Era	
938	Moletsi Granite	None	Rmol	AP	*	*	Randian	Era	
584	Molteno	Formation	TRm	AP	Karoo	Supergroup	Triassic	Sys	MS
168	Mome	Formation	Rmm	AP	Nsuze	Group	Randian	Era	Ca
230	Mondeor	Formation	Rmo	AP	Turffontein	Subgroup	Randian	Era	
275	Monte Christo	Formation	Vmo	AP	Malmani	Subgroup	Vaalian	Era	
706	Monteville	Formation	Vmv	AP	Campbell Rand	Subgroup	Vaalian	Era	
1993	Montvue Granite	None	N/C*m	AP	Cape Granite	Suite	Cambrian	Sys	Ca
1993	Montvue Granite	None	N/C*m	AP	Cape Granite	Suite	Namibian	Era	Ca
18	Moodies	Group	Zm	AP	Barberton	Supergroup	Swazian	Era	
721	Mooidraai	Formation	Vmd	AP	Voëlwater	Subgroup	Vaalian	Era	
956	Mooihoek Pyroxenite	None	Vmi	AP	Dwars River	Subsuite	Vaalian	Era	
976	Moorddrift Harzburgite-Pyroxenite	None	Vmf	NY	Zoetveld	Subsuite	Vaalian	Era	MS
1198	Moordenaars	Member	Pmo	NY	Abrahamskraal	Formation	Permian	Sys	
488	Moorreesburg	Formation	Nmo	AP	Swartland	Subgroup	Namibian	Era	
939	Mosita Granite	None	Rmos	NY	*	*	Randian	Era	
744	Mositone Conglomerate	Member	K*ms	AP	Blouberg	Formation	Kheisian	Sys	
147	Mothiba	Formation	Zmt	AP	Pietersburg	Group	Swazian	Era	
340	Mottels River	Formation	K*ml	NY	Vyfbeker Metamorphic	Suite	Kheisian	Sys	
15	Mount Dowe	Group	Zmd	AP	Beit Bridge	Complex	Swazian	Era	
2136	Mount Thesiger	Formation	Tmt	NY	*	*	Tertiary	Sys	
730	Mountain View	Member	K*mt	AP	Groblershoop	Formation	Kheisian	Sys	
593	Movene	Formation	Jm	AP	Lebombo	Group	Jurassic	Sys	
25	Mozaan	Group	Rm	AP	Pongola	Supergroup	Randian	Era	
940	Mpageni Granite	None	Rmp	AP	*	*	Randian	Era	
675	Mpama	Member	Rmpa	AP	Mantonga	Formation	Randian	Era	
602	Mpilo	Formation	Jmp	AP	Bumbeni	Complex	Jurassic	Sys	MS
461	Mpisi	Formation	N*mp	AP	Matigulu	Group	Namaquan	Sys	
175	Mpongoza	Formation	Rmpo	NY	Nsuze	Group	Randian	Era	
1354	Mpuluzi Granite	None	Zmz	NY	*	*	Swazian	Era	
1328	Mpunga	Formation	Rmpu	AP	Mozaan	Group	Randian	Era	
185	Mpushana	Formation	Rmps	NY	Klipwal	Subgroup	Randian	Era	
1700	Msikaba	Formation	Dm	AP	*	*	Devonian	Sys	

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170	Msukane	Formation	Rms	AP	Nsuze	Group	Randian	Era	
603	Msunduze	Formation	Jms	AP	Bumbeni	Complex	Jurassic	Sys	MS
1690	Mswati Granite	Suite	Rmw	NY	*	*	Randian	Era	
455	Mtengu	Formation	N*mt	AP	Tugela	Group	Namaquan	Sys	
2139	Mtombe Granite	None	Rmto	NA	*	*	Randian	Era	
1130	Mucklebraes	Formation	N*mc	NY	Mzimkulu	Group	Namaquan	Sys	
2169	Mud River Monzogabbro	None	C*mr	NY	Cape Granite	Suite	Cambrian	Sys	
141	Mulati	Formation	Zml	AP	Gravelotte	Group	Swazian	Era	
800	Muldersdrif	Complex	Zmu	AP	*	*	Swazian	Era	
878	Munster	Suite	N*mu	AP	*	*	Namaquan	Sys	Ca
750	Musekwa Basalt	Member	K*mw	AP	Nzhelele	Formation	Kheisian	Sys	
751	Mutale Tuff	Member	K*mu	AP	Nzhelele	Formation	Kheisian	Sys	
628	Muzi	Formation	C^mu	AP	*	*	Cenozoic	Era	
746	My Darling Trachyandesite	Member	K*my	AP	Blouberg	Formation	Kheisian	Sys	
619	Mzamba	Formation	Km	AP	*	*	Cretaceous	Sys	
462	Mzimkulu	Group	N*mz	AP	*	*	Namaquan	Sys	Ca
1143	Mzimlilo Granite	None	N*mi	AP	*	*	Namaquan	Sys	Ca
622	Mzinene	Formation	Kmz	AP	Zululand	Group	Cretaceous	Sys	
875	Mzumbe Granitoid	Suite	N*mm	AP	*	*	Namaquan	Sys	Ca
1233	N'rougas Granite	None	N*nr	NY	Keimoes	Suite	Namaquan	Sys	
867	Naab	Suite	N*na	NY	*	*	Namaquan	Sys	
100	Nab	Subgroup	K*na	NY	Bushmanland	Group	Kheisian	Sys	
1019	Nababeep Gneiss	None	N*nb	AP	Little Namaqualand	Suite	Namaquan	Sys	
510	Nababis	Formation	Nnb	AP	Fish River	Subgroup	Namibian	Era	
639	Nahoon	Formation	Qn	AP	Algoa	Group	Quaternary	Sys	LS
1699	Nakanas	Formation	K*nk	NY	Bushmanland	Group	Kheisian	Sys	
69	Nama	Group	N-C*n	AP	*	*	Cambrian	Sys	
69	Nama	Group	N-C*n	AP	*	*	Namibian	Era	
374	Namies	Formation	K*nm	AP	Aggeneys	Subgroup	Kheisian	Sys	
2212	Namies Suid Gneiss	None	N*nm	NY	*	*	Namaquan	Sys	
637	Nanaga	Formation	C^n	AP	Algoa	Group	Cenozoic	Era	LS
1205	Naragas	Formation	Vna	NY	Koegas	Subgroup	Vaalian	Era	
119	Nardouw	Subgroup	S-Dn	AP	Table Mountain	Group	Devonian	Sys	Ca
119	Nardouw	Subgroup	S-Dn	AP	Table Mountain	Group	Silurian	Sys	Ca
2221	Naroep Gneiss	None	N*np	NY	*	*	Namaquan	Sys	
1080	Naros Granite	None	N*ns	AP	*	*	Namaquan	Sys	
2121	Narries	Subsuite	K*nr	NY	Koelmanskop Metamorphic	Suite	Kheisian	Sys	
2009	Nasep Quartzite	Member	Nna	AP	Urusis	Formation	Namibian	Era	
1994	Nassau Biotite Granite	None	N/C*n	AP	Cape Granite	Suite	Cambrian	Sys	Ca
1994	Nassau Biotite Granite	None	N/C*n	AP	Cape Granite	Suite	Namibian	Era	Ca
74	Natal	Group	On	AP	*	*	Ordovician	Sys	IP
1714	Nauga	Formation	Vnu	NY	Campbell Rand	Subgroup	Vaalian	Era	
1701	Ndonyane	Formation	N*nd	AP	Mapumulo	Group	Namaquan	Sys	Ca
986	Nebo Granite	None	Vn	AP	Lebowa Granite	Suite	Vaalian	Era	
293	Nederhorst	Formation	Vne	AP	Pretoria	Group	Vaalian	Era	
1030	Neilers Drift Granite	None	N*ne	NY	Keimoes	Suite	Namaquan	Sys	
1713	Nelani	Formation	Vnl	NY	Koegas	Subgroup	Vaalian	Era	
764	Nels River	Member	Nne	AP	Groenefontein	Formation	Namibian	Era	Ca
915	Nelshoogte Gneiss	None	Znh	AP	*	*	Swazian	Era	
835	Nelspruit	Suite	Zne	AP	*	*	Swazian	Era	Ca
1754	Newspaper	Member	One	AP	Mariannhill	Formation	Ordovician	Sys	LS
809	Ngoye	Complex	N*ny	AP	*	*	Namaquan	Sys	Ca
437	Ngubevu	Formation	N*ng	AP	Mfongosi	Group	Namaquan	Sys	
2144	Ngwane Gneiss	None	Znw	NA	*	*	Swazian	Era	
159	Ngweni	Formation	Zng	NY	Empangeni Metamorphic	Suite	Swazian	Era	
735	Ngwepe Tuff	Member	K*ng	AP	Setlaole	Formation	Kheisian	Sys	
2140	Nhlangano Gneiss	None	Rnl	NA	*	*	Randian	Era	
161	Nhlebela	Formation	Rnh	AP	Bivane	Subgroup	Randian	Era	
2010	Niederhagen Quartzite	Member	Nni	AP	Nudaus	Formation	Namibian	Era	
1004	Nieuwe Post Wes Gneiss	None	K*ni	NY	Brakwater Metamorphic	Suite	Kheisian	Sys	

CODE	LITHO NAME	RANK	LABEL	ST	PARENT NAME	RANK	CHRONO NAME	RANK	PUB
2013	Nigramoep	Member	Nng	NY	Dabis	Formation	Namibian	Era	
157	Nkandla	Formation	Znk	NY	*	*	Swazian	Era	
181	Nkoneni	Subgroup	Rnk	AP	Mozaan	Group	Randian	Era	
440	Nkunzana	Formation	N*nk	AP	Mfongosi	Group	Namaquan	Sys	
1017	Noenoemaasberg Gneiss	None	K*nn	AP	Gladkop	Suite	Kheisian	Sys	
23	Nondweni	Group	Zn	AP	*	*	Swazian	Era	Ca
822	Nooitgedacht Carbonatite	Complex	N*no	AP	*	*	Namaquan	Sys	
762	Nooitgedagt	Member	Nno	AP	Matjies River	Formation	Namibian	Era	LS
2128	Noriseep	Formation	K*ns	NY	Droëboom	Group	Kheisian	Sys	
579	Normandien	Formation	Pn	NY	Adelaide	Subgroup	Permian	Sys	
1702	Norree	Formation	Nnr	NY	Malmesbury	Group	Namibian	Era	
2218	Noubestaan Gneiss	None	N*nn	NY	*	*	Namaquan	Sys	
1772	Noudap Gneiss	None	K*nd	NY	*	*	Kheisian	Sys	
403	Nous	Formation	K*no	AP	Haib	Subgroup	Kheisian	Sys	
1082	Nous West Tonalite	None	N*nw	NY	*	*	Namaquan	Sys	
1692	Nouzees	Suite	N*nz	NY	*	*	Namaquan	Sys	
837	Novengilla Gabbro	Suite	Rno	AP	Rooiwater	Complex	Randian	Era	
2102	Nqwadolo Granite	None	N*nq	NY	Oribi Gorge Granitoid	Suite	Namaquan	Sys	MS
923	Nseleni Gneiss	None	Zns	NY	*	*	Swazian	Era	
24	Nsuze	Group	Rn	AP	Pongola	Supergroup	Randian	Era	
893	Ntabankosi Rhyolite	Suite	Jnt	AP	*	*	Jurassic	Sys	
1691	Ntabayezulu Layered	Suite	Jny	AP	*	*	Jurassic	Sys	Ca
589	Ntabene	Formation	TRn	AP	Karoo	Supergroup	Triassic	Sys	MS
1783	Ntanyana	Formation	Rny	NY	Nkoneni	Subgroup	Randian	Era	
59	Ntingwe	Group	N*n	AP	*	*	Namaquan	Sys	
1732	Ntombe	Formation	Rnt	AP	Dwaalhoek	Subgroup	Randian	Era	
2006	Nudaus	Formation	Nnd	AP	Schwarzrand	Subgroup	Namibian	Era	
477	Numees	Formation	Nnu	AP	Port Nolloth	Group	Namibian	Era	IP
1773	Nuwefontein Granite	None	N*nf	NY	Spektakel	Suite	Namaquan	Sys	
1070	Nuwerus Gneiss	None	N*nu	NY	Little Namaqualand	Suite	Namaquan	Sys	
605	Nxwala	Member	Jnx	AP	Fenda	Formation	Jurassic	Sys	
109	Nylstroom	Subgroup	K*n	AP	Waterberg	Group	Kheisian	Sys	
590	Nyoka	Formation	TRny	AP	Karoo	Supergroup	Triassic	Sys	MS
431	Nzhelele	Formation	K*nz	AP	Soutpansberg	Group	Kheisian	Sys	
1995	Nzimane Granite	None	Rnz	AP	*	*	Randian	Era	Ca
274	Oaktree	Formation	Voa	AP	Malmani	Subgroup	Vaalian	Era	
683	Observatory Shale	Member	Rob	AP	Parktown	Formation	Randian	Era	
1741	Oceola	Member	Voc	AP	Vryburg	Formation	Vaalian	Era	LS
1684	Odwaleni	Subgroup	Ro	AP	Mozaan	Group	Randian	Era	
6	Olifantshoek	Supergroup	K*o	AP	*	*	Kheisian	Sys	
582	Oliviershoek	Member	TRo	NY	Burgersdorp	Formation	Triassic	Sys	
352	Omdraai	Formation	K*om	NY	Biesje Poort	Group	Kheisian	Sys	
314	Ongeluk	Formation	Vo	AP	Postmasburg	Group	Vaalian	Era	
2127	Onseepkans	Formation	K*on	NY	Droëboom	Group	Kheisian	Sys	
16	Onverwacht	Group	Zo	AP	Barberton	Supergroup	Swazian	Era	
2023	Oograbies West Gneiss	None	K*oo	NY	Vioolsdrif	Suite	Kheisian	Sys	
2049	Oorkraal Amphibolite	None	N*oo	NY	*	*	Namaquan	Sys	
1100	Opdam Granite	None	N*op	AP	T'Oubep	Suite	Namaquan	Sys	Ca
196	Orange Grove	Formation	Ror	AP	Hospital Hill	Subgroup	Randian	Era	
56	Orange River	Group	K*or	AP	*	*	Kheisian	Sys	
885	Oranjemund	Formation	No	AP	Gariep	Supergroup	Namibian	Era	IP
874	Oribi Gorge Granitoid	Suite	N*o	AP	*	*	Namaquan	Sys	Ca
237	Orkney	Formation	Rok	AP	Klipriviersberg	Group	Randian	Era	
537	Osberg	Formation	Do	AP	Bidouw	Subgroup	Devonian	Sys	
389	Ou-Eendop	Formation	K*ou	NY	Khurisberg	Subgroup	Kheisian	Sys	
1199	Oudeberg	Member	Po	AP	Balfour	Formation	Permian	Sys	
1196	Oukloof	Member	Pok	NY	Teekloof	Formation	Permian	Sys	
2124	Oupvlakte	Formation	K*op	NY	*	*	Kheisian	Sys	
1682	Ozwana	Subgroup	Roz	AP	Nsuze	Group	Randian	Era	
1996	Paardeberg Granite	None	N/C*p	AP	Cape Granite	Suite	Cambrian	Sys	Ca
1996	Paardeberg Granite	None	N/C*p	AP	Cape Granite	Suite	Namibian	Era	Ca
2087	Paarl Pluton	Pluton	N-C*p	IF	Cape Granite	Suite	Cambrian	Sys	Ca

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2087	Paarl Pluton	Pluton	N-C*p	IF	Cape Granite	Suite	Namibian	Era	Ca
521	Pakhuis	Formation	Opa	AP	Table Mountain	Group	Ordovician	Sys	
1150	Palala Granite	None	Vpl	AP	*	*	Vaalian	Era	
716	Paling	Member	Vpg	AP	Gamagara	Formation	Vaalian	Era	
1203	Palingkloof	Member	Ppa	AP	Balfour	Formation	Permian	Sys	
1217	Palmietfontein	Formation	Rpf	NY	Government	Subgroup	Randian	Era	
946	Palmietfontein Granite	None	Rpm	NY	*	*	Randian	Era	
795	Pannetjie	Formation	Vpn	AP	Koegas	Subgroup	Vaalian	Era	
1710	Papkuil	Formation	Vpa	NY	Campbell Rand	Subgroup	Vaalian	Era	
396	Paradys River	Formation	K*pa	AP	Orange River	Group	Kheisian	Sys	
197	Parktown	Formation	Rpa	AP	Hospital Hill	Subgroup	Randian	Era	
2099	Parys Granite/Gneiss	None	Zpa	NY	*	*	Swazian	Era	
99	Pella	Subgroup	K*pe	AP	Bushmanland	Group	Kheisian	Sys	
279	Penge	Formation	Vpe	AP	Chuniespoort	Group	Vaalian	Era	
520	Peninsula	Formation	Op	AP	Table Mountain	Group	Ordovician	Sys	
1035	Perdeberg Monzonite	None	N*pe	NY	*	*	Namaquan	Sys	
771	Perdepoort	Member	Dp	AP	Witpoort	Formation	Devonian	Sys	
189	Perdeput	Formation	Rpe	AP	Prieskaspoort	Subgroup	Randian	Era	
823	Phalaborwa	Complex	K*p	AP	*	*	Kheisian	Sys	
1728	Pickelhaube	Formation	Npc	NY	Hilda	Subgroup	Namibian	Era	IP
518	Piekenierskloof	Formation	Opi	AP	Table Mountain	Group	Ordovician	Sys	LS
824	Pienaars River	Complex	N*pi	AP	*	*	Namaquan	Sys	
842	Piet Retief Gabbro	Suite	Rpi	AP	Usushwana	Complex	Randian	Era	
1010	Piet Rooi's Puts Gneiss	None	K*pp	NY	Vyfbeker Metamorphic	Suite	Kheisian	Sys	
351	Piet Rooisberg	Formation	K*pb	NY	Biesje Poort	Group	Kheisian	Sys	
570	Pietermaritzburg	Formation	Pp	AP	Ecca	Group	Permian	Sys	
21	Pietersburg	Group	Zp	AP	*	*	Swazian	Era	
480	Piketberg	Formation	Npi	AP	Boland	Subgroup	Namibian	Era	
825	Pilanesberg	Complex	N*p	AP	*	*	Namaquan	Sys	MS
2126	Pipeline Gneiss	None	K*pi	NY	*	*	Kheisian	Sys	
2012	Plaatjiesfontein	Member	Npl	NY	Dabis	Formation	Namibian	Era	
1221	Plat Sjambok	Suite	N*pl	AP	*	*	Namaquan	Sys	Ca
31	Platberg	Group	Rpl	AP	Ventersdorp	Supergroup	Randian	Era	
1742	Pluto's Vale	Member	Ppl	AP	Ripon	Formation	Permian	Sys	LS
334	Poliesberg	Formation	K*po	AP	*	*	Kheisian	Sys	LS
2118	Polisiehoek Granite	None	N*po	NY	*	*	Namaquan	Sys	
942	Pompey Granite	None	Rpo	AP	Vorster	Suite	Randian	Era	
3	Pongola	Supergroup	Rp	AP	*	*	Randian	Era	
1204	Poortjie	Member	Ppo	AP	Teekloof	Formation	Permian	Sys	
516	Populierbos	Formation	C*p	NY	Klipheuwel	Group	Cambrian	Sys	
487	Porseleinberg	Formation	Nps	AP	Swartland	Subgroup	Namibian	Era	
627	Port Durnford	Formation	Qp	AP	*	*	Pleistocene	Ser	
1725	Port Nolloth	Group	Np	NY	Gariep	Supergroup	Namibian	Era	IP
481	Porterville	Formation	Npt	AP	Boland	Subgroup	Namibian	Era	
1177	Post-Transvaal Diabases	None		IF	*	*	Mokolian	Era	
1178	Post-Waterberg Diabases	None		IF	*	*	Mokolian	Era	
1679	Postmasburg	Group	Vpo	NY	Transvaal	Supergroup	Vaalian	Era	
40	Pretoria	Group	Vp	AP	Transvaal	Supergroup	Vaalian	Era	Ca
88	Prieskaspoort	Subgroup	Rpk	AP	Marydale	Group	Randian	Era	
558	Prince Albert	Formation	Ppr	AP	Ecca	Group	Permian	Sys	MS
201	Promise	Formation	Rpr	AP	Government	Subgroup	Randian	Era	
2197	Prospect Hill	Formation	Tp	NY	Sandveld	Group	Miocene	Ser	
363	Prynnsberg	Formation	K*pr	NY	Brulpan	Group	Kheisian	Sys	
355	Puntsit	Formation	K*pu	NY	Biesje Poort	Group	Kheisian	Sys	
1008	Putsies Gneiss	None	K*pt	NY	Vyfbeker Metamorphic	Suite	Kheisian	Sys	
1230	Pypklip Granite	None	N*py	NY	Keimoes	Suite	Namaquan	Sys	
972	Pyramid Gabbro-Norite	None	Vpy	AP	Rustenburg Layered	Suite	Vaalian	Era	
2105	Quagga's Kop	Formation	C^q	NY	*	*	Cenozoic	Era	
172	Qudeni	Formation	Rq	AP	Nsuze	Group	Randian	Era	
1132	Quha	Formation	N*q	AP	Mapumulo	Group	Namaquan	Sys	Ca
1329	Qwasha	Formation	Rqw	AP	Mozaan	Group	Randian	Era	
906	Ramansdrif	Subsuite	K*rm	NY	Vioolsdrif	Suite	Kheisian	Sys	

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215	Randfontein	Formation	Rra	AP	Johannesburg	Subgroup	Randian	Era	
849	Rashoop Granophyre	Suite	Vra	AP	Bushveld	Complex	Vaalian	Era	
367	Ratel Draai	Formation	N*ra	NY	Areachap	Group	Namaquan	Sys	
356	Rautenbach Se Kop	Formation	K*ra	AP	Biesje Poort	Group	Kheisian	Sys	
290	Rayton	Formation	Vry	AP	Pretoria	Group	Vaalian	Era	
778	Red Rocks	Member	Jr	AP	Clarens	Formation	Jurassic	Sys	
180	Redcliff	Formation	Rre	AP	Mozaan	Group	Randian	Era	
1005	Regt Kyk Gneiss	None	K*re	NY	Brakwater Metamorphic	Suite	Kheisian	Sys	
1790	Reivilo	Formation	Vrv	NY	Campbell Rand	Subgroup	Vaalian	Era	
1015	Renosterkop Gneiss	None	N*re	NY	*	*	Namaquan	Sys	
194	Rhenosterhoek	Formation	Rrh	AP	Dominion	Group	Randian	Era	
739	Rhenosterpoort Quartz Porphyry	Member	K*rh	AP	Swaershoek	Formation	Kheisian	Sys	
193	Rhenosterspruit	Formation	Rrs	AP	Dominion	Group	Randian	Era	
888	Richtersveld	Suite	Nr	AP	*	*	Namibian	Era	
1085	Riemvasmaak Gneiss	None	N*rv	NY	*	*	Namaquan	Sys	
322	Riet Put	Formation	K*ri	NY	*	*	Kheisian	Sys	
1043	Rietberg Granite	None	N*ri	AP	Spektakel	Suite	Namaquan	Sys	
826	Rietfontein	Complex	Vrt	AP	*	*	Vaalian	Era	
686	Rietfontein Tillite	Bed	Rrf	NY	Coronation	Formation	Randian	Era	
244	Rietgat	Formation	Rrg	AP	Platberg	Group	Randian	Era	
789	Rietheuvel	Member	Qri	AP	Amanzi	Formation	Quaternary	Sys	
766	Rietkloof	Member	C*r	AP	Vaartwell	Formation	Cambrian	Sys	Ca
209	Rietkuil	Formation	Rrk	NY	Jeppestown	Subgroup	Randian	Era	
2030	Rietpoort Granite	None	Kr	NY	Koegel Fontein	Complex	Cretaceous	Sys	
527	Rietvlei	Formation	Dr	AP	Nardouw	Subgroup	Devonian	Sys	LS
1318	Riffontein	Formation	Vrf	AP	Makeckaan	Subgroup	Vaalian	Era	Ca
1320	Rinkhalskop	Formation	Vri	AP	Rooiberg	Group	Vaalian	Era	Ca
561	Ripon	Formation	Pr	AP	Ecca	Group	Permian	Sys	LS
662	Riverton	Formation	Qr	AP	*	*	Quaternary	Sys	
614	Robberg	Formation	J-Kr	AP	*	*	Cretaceous	Sys	MS
614	Robberg	Formation	J-Kr	AP	*	*	Jurassic	Sys	MS
1189	Robertson Melilitite	None	Tr	AP	*	*	Tertiary	Sys	
2093	Robertson Pluton	Pluton	N-C*r	IF	Cape Granite	Suite	Cambrian	Sys	
2093	Robertson Pluton	Pluton	N-C*r	IF	Cape Granite	Suite	Namibian	Era	
1064	Rok Optel Granite	None	N*rk	NY	Keimoes	Suite	Namaquan	Sys	
1160	Rondavel Syenite	None	N*rn	AP	Pienaars River	Complex	Namaquan	Sys	
827	Roodekraal	Complex	Vre	AP	*	*	Vaalian	Era	
801	Roodekrans	Complex	Zr	AP	*	*	Swazian	Era	
881	Roodeplaat	Suite	N*r	AP	Pienaars River	Complex	Namaquan	Sys	
208	Roodepoort	Formation	Rro	AP	Jeppestown	Subgroup	Randian	Era	
177	Roodewal	Formation	Rrw	NY	Nsuze	Group	Randian	Era	
41	Rooiberg	Group	Vro	AP	Transvaal	Supergroup	Vaalian	Era	
1309	Rooibok Conglomerate	Member	Vrb	NY	Kwarriehoek	Formation	Vaalian	Era	Ca
729	Rooidam	Member	K*ro	NY	Toeslaan	Formation	Kheisian	Sys	
281	Rooihoogte	Formation	Vrh	AP	Pretoria	Group	Vaalian	Era	
1180	Rooiklip Granite	None	C*ro	NY	Cape Granite	Suite	Cambrian	Sys	
948	Rooikop Granophyre Porphyry	None	Vrk	AP	Rashoop Granophyre	Suite	Vaalian	Era	
775	Rooinek	Member	Pro	NY	Normandien	Formation	Permian	Sys	
1235	Rooinekke Iron-Formation	Member	Vrn	NY	Heynskop	Formation	Vaalian	Era	
1223	Rooipoort Gabbronorite	None	Vrp	NY	Rustenburg Layered	Suite	Vaalian	Era	
1048	Rooiputs Granophyre	None	N*ro	AP	*	*	Namaquan	Sys	Ca
770	Rooirand	Member	Dro	AP	Witpoort	Formation	Devonian	Sys	
802	Rooiwater	Complex	Rr	AP	*	*	Randian	Era	
899	Roossenekal	Subsuite	Vrs	NY	Rustenburg Layered	Suite	Vaalian	Era	
1449	Rosedale	Member	Rrd	NY	Elsburg	Formation	Randian	Era	
1743	Rosendal	Member	Vrd	AP	Vryburg	Formation	Vaalian	Era	LS
953	Rostock Bronzitite	None	Vrz	AP	Croydon	Subsuite	Vaalian	Era	
397	Rosyntjieberg	Formation	K*r	AP	Orange River	Group	Kheisian	Sys	
470	Rouxville	Formation	N*rx	AP	Koras	Group	Namaquan	Sys	Ca
349	Rozynen Bosch	Formation	K*rz	NY	Vyfbeker	Suite	Kheisian	Sys	

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					Metamorphic				
146	Rubbervale	Formation	Zru	AP	Gravelotte	Group	Swazian	Era	
970	Ruighoek Pyroxenite	None	Vru	AP	Schilpadnest	Subsuite	Vaalian	Era	
2053	Ruiter Se Berg	Formation	Mru	NY	Kamiesberg	Subgroup	Mokolian	Era	
468	Rusplaas	Formation	N*ru	AP	Koras	Group	Namaquan	Sys	Ca
306	Rust De Winter	Formation	Vrw	AP	Transvaal	Supergroup	Vaalian	Era	
850	Rustenburg Layered	Suite	Vr	AP	Bushveld	Complex	Vaalian	Era	
1175	Rykoppies Gabbro	None	Rry	NY	*	*	Randian	Era	
499	Saasveld	Formation	Nss	AP	Kaaimans	Group	Namibian	Era	
1176	Sabie Sands Granophyre	None	N*ss	NY	*	*	Namaquan	Sys	
266	Sadowa	Formation	Rsa	AP	Wolkberg	Group	Randian	Era	MS
2022	Safnek Gneiss	None	N*sf	NY	Little Namaqualand	Suite	Namaquan	Sys	
633	Saldanha	Formation	Ts	AP	*	*	Miocene	Ser	
2090	Saldanha Batholith	Batholith	N-C*sa	IF	Cape Granite	Suite	Cambrian	Sys	MS
2090	Saldanha Batholith	Batholith	N-C*sa	IF	Cape Granite	Suite	Namibian	Era	MS
2179	Saldanha Quartz Porphyry	None	N/C*sl	NY	Cape Granite	Suite	Cambrian	Sys	
2179	Saldanha Quartz Porphyry	None	N/C*sl	NY	Cape Granite	Suite	Namibian	Era	
1319	Salie Sloot	Formation	Vsa	AP	Makeckaan	Subgroup	Vaalian	Era	Ca
910	Salisbury Kop Granite	None	Zsk	AP	*	*	Swazian	Era	
638	Salnova	Formation	Qs	AP	Algoa	Group	Pleistocene	Ser	LS
2217	Samoep Granite	None	N*se	NY	*	*	Namaquan	Sys	
435	Samungu	Formation	N*sa	AP	Mfongosi	Group	Namaquan	Sys	
908	Sand River Gneiss	None	Zsr	AP	*	*	Swazian	Era	
1774	Sandbaken Metabasite	None	N*sd	AP	*	*	Namaquan	Sys	Ca
332	Sandkoppies	Formation	K*sa	NY	Brakwater Metamorphic	Suite	Kheisian	Sys	
500	Sandkraal	Formation	Nsn	AP	Kaaimans	Group	Namibian	Era	
347	Sandnoute	Formation	K*sn	NY	*	*	Kheisian	Sys	
541	Sandpoort	Formation	Ds	AP	Traka	Subgroup	Devonian	Sys	
353	Sandputs	Formation	K*sd	NY	Biesje Poort	Group	Kheisian	Sys	MS
414	Sandriviersberg	Formation	K*sb	AP	Kransberg	Subgroup	Kheisian	Sys	
128	Sandspruit	Formation	Zs	AP	Tjakastad	Subgroup	Swazian	Era	
1677	Sandveld	Group	C^s	NY	*	*	Cenozoic	Era	MS
525	Sardinia Bay	Formation	Osb	NY	Table Mountain	Group	Ordovician	Sys	MS
1314	Saxonia Grit	Member	Vsx	NY	Kwarriehoek	Formation	Vaalian	Era	Ca
263	Schelem	Formation	Rsc	AP	Wolkberg	Group	Randian	Era	MS
640	Schelm Hoek	Formation	Qsc	AP	Algoa	Group	Holocene	Ser	LS
805	Schiel Alkaline	Complex	Vsc	AP	*	*	Vaalian	Era	MS
901	Schilpadnest	Subsuite	Vss	NY	Rustenburg Layered	Suite	Vaalian	Era	
308	Schmidtsdrif	Subgroup	Vs	AP	Ghaap	Group	Vaalian	Era	MS
497	Schoemanspoort	Formation	C*s	AP	*	*	Cambrian	Sys	Ca
776	Schoondraai	Member	Psc	NY	Normandien	Formation	Permian	Sys	
136	Schoongezicht	Formation	Zsc	NY	Fig Tree	Group	Swazian	Era	MS
496	Schoongezigt	Formation	C*sc	AP	Kansa	Group	Cambrian	Sys	Ca
303	Schrikkloof	Formation	Vsf	AP	Rooiberg	Group	Vaalian	Era	
1079	Schuitdrift Gneiss	None	N*sc	NY	*	*	Namaquan	Sys	
1171	Schurwedraai Alkali Granite	None	Vsu	AP	*	*	Vaalian	Era	MS
117	Schwarzrand	Subgroup	N-C*s	AP	Nama	Group	Cambrian	Sys	
117	Schwarzrand	Subgroup	N-C*s	AP	Nama	Group	Namibian	Era	
261	Sekororo	Formation	Rse	AP	Wolkberg	Group	Randian	Era	MS
264	Selati	Formation	Rsl	AP	Wolkberg	Group	Randian	Era	MS
460	Sequembi	Formation	N*sq	AP	Matigulu	Group	Namaquan	Sys	
2199	Serala	Formation	Rser	AP	*	*	Randian	Era	
955	Serokolo Bronzitite	None	Vse	AP	Croydon	Subsuite	Vaalian	Era	
736	Sesalong Conglomerate	Member	K*ss	AP	Mogalakwena	Formation	Kheisian	Sys	
418	Setlaole	Formation	K*se	AP	Matlabas	Subgroup	Kheisian	Sys	
879	Sezela	Suite	N*sz	AP	*	*	Namaquan	Sys	Ca
997	Shamiriri Granite	None	Rsr	AP	*	*	Randian	Era	
134	Sheba	Formation	Zsh	AP	Fig Tree	Group	Swazian	Era	MS
951	Shelter Norite	None	Vsh	AP	Rustenburg Layered	Suite	Vaalian	Era	
998	Shirindi Granite	None	Rsh	AP	*	*	Randian	Era	

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428	Sibasa	Formation	K*si	AP	Soutpansberg	Group	Kheisian	Sys	
442	Sibudeni	Formation	N*sb	AP	Mfongosi	Group	Namaquan	Sys	
844	Sicunusa Granite	Suite	Rsu	NY	*	*	Randian	Era	
1142	Sikombe Granite	None	N*so	AP	*	*	Namaquan	Sys	Ca
452	Silambo	Formation	N*si	AP	Tugela	Group	Namaquan	Sys	
498	Silver River	Formation	Nsi	AP	Kaaimans	Group	Namibian	Era	
288	Silverton	Formation	Vsi	AP	Pretoria	Group	Vaalian	Era	
945	Singelele Gneiss	None	Rsi	AP	Beit Bridge	Complex	Randian	Era	
1734	Sinqeni	Formation	Rsq	AP	Mozaan	Group	Randian	Era	
714	Sishen	Member	Vsn	AP	Gamagara	Formation	Vaalian	Era	
813	Sithilo Serpentinite-Talc	Complex	N*st	AP	*	*	Namaquan	Sys	
1750	Situndu	Member	Os	AP	Durban	Formation	Ordovician	Sys	LS
501	Skaapkop	Formation	Nsk	AP	Kaaimans	Group	Namibian	Era	
943	Skalkseput Granite	None	Rss	AP	*	*	Randian	Era	
1229	Skeerhok Granite	None	N*sk	NY	Keimoes	Suite	Namaquan	Sys	
392	Skelmpoort	Formation	K*sm	NY	Aggeneys	Subgroup	Kheisian	Sys	
732	Skerpioenpunt	Member	K*sr	AP	Groblershoop	Formation	Kheisian	Sys	
515	Skilpadhek	Group	Rsp	NY	Transvaal	Supergroup	Randian	Era	
412	Skilpadkop	Formation	K*sk	AP	Matlabas	Subgroup	Kheisian	Sys	
772	Skitterykloof	Member	Dsk	AP	Witpoort	Formation	Devonian	Sys	
567	Skoorsteenberg	Formation	Ps	NY	Ecca	Group	Permian	Sys	
2112	Skuitklip Granite	None	N*sku	NY	*	*	Namaquan	Sys	
524	Skurweberg	Formation	Ss	AP	Nardouw	Subgroup	Silurian	Sys	LS
179	Skurwerant	Formation	Rsk	AP	Mozaan	Group	Randian	Era	
607	Slagboom	Formation	Jsl	AP	Suurberg	Group	Jurassic	Sys	Ca
1114	Slaphakskeen Gneiss	None	N*sl	NY	*	*	Namaquan	Sys	
1997	Slent Granite	None	N/C*s	AP	Cape Granite	Suite	Cambrian	Sys	Ca
1997	Slent Granite	None	N/C*s	AP	Cape Granite	Suite	Namibian	Era	Ca
2175	Slippers Bay Granite	None	N/C*sb	AP	Cape Granite	Suite	Cambrian	Sys	
2175	Slippers Bay Granite	None	N/C*sb	AP	Cape Granite	Suite	Namibian	Era	
335	Slypsteenkrans	Formation	K*sl	NY	*	*	Kheisian	Sys	
2114	Smalhoek Gneiss	None	N*sh	NY	*	*	Namaquan	Sys	
298	Smelterskop	Formation	Vsm	AP	Pretoria	Group	Vaalian	Era	
999	Smitskraal Granite	None	Rsm	AP	*	*	Randian	Era	
944	Soekmekaar Granite	None	Rso	NY	*	*	Randian	Era	
783	Soetgenoeg	Member	Kso	AP	Sundays River	Formation	Cretaceous	Sys	
502	Soetkraal	Formation	Nso	AP	Kaaimans	Group	Namibian	Era	
599	Solitude	Formation	P-TRs	AP	Karoo	Supergroup	Permian	Sys	
599	Solitude	Formation	P-TRs	AP	Karoo	Supergroup	Triassic	Sys	
360	Sout River	Formation	K*sv	NY	*	*	Kheisian	Sys	
551	Soutkloof	Formation	Cso	AP	Kommadagga	Subgroup	Carboniferous	Sys	
58	Soutpansberg	Group	K*s	AP	*	*	Kheisian	Sys	Ca
325	Soutputs	Formation	K*so	NY	*	*	Kheisian	Sys	
862	Spektakel	Suite	N*s	AP	*	*	Namaquan	Sys	
321	Spioenkop	Formation	K*sp	AP	*	*	Kheisian	Sys	
828	Spitskop	Complex	N*sp	AP	*	*	Namaquan	Sys	MS
369	Sprigg	Formation	N*sg	NY	Areachap	Group	Namaquan	Sys	
2027	Springbok	Formation	K*sg	NY	Khurisberg	Subgroup	Kheisian	Sys	
1332	Springfontyn	Formation	Qsp	NY	Sandveld	Group	Quaternary	Sys	
623	St Lucia	Formation	Kst	AP	Zululand	Group	Cretaceous	Sys	
1675	Stalhoek	Complex	K*sh	NY	*	*	Kheisian	Sys	
949	Stavoren Granophyre	None	Vsv	AP	Rashoop Granophyre	Suite	Vaalian	Era	
426	Stayt	Formation	K*sy	AP	Soutpansberg	Group	Kheisian	Sys	
988	Steelpoort Park Granite	None	Vsp	NY	Lebowa Granite	Suite	Vaalian	Era	
2177	Steenbergs Cove Granite Porphyry	None	C*sn	AP	Cape Granite	Suite	Cambrian	Sys	
294	Steenkampsberg	Formation	Vsb	AP	Pretoria	Group	Vaalian	Era	
466	Steenkampsputs	Formation	N*ste	AP	Koras	Group	Namaquan	Sys	Ca
1195	Steenkampsvlakte	Member	Pst	NY	Teekloof	Formation	Permian	Sys	
2210	Steenkampsvlei	Member	K*ste	NY	Kraandraai	Formation	Namaquan	Sys	
188	Steenkop	Formation	Rst	AP	Prieskaspoort	Subgroup	Randian	Era	
1016	Steinkopf Gneiss	None	K*sf	AP	Gladkop	Suite	Kheisian	Sys	
2086	Stellenbosch Batholith	Batholith	N-C*st	IF	Cape Granite	Suite	Cambrian	Sys	
2086	Stellenbosch Batholith	Batholith	N-C*st	IF	Cape Granite	Suite	Namibian	Era	

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422	Sterk River	Formation	K*st	AP	Nylstroom	Subgroup	Kheisian	Sys	
671	Sterkfontein	Formation	C^st	AP	*	*	Cenozoic	Era	
140	Steynskraal	Formation	Zst	NY	*	*	Swazian	Era	
1045	Stillerus Metagabbro	None	N*sti	NY	*	*	Namaquan	Sys	
476	Stinkfontein	Subgroup	Nst	AP	Port Nolloth	Group	Namibian	Era	IP
2057	Stoffelskop	Formation	Mst	NY	Kamiesberg	Subgroup	Mokolian	Era	
1999	Stofkraal	Formation	C*st	NY	Brandkop	Subgroup	Cambrian	Sys	
917	Stolzburg Gneiss	None	Zsz	AP	*	*	Swazian	Era	
1078	Stolzenfels Enderbite	None	N*sto	NY	*	*	Namaquan	Sys	
1705	Strandveld	Formation	Qst	NY	Bredasdorp	Group	Quaternary	Sys	
1028	Straussburg Granite	None	N*str	AP	Keimoes	Suite	Namaquan	Sys	Ca
286	Strubenkop	Formation	Vst	AP	Pretoria	Group	Vaalian	Era	
1065	Stukkende Dam Granite	None	N*stu	NY	Keimoes	Suite	Namaquan	Sys	
1775	Styger Kraal Syenite	None	N*sty	NY	Spektakel	Suite	Namaquan	Sys	
362	Sultanaoord	Formation	K*su	AP	Vaalkoppies	Group	Kheisian	Sys	
1169	Sun City Syenite	None	N*su	NY	Pilanesberg	Complex	Namaquan	Sys	
612	Sundays River	Formation	Ks	AP	Uitenhage	Group	Cretaceous	Sys	
895	Sutherland	Suite	Ksu	AP	*	*	Cretaceous	Sys	
79	Suurberg	Group	Js	AP	*	*	Jurassic	Sys	Ca
410	Swaershoek	Formation	K*sw	AP	Nylstroom	Subgroup	Kheisian	Sys	
1084	Swanartz Gneiss	None	N*sn	NY	*	*	Namaquan	Sys	
768	Swart River Phyllite	Member	Nsw	AP	Skaapkop	Formation	Namibian	Era	
1776	Swartbank Granite	None	N/C*sw	NY	Kuboos-Bremen	Suite	Cambrian	Sys	
1776	Swartbank Granite	None	N/C*sw	NY	Kuboos-Bremen	Suite	Namibian	Era	
1210	Swartkop	Formation	Rsw	NY	Marydale	Group	Randian	Era	
780	Swartkops Sandstone	Member	J-Ks	AP	Kirkwood	Formation	Cretaceous	Sys	
780	Swartkops Sandstone	Member	J-Ks	AP	Kirkwood	Formation	Jurassic	Sys	
467	Swartkopsleegte	Formation	N*sw	AP	Koras	Group	Namaquan	Sys	Ca
672	Swartkrans	Formation	C^sw	AP	*	*	Cenozoic	Era	
113	Swartland	Subgroup	Ns	AP	Malmesbury	Group	Namibian	Era	
1077	Swartmodder Granite/Gneiss	None	N*sm	NY	*	*	Namaquan	Sys	
2113	Swartoup Enderbite	None	N*sr	NY	*	*	Namaquan	Sys	
1231	Swartputs Granite	None	N*swp	NY	Keimoes	Suite	Namaquan	Sys	
1718	Swartrant	Formation	Psw	NY	Karoo	Supergroup	Permian	Sys	
544	Swartruggens	Formation	Dsw	AP	Weltevrede	Subgroup	Devonian	Sys	Ca
550	Swartwaterspoort	Formation	Csw	AP	Kommadagga	Subgroup	Carboniferous	Sys	
2096	Swellendam Pluton	Pluton	N-C*sw	IF	Cape Granite	Suite	Cambrian	Sys	
2096	Swellendam Pluton	Pluton	N-C*sw	IF	Cape Granite	Suite	Namibian	Era	
195	Syferfontein	Formation	Rs	AP	Dominion	Group	Randian	Era	
382	T'hammaberg	Formation	K*tm	NY	Nab	Subgroup	Kheisian	Sys	MS
1226	T'Oubep	Suite	N*tb	AP	*	*	Namaquan	Sys	Ca
71	Table Mountain	Group	O-Dt	AP	Cape	Supergroup	Devonian	Sys	Ca
71	Table Mountain	Group	O-Dt	AP	Cape	Supergroup	Ordovician	Sys	Ca
71	Table Mountain	Group	O-Dt	AP	Cape	Supergroup	Silurian	Sys	Ca
738	Tafelkop Conglomerate	Member	K*ta	AP	Mogalakwena	Formation	Kheisian	Sys	
2116	Tafelkop Gneiss	None	N*ta	NY	*	*	Namaquan	Sys	
165	Taka	Formation	Rta	AP	Nsuze	Group	Randian	Era	
127	Tarkastad	Subgroup	TRt	AP	Beaufort	Group	Triassic	Sys	
1398	Tatasberg	Complex	N-C*t	AP	Kuboos-Bremen	Suite	Cambrian	Sys	
1398	Tatasberg	Complex	N-C*t	AP	Kuboos-Bremen	Suite	Namibian	Era	
667	Taung	Formation	Qt	AP	*	*	Pleistocene	Ser	
1193	Teekloof	Formation	Pte	AP	Adelaide	Subgroup	Permian	Sys	
1236	Terra Nostra	Formation	Zte	NY	*	*	Swazian	Era	MS
742	Thalalane Feldspathic Sandstone	Member	K*th	AP	Blouberg	Formation	Kheisian	Sys	
1733	Thalu	Formation	Rtl	AP	Dwaalhoek	Subgroup	Randian	Era	
449	Thawini	Formation	N*tw	AP	Tugela	Group	Namaquan	Sys	
129	Theespruit	Formation	Zth	AP	Tjakastad	Subgroup	Swazian	Era	
162	Thembeni	Formation	Rte	AP	Nsuze	Group	Randian	Era	
840	Thole	Suite	Rth	NY	*	*	Randian	Era	
458	Thondo	Formation	N*th	AP	Matigulu	Group	Namaquan	Sys	
566	Tierberg	Formation	Pt	AP	Ecca	Group	Permian	Sys	MS
1172	Timbavati Gabbro	None	N*ti	AP	*	*	Namaquan	Sys	

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282	Timeball Hill	Formation	Vti	AP	Pretoria	Group	Vaalian	Era	
85	Tjakastad	Subgroup	Zt	AP	Onverwacht	Group	Swazian	Era	
1785	Tobolsk	Formation	Rto	AP	Odwaleni	Subgroup	Randian	Era	
354	Toeslaan	Formation	K*to	AP	Biesje Poort	Group	Kheisian	Sys	
1704	Toggekry	Formation	Zto	AP	Nondweni	Group	Swazian	Era	Ca
447	Tondweni	Formation	N*to	AP	Tugela	Group	Namaquan	Sys	
726	Top Dog	Formation	K*td	AP	Brulsand	Subgroup	Kheisian	Sys	
532	Tra-Tra	Formation	Dtr	AP	Ceres	Subgroup	Devonian	Sys	
122	Traka	Subgroup	Dt	AP	Bokkeveld	Group	Devonian	Sys	Ca
931	Transport Granite	None	Rtr	AP	Mashishimale	Suite	Randian	Era	
10	Transvaal	Supergroup	Vt	AP	*	*	Vaalian	Era	
829	Trompsburg	Complex		AP	*	*	Proterozoic	Eon	
1744	Trumpeters	Member	Ptr	AP	Ripon	Formation	Permian	Sys	LS
402	Tsams	Formation	K*ts	AP	Haib	Subgroup	Kheisian	Sys	
1777	Tsawela Gneiss	None	Zts	NY	*	*	Swazian	Era	
595	Tshidzi	Formation	Pts	AP	Karoo	Supergroup	Permian	Sys	
427	Tshifhefhe	Formation	K*t	AP	Soutpansberg	Group	Kheisian	Sys	
779	Tshipise	Member	Jt	AP	Clarens	Formation	Jurassic	Sys	
1186	Tshokwane Granophyre	None	Jts	AP	*	*	Jurassic	Sys	
61	Tugela	Group	N*t	AP	*	*	Namaquan	Sys	
871	Tugela Rand Layered	Suite	N*tg	AP	*	*	Namaquan	Sys	Ca
1108	Tuins Granite	None	N*tn	NY	*	*	Namaquan	Sys	
1753	Tulini	Member	Ot	AP	Mariannhill	Formation	Ordovician	Sys	LS
443	Tuma	Formation	N*tu	AP	Tugela	Group	Namaquan	Sys	
94	Turffontein	Subgroup	Rt	AP	Central Rand	Group	Randian	Era	
928	Turfloop Granite	None	Rtu	AP	*	*	Randian	Era	
1129	Turtle Bay	Suite	N*tt	AP	*	*	Namaquan	Sys	Ca
1788	Tusschenin	Formation	Rts	NY	Government	Subgroup	Randian	Era	
1166	Tusschenkomst Foyaite	None	N*ts	AP	Pilanesberg	Complex	Namaquan	Sys	
1012	Twakputs Gneiss	None	K*tw	AP	Koelmanskop Metamorphic	Suite	Kheisian	Sys	Ca
1161	Tweefontein Breccia	None	N*tf	AP	Pienaars River	Complex	Namaquan	Sys	
969	Tweelaagte Bronzitite	None	Vtw	AP	Vlakfontein	Subsuite	Vaalian	Era	
830	Tweerivier Carbonatite	Complex	N*tr	AP	*	*	Namaquan	Sys	
489	Tygerberg	Formation	Nt	AP	Malmesbury	Group	Namibian	Era	
270	Tygerkloof	Formation	Rty	AP	Buffelsfontein	Group	Randian	Era	
2014	Uilkraal	Member	Nui	NY	Dabis	Formation	Namibian	Era	
364	Uitdraai	Formation	K*u	AP	Brulpan	Group	Kheisian	Sys	
80	Uitenhage	Group	J-Ku	AP	*	*	Cretaceous	Sys	
80	Uitenhage	Group	J-Ku	AP	*	*	Jurassic	Sys	
853	Uitkomst	Complex	Vui	NY	*	*	Vaalian	Era	
2176	Uitkoms Granite	None	N/C*u	AP	Cape Granite	Suite	Cambrian	Sys	
2176	Uitkoms Granite	None	N/C*u	AP	Cape Granite	Suite	Namibian	Era	
152	Uitkyk	Formation	Zu	AP	Pietersburg	Group	Swazian	Era	
930	Uitloop Granite	None	Rui	AP	Mashashane	Suite	Randian	Era	IP
494	Uitvlug	Formation	C*u	AP	Kansa	Group	Cambrian	Sys	Ca
2129	Uitvlugt Granite	None	Ruv	AP	Mashashane	Suite	Randian	Era	
191	Uitzigt	Formation	Ruz	AP	Doornfontein	Subgroup	Randian	Era	
707	Ulco	Member	Tum	NY	Reivilo	Formation	Vaalian	Era	
625	Uloa	Formation	Tu	AP	*	*	Tertiary	Sys	
773	Ulundi Conglomerate	Member	Ou	AP	Durban	Formation	Ordovician	Sys	LS
2147	Umkwelane	Formation	Tum	NY	Maputaland	Group	Neogene	Sbsys	
703	Union Tin Tuff	Member	Vun	AP	Kwaggasnek	Formation	Vaalian	Era	
1294	Upper	Zone	Vu	IF	Rustenburg Layered	Suite	Vaalian	Era	
2005	Urusis	Formation	Nu	AP	Schwarzrand	Subgroup	Namibian	Era	
804	Usushwana	Complex	Ru	AP	*	*	Randian	Era	
2142	Usutu	Suite	Zus	NA	*	*	Swazian	Era	
1001	Utrecht Granite	None	Vut	AP	*	*	Vaalian	Era	
1237	Vaalfontein Gneiss	None	Rva	NY	*	*	Randian	Era	
1104	Vaalhoek Granite	None	N*va	NY	*	*	Namaquan	Sys	
680	Vaalkop Rhyolite	Member	Rvk	AP	Amsterdam	Formation	Randian	Era	
51	Vaalkoppies	Group	K*va	NY	*	*	Kheisian	Sys	
1023	Vaalputs Granite	None	N*v	NY	Keimoes	Suite	Namaquan	Sys	
416	Vaalwater	Formation	K*vw	AP	Kransberg	Subgroup	Kheisian	Sys	

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493	Vaartwell	Formation	C*v	AP	Kansa	Group	Cambrian	Sys	Ca
358	Valsvlei	Formation	K*vv	NY	Biesje Poort	Group	Kheisian	Sys	
1440	Van Den Heeversrust	Member	Rvh	NY	Elsburg	Formation	Randian	Era	
508	Van Stadens	Formation	Nvs	NY	Gamtoos	Group	Namibian	Era	
1228	Van Wyks Pan	Formation	N*vw	NY	Areachap	Group	Namaquan	Sys	
2000	Van Zylkop	Formation	C*vz	NY	Brandkop	Subgroup	Cambrian	Sys	
70	Vanrhynsdorp	Group	N-C*v	NY	*	*	Cambrian	Sys	
70	Vanrhynsdorp	Group	N-C*v	NY	*	*	Namibian	Era	
1068	Varsput Granodiorite	None	N*vp	NY	Keimoes	Suite	Namaquan	Sys	
634	Varswater	Formation	Tv	AP	Sandveld	Group	Tertiary	Sys	MS
1331	Velddrif	Formation	Qv	AP	Sandveld	Group	Quaternary	Sys	
5	Ventersdorp	Supergroup	Rv	AP	*	*	Randian	Era	
348	Venterskop	Formation	K*vn	NY	*	*	Kheisian	Sys	
1397	Venterspost	Formation	Rve	AP	*	*	Randian	Era	
985	Verena Porphyritic Granite	None	Vvn	AP	Lebowa Granite	Suite	Vaalian	Era	
581	Verkykerskop	Formation	TRv	NY	Tarkastad	Subgroup	Triassic	Sys	
291	Vermont	Formation	Vve	AP	Pretoria	Group	Vaalian	Era	
950	Verongelukspruit Granophyre	None	Vvg	NY	Rashoop Granophyre	Suite	Vaalian	Era	
725	Verwater	Formation	K*ve	AP	Brulsand	Subgroup	Kheisian	Sys	
785	Vetmaak	Member	Kv	AP	Sundays River	Formation	Cretaceous	Sys	
503	Victoria Bay	Formation	Nvi	AP	Kaaimans	Group	Namibian	Era	
979	Villa Nora Gabbro-Anorthosite	None	Vvi	NY	Rustenburg Layered	Suite	Vaalian	Era	
857	Vioolsdrif	Suite	K*vi	AP	*	*	Kheisian	Sys	
563	Vischkuil	Formation	Pvi	AP	Ecca	Group	Permian	Sys	LS
900	Vlakfontein	Subsuite	Vvl	NY	Rustenburg Layered	Suite	Vaalian	Era	
678	Vlakhoek	Member	Rvl	AP	Sinqeni	Formation	Randian	Era	
2021	Vlakmyn Syenite	None	N*vl	NY	Little Namaqualand	Suite	Namaquan	Sys	
1212	Vogelstruisbult	Formation	K*vo	NY	Jacomyns Pan	Group	Kheisian	Sys	
572	Volksrust	Formation	Pvo	AP	Ecca	Group	Permian	Sys	
2209	Volmoed	Formation	K*vl	NY	*	*	Namaquan	Sys	
45	Volop	Group	K*v	AP	Olifantshoek	Supergroup	Kheisian	Sys	
974	Volspruit Pyroxenite	None	Vvo	AP	Zoetveld	Subsuite	Vaalian	Era	MS
530	Voorstehoek	Formation	Dv	AP	Ceres	Subgroup	Devonian	Sys	MS
848	Vorster	Suite	Rvo	NY	*	*	Randian	Era	
315	Voëlwater	Subgroup	Vv	AP	Postmasburg	Group	Vaalian	Era	
757	Vredefontein	Formation	Nvr	AP	Stinkfontein	Subgroup	Namibian	Era	IP
2083	Vredenburg Batholith	Batholith	N-C*vr	IF	Cape Granite	Suite	Cambrian	Sys	IP
2083	Vredenburg Batholith	Batholith	N-C*vr	IF	Cape Granite	Suite	Namibian	Era	
2173	Vredenburg Granite	None	N/C*ve	AP	Cape Granite	Suite	Cambrian	Sys	
2173	Vredenburg Granite	None	N/C*ve	AP	Cape Granite	Suite	Namibian	Era	
151	Vrischgewaagd	Formation	Zv	AP	Pietersburg	Group	Swazian	Era	
728	Vryboom	Formation	K*vr	AP	Brulsand	Subgroup	Kheisian	Sys	
307	Vryburg	Formation	Vvr	AP	Transvaal	Supergroup	Vaalian	Era	LS
571	Vryheid	Formation	Pv	AP	Ecca	Group	Permian	Sys	
727	Vuilnek	Formation	K*vu	AP	Brulsand	Subgroup	Kheisian	Sys	
173	Vutshini	Formation	Rvu	AP	Nsuze	Group	Randian	Era	
905	Vuurdood	Subsuite	K*vd	NY	Vioolsdrif	Suite	Kheisian	Sys	
855	Vyfbeker Metamorphic	Suite	K*vy	NY	Hartbees River	Complex	Kheisian	Sys	
759	Waaihoek	Member	Nwa	AP	Porterville	Formation	Namibian	Era	
548	Waaipoort	Formation	Cw	AP	Lake Mentz	Subgroup	Carboniferous	Sys	
534	Waboomberg	Formation	Dwb	AP	Bidouw	Subgroup	Devonian	Sys	
1350	Wachteenbeetje	Formation	Rwc	AP	Transvaal	Supergroup	Randian	Era	Ca
644	Waenhuiskrans	Formation	Qw	AP	Bredasdorp	Group	Pleistocene	Ser	LS
542	Wagen Drift	Formation	Dwa	AP	Weltevrede	Subgroup	Devonian	Sys	
1727	Wallekraal	Formation	Nw	NY	Hilda	Subgroup	Namibian	Era	IP
1162	Wallmannsthal Foyaite	None	N*wl	AP	Pienaars River	Complex	Namaquan	Sys	
1778	Wangu Granite Gneiss	None	N*wn	AP	*	*	Namaquan	Sys	Ca
642	Wankoe	Formation	Tw	AP	Bredasdorp	Group	Pliocene	Ser	LS
2115	Warmbad Suid Granite	None	N*wb	NY	*	*	Namaquan	Sys	
682	Water Tower Shale	Member	Rwt	AP	Parktown	Formation	Randian	Era	
57	Waterberg	Group	K*w	AP	*	*	Kheisian	Sys	

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565	Waterford	Formation	Pwa	AP	Ecca	Group	Permian	Sys	
1716	Waterkloof	Formation	Pwk	NY	Dwyka	Group	Permian	Sys	
1220	Waterkop	Suite	N*wa	AP	*	*	Namaquan	Sys	Ca
1745	Waterloo	Member	Vwa	AP	Vryburg	Formation	Vaalian	Era	LS
268	Waterval	Formation	Rwa	AP	Buffelsfontein	Group	Randian	Era	
144	Weigel	Formation	Zwe	AP	Gravelotte	Group	Swazian	Era	
1998	Wela	Formation	Zwl	AP	*	*	Swazian	Era	Ca
1167	Welgeval Foyaite	None	N*wg	AP	Pilanesberg	Complex	Namaquan	Sys	
471	Welgevind	Formation	N*we	AP	Koras	Group	Namaquan	Sys	Ca
1717	Wellington	Formation	Pwe	NY	Dwyka	Group	Permian	Sys	
2091	Wellington Pluton	Pluton	N-C*w	IF	Cape Granite	Suite	Cambrian	Sys	
2091	Wellington Pluton	Pluton	N-C*w	IF	Cape Granite	Suite	Namibian	Era	
123	Weltevrede	Subgroup	Dw	AP	Witteberg	Group	Devonian	Sys	
1224	Weltevrede	Formation	Dwe	AP	Witteberg	Group	Devonian	Sys	
657	Wessels	Formation	Twe	AP	Kalahari	Group	Tertiary	Sys	
28	West Rand	Group	Rwr	AP	Witwatersrand	Supergroup	Randian	Era	
794	Westerberg	Member	Vwe	AP	Kuruman	Formation	Vaalian	Era	
235	Westonaria	Formation	Rwe	AP	Klipriviersberg	Group	Randian	Era	
1755	Westville	Member	Ow	AP	Mariannhill	Formation	Ordovician	Sys	LS
1780	White Mfolozi	Formation	Rwh	NY	Bivane	Subgroup	Randian	Era	
559	Whitehill	Formation	Pw	AP	Ecca	Group	Permian	Sys	Ca
2041	Widouw	Formation	Nwi	NY	Gifberg	Group	Namibian	Era	
417	Wilge River	Formation	K*wg	AP	Waterberg	Group	Kheisian	Sys	
1746	Wilgehout River	Member	Pwi	AP	Collingham	Formation	Permian	Sys	LS
53	Wilgenhoutsdrif	Group	N*w	AP	*	*	Namaquan	Sys	
935	Willie Granite	None	Rwi	AP	Vorster	Suite	Randian	Era	
663	Windsorton	Formation	C^w	AP	*	*	Cenozoic	Era	
398	Windvlakte	Formation	K*wi	AP	Orange River	Group	Kheisian	Sys	
2059	Winkelhaak	Member	Rwn	NY	Kimberley	Formation	Randian	Era	
958	Winnaarshoek Norite-Anorthosite	None	Vwn	AP	Dsjate	Subsuite	Vaalian	Era	
2032	Winterhoek	Subgroup	Owi	NY	Table Mountain	Group	Ordovician	Sys	
957	Winterveld Norite-Anorthosite	None	Vwv	AP	Dwars River	Subsuite	Vaalian	Era	
269	Witfonteinrant	Formation	Rwf	AP	Buffelsfontein	Group	Randian	Era	
329	Witklip	Formation	K*wk	NY	Arribees	Group	Kheisian	Sys	
1706	Witkop	Formation	Zwi	AP	Nondweni	Group	Swazian	Era	Ca
1103	Witpad Granodiorite	None	N*wi	AP	T'Oubep	Suite	Namaquan	Sys	Ca
545	Witpoort	Formation	Dwi	AP	Witteberg	Group	Devonian	Sys	
1707	Witrivier	Formation	Zw	AP	*	*	Swazian	Era	Ca
73	Witteberg	Group	D-Cw	AP	Cape	Supergroup	Carboniferous	Sys	
73	Witteberg	Group	D-Cw	AP	Cape	Supergroup	Devonian	Sys	
1013	Witwater Gneiss	None	K*ww	NY	Koelmanskop Metamorphic	Suite	Kheisian	Sys	
4	Witwatersrand	Supergroup	Rw	AP	*	*	Randian	Era	
645	Witzand	Formation	Qwi	NY	Sandveld	Group	Quaternary	Sys	
343	Wolfkop	Formation	K*wo	NY	Vyfbeker Metamorphic	Suite	Kheisian	Sys	
36	Wolkberg	Group	Rwo	AP	Transvaal	Supergroup	Randian	Era	
674	Wolvenkop Ferruginous Quartzite	Bed	Rwl	AP	Mantonga	Formation	Randian	Era	
1747	Wonderfontein	Member	Pwo	AP	Ripon	Formation	Permian	Sys	LS
1179	Woodville Granite	None	N/C*w	NY	Cape Granite	Suite	Cambrian	Sys	
1179	Woodville Granite	None	N/C*w	NY	Cape Granite	Suite	Namibian	Era	
2095	Worcester Granite	None	N-C*wo	IF	Cape Granite	Suite	Cambrian	Sys	
2095	Worcester Granite	None	N-C*wo	IF	Cape Granite	Suite	Namibian	Era	
386	Wortel	Formation	K*wr	NY	Aggeneys	Subgroup	Kheisian	Sys	
457	Woshane	Formation	N*wo	AP	Tugela	Group	Namaquan	Sys	
448	Wosi	Formation	N*ws	AP	Tugela	Group	Namaquan	Sys	
535	Wuppertal	Formation	Dwu	AP	Bidouw	Subgroup	Devonian	Sys	
1168	Wydhoek Foyaite	None	N*wd	AP	Pilanesberg	Complex	Namaquan	Sys	
1088	Wyepoort Granite	None	N*wy	AP	*	*	Namaquan	Sys	Ca
430	Wyllies Poort	Formation	K*wy	AP	Soutpansberg	Group	Kheisian	Sys	MS
1076	Yas Gneiss	None	K*y	NY	*	*	Kheisian	Sys	

CODE	LITHO NAME	RANK	LABEL	ST	PARENT NAME	RANK	CHRONO NAME	RANK	PUB
148	Ysterberg	Formation	Zy	AP	Pietersburg	Group	Swazian	Era	
1333	Yzerfontein Gabbro-monzonite	None	C*y	NY	*	*	Cambrian	Sys	
1098	Zand Vley Granite	None	N*za	AP	T'Oubep	Suite	Namaquan	Sys	Ca
330	Zandbergshoop	Formation	K*z	NY	De Kruis	Group	Kheisian	Sys	
2060	Zandfontein	Member	Rza	NY	Kimberley	Formation	Randian	Era	
150	Zandrivierspoort	Formation	Zza	AP	Pietersburg	Group	Swazian	Era	
2011	Zaris	Formation	Nz	AP	Kuibis	Subgroup	Namibian	Era	
259	Zeekoebaart	Formation	Rz	AP	*	*	Randian	Era	
451	Zidoni	Formation	N*zi	AP	Tugela	Group	Namaquan	Sys	
2100	Zoetfontein Gneiss	None	Rzo	NY	*	*	Randian	Era	
902	Zoetveld	Subsuite	Vzo	NY	Rustenburg Layered	Suite	Vaalian	Era	
372	Zonderhuis	Formation	N*z	AP	Wilgenhoutsdrif	Group	Namaquan	Sys	
2031	Zout Rivier Basalt	None	Kzr	NY	Koegel Fontein	Complex	Cretaceous	Sys	
1748	Zoute Kloof	Member	Pz	AP	Collingham	Formation	Permian	Sys	LS
81	Zululand	Group	Kz	AP	*	*	Cretaceous	Sys	
101	Zuurwater	Subgroup	K*zu	NY	Bushmanland	Group	Kheisian	Sys	
454	Zwaneni	Formation	N*zw	AP	Tugela	Group	Namaquan	Sys	
947	Zwartbank Pseudogranophyre	None	Vz	AP	Rashoop Granophyre	Suite	Vaalian	Era	
133	Zwartkoppie	Formation	Zzw	AP	Geluk	Subgroup	Swazian	Era	
1693	Zwartwater	Suite	Zz	AP	*	*	Swazian	Era	Ca

CHRONO UNIT TEXT LABELS INCORPORATED IN LITHO UNIT LABELS		
TEXT LABEL	**CHRONO NAME**	**CHRONO RANK**
C	CARBONIFEROUS	SYS
C*	CAMBRIAN	SYS
C^	CENOZOIC	ERA
D	DEVONIAN	SYS
J	JURASSIC	SYS
K	CRETACEOUS	SYS
K*	KHEISIAN	SYS
M	MOKOLIAN	ERA
N	NAMIBIAN	ERA
N*	NAMAQUAN	SYS
O	ORDOVICIAN	SYS
P	PERMIAN	SYS
Q	QUATERNARY	SYS
R	RANDIAN	ERA
S	SILURIAN	SYS
T	TERTIARY	SYS
TR	TRIASSIC	SYS
V	VAALIAN	ERA
Z	SWAZIAN	ERA
	MESOZOIC	ERA
	PALAEOZOIC	ERA