

Fine Aggregate Resources in the Greater Cape Town Area

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Research Field: Structural Engineering and Materials
Duration: 2012 - 2013



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To my loving mother, Caroline Walker,
your strength and fighting spirit is an
inspiration to us all.

Acknowledgements

In obtaining a Master degree, there are many pressures placed upon a student that require the loving support of the people surrounding them. As a result I would like to acknowledge a few people who have had an input in helping me achieve my Masters degree.

Firstly I would like to thank my family for all their love and support and for always encouraging me to keep going and to get my work done. My Father, Peter Walker, for all his financial support and for always giving me his fatherly advice, resulting in him inspiring me with many of the thoughts and ideas that have made this dissertation. My Mother, Caroline Walker, who throughout her very hard time suffering with cancer never failed to inspire me and to always make sure I was getting my work done. Her bravery and selflessness inspired me, and her love and support for me was endless. May she rest in peace, knowing that none of this would have been possible without her loving support and guidance.

I would also like to thank Christopher Pullan for his endless hours spent assisting me with the structure and content of my Masters dissertation. He spent so much of his time ensuring that it was the best quality that I could produce. I would also like to thank Chris for supporting my mother and for caring for her unconditionally, allowing me the peace of mind that my mother was being looked after and this allowed me to persevere with my studies.

I would then also like to thank my supervisor for his support and encouragement to produce this dissertation. CoMSIRU also needs to be acknowledged for the financial support, allowing me to obtain my Masters Qualification.

Lastly but not least of all, I would like to thank Samantha Stoffberg and her family for taking me in and treating me like family. Their support was second to none, especially through the difficulties I have endured throughout the duration of my Masters.

Abstract

Fine aggregate resources in the Greater Cape Town area have historically been in abundant supply. This supply has been typically comprised of the extensive natural building sand deposits that are scattered throughout the region. However, over the past decade increasing concerns have been raised regarding their long-term availability. This concern has arisen from reports suggesting the diminishing reserves of naturally occurring fine aggregates, which have historically dominated the market, and are beginning to near the end of their reserve life. The research undertaken in this thesis was to assess the plausibility of this concern and ascertain an understanding as to the future supply of resources in the region.

In order to address the issues raised, a comprehensive understanding of fine aggregates, their properties and their source are required. This was developed in a literature review, whereby this knowledge provided an understanding as to the type of material that is preferable for fine aggregate use.

The findings highlights the importance of using a resource that possesses properties, which are most appropriate for its specific use. In terms of concrete, this is achieved through using materials which possess the following preferred properties: (1) round particle shape and smooth surface texture, (2) a wide range of particle sizes that are well distributed, and (3) a mineralogical composition that is relatively inert, thus is not deleterious in concrete. Additionally, a resource must be economically viable, and be exploited in a manner such that the development aims to safeguard the environment for the benefit of current and future generations. These concepts and principles were then applied to the subsequent study into the fine aggregate resources located within the greater Cape Town region.

The study concluded that there is a forthcoming supply shortage of natural fine aggregates in the Greater Cape Town area. This shortage is not due to the complete depletion of these resources, but rather due to increased difficulty of the accessibility of sands suitable for use in concrete. In estimation of the available resource remaining, figures reported by Cole from the Council for Geoscience in 2011 have suggested that there is approximately a residual supply of building sands that could last between 10 and 20 years.

The situation has been exacerbated by the apparent lack of price differential on the rapidly depleting natural resources that have significant value to the construction industry. This appears to be a pricing anomaly, which the market is not recognising. Additionally, the exploitation of new natural sand deposits is becoming increasingly rare, as in most cases these deposits suffer from inaccessibility issues for reasons attributed to: competing land uses, environmental considerations, or the limited extent of their reserve life. The attraction towards resources outside of the Greater Cape Town area is limited due to their considerable distances that they lie from the consumer market, thus making them virtually uneconomical for use.

However, the situation conveyed in the media reports sanctioned by the City of Cape Town on the shortage of fine aggregate supply within the region, are not as critical as portrayed to the public. There are vast 'hard rock' deposits that are present within the region that can be used to produce crushed fine aggregate. This resource was initially limited due to the inferior aggregate produced and higher cost per unit supplied, though with technological improvements, these issues have become less of a factor. As a result, these resources have already begun to provide a considerable proportion of fine aggregates supplied within the region.

In terms of future supply of fine aggregates within the Greater Cape Town area, there are additional resources that are suggested to have considerable potential. These resources comprise of the offshore marine sands, site derived materials and recycled aggregates. However, each resource has obstacles that need to be overcome in order for them to be utilised. These obstacles consist of: economic, and environmental difficulties. Subsequently these resources have been identified for potential research topics that should be researched further, in order to properly gauge their full potential.

In conclusion, the future supply of fine aggregates in the greater Cape Town region is relatively secure and will primarily be constituted by crushed aggregate resources. Additional resources such as the diminishing supply of natural sands, site-derived and recycled aggregates, will supplement this supply. In cases where the aggregate quality is insufficient, it can be used in sub-grade uses, or blended with another resource, in order to produce an aggregate appropriate for use. Currently the primary factor dictating an aggregates usage, is its economics, however progress has been to make their environmental footprint more important. This requires further research as the current metrics guiding this progress are unable to quantify all environmental impacts, such as the effects experienced on the local ecosystem and the surrounding settlements.

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List of Abbreviations

ca.	-	Circa (approximately)
CGS	-	Cape Granite Suite
C&CI	-	Cement and Concrete Institute of South Africa
C&D	-	Construction and Demolition
FM	-	Fineness Modulus
GDP	-	Gross Domestic Product
ha	-	Hectare
ICE	-	Institution of Civil Engineers
ITZ	-	Interfacial Transition Zone
kg	-	Kilogram
km	-	Kilometre
l	-	Litre
MG	-	Malmesbury Group
m	-	Metre
m ³	-	Cubic metre
mm	-	Millimetre
Mt.	-	Million tons
SF	-	Springfontein Formation
TMG	-	Table Mountain Group
WF	-	Witzands Formation

Glossary of Terms

- Carbon Footprint - The amount of carbon dioxide released into the earth's atmosphere as a result of the activities of a particular individual, organization or population. (Oxford Dictionaries, 2012)
- Ecological Footprint - The demand that humans place upon the Earth's ecological resources, typically expressed as the amount of land that is required to sustain a given population's use of natural resources. (Oxford Dictionaries, 2012)

Engineering Terminology

- Aggregates - Materials that form a component of composite materials such as concrete, and are used to dilute the cement paste creating more stability, strength and durability. They are formed by the natural disintegration of rock or created by mechanical crushing or milling. They are used in the form of sand, gravel and crushed stone, however other sources are recycled concrete, slag and geosynthetic aggregates. (Grieve, 2009)
- Concrete - Concrete is a composite material used for structural purposes in the Construction Industry, typically consisting of cement, aggregate (both a fine and coarse component) and water. It can also include the addition of cement extenders and admixtures to enhance specific material properties required. (Grieve, 2009)
- Coarse aggregate - Coarse aggregate consists of stone sized particles that are of a particle size such that they are retained in a sieve consisting of square apertures of nominal size 4,75mm.
- Crushed aggregate - Aggregate that is obtained from the artificial crushing of rock material. (Alexander & Mindess, 2005)
- Fill sand - Aggregate used to build up an area of land. (Oxford Dictionaries, 2012)
- Fine aggregate - Fine aggregate is a term used to describe the material that is of a particle size such that 90% of the material passes through a sieve consisting of square apertures of nominal size 4.75mm and retained on a sieve consisting of square apertures of nominal size 0,075mm. This material generally consists of sand. (Grieve, 2009)
- Foundry sand - Foundry sand is a silica-based sand this is combined with clay or oils etc., to create a mould that is used for the casting of metal shapes. (Oxford Dictionaries, 2012)
- Grading - Grading is the particle size and distribution of aggregate material, typically defined as the cumulative percentage of the mass of particles passing through sieves of standard aperture sizes. (Grieve, 2009)

- Mineralogical composition - The chemical properties of the fine aggregate particles used in a concrete mix. (Smith & Collis, 2001)
- Mortar - Mortar is a mixture consisting essentially of cement, sand and water. It also is used to describe the hardened form of this mixture. (Smith & Collis, 2001)
- Natural aggregate - Aggregate comprised of material that occurs naturally in the environment. These sources comprise of colluvial and hillwash, fluvial, alluvial, aeolian and marine sands. (Alexander & Mindess, 2005)
- Particle shape - The external profile, outlining the shape of the aggregate particles, typically defined according to sphericity, roundness and form. (Barrett, 1980)
- Plaster - Plaster is a composite material consisting of a binder (lime, gypsum or cement), sand and water that harden to form a smooth, flat surface on walls or ceilings. (Cement & Concrete Institute (C&CI), 1998)
- Recycled aggregate - Aggregate comprising material obtained through the processing of reclaimed concrete derived from the demolition of concrete structures. (Grieve, 2009)
- Surface texture - The feel, appearance and consistency of the surface of the aggregate particles. (Alexander & Mindess, 2005)

Geological Terminology

- Aeolian Sands - Aeolian sands, also known as Eolian Sands, are sands formed in sedimentary structures as a result of erosion, transportation and deposition, accomplished by wind. (American Geological Institute, 1997)
- Alluvium - Alluvium is a term given to material (clay, silt, sand and gravel or other similar unconsolidated material), deposited from a stream or river. This material would have been deposited in relatively recent geological time. These deposits are substantially more developed towards the lower end of the river's watercourse, where the gradient has flattened out. (American Geological Institute, 1997)
- Attrition - Attrition is the process of wearing down of rock fragments or particles by frictional forces placed upon them through regular impacts between other surfaces that occur in their movement due to wind, waves and running water. This results in the rock fragments and particles being broken down further into smaller fragments and particles. (American Geological Institute, 1997)
- Colluvial sands - Colluvial sands are a type of colluvium, where the sediments have been deposited as a result of viscous flows. These viscous flows refer to mud flows, debris flows and soil creep. As a result of the viscous flows, these soils also contain sediment transported in the viscous liquid combined with the eroded material, thus have a greater concentration of clays and silts, than that of hillwash sands. (Cole & Viljoen, 2001)

- Colluvium - Colluvium is any loose, heterogeneous mass of soil material and/or rock fragments that have been deposited at the base of slopes or hillsides, by gradual soil creep due to gravity or rain-wash or sheet-wash. (American Geological Institute, 1997)
- Digenesis - Digenesis refers to all of the physical, chemical and biological changes that sediment undergoes after its initial deposition. It consists of weathering and metamorphism, occurring during or after lithification of the deposit. (American Geological Institute, 1997)
- Erosion - Erosion is a geological process of materials of the Earth's crust that are mechanically broken-down and simultaneously transported from one place to another, through natural processes. These mechanical processes include the breakdown of material through abrasion due to running water (inclusive of rainfall), wind, moving ice or waves and currents. (American Geological Institute, 1997)
- Fluvial sands - Sands that are transported by, suspended in, and deposited by a river or stream. (American Geological Institute, 1997)
- 'Hard' rock - 'Hard' rock is consolidated rock that underlies the surface of the earth, typically constituted by igneous or metamorphic rock. (American Geological Institute, 1997)
- Heterogeneity - Heterogeneous is a term used to describe a geological deposit that is lacking in uniformity, thus consisting of a variety of minerals. (American Geological Institute, 1997)
- Hillwash sands - Hillwash sands are a type of colluvium, where the sediments have been deposited as a resultant of water flows, which are in the form of sheet-wash, rill-wash and gullies (large rills). This does not refer to sediments that have been transported by large water features such as rivers. (Cole & Viljoen, 2001)
- Lithification - The process involving the transformation of newly deposited, unconsolidated sediment into solid rock. This involves processes of cementation, compaction, desiccation and crystallization. This can occur concurrent, or shortly to a long time after deposition occurs. (American Geological Institute, 1997)
- Longshore drift - Material (sand, shingle and shell fragments) that is moved along the shore through waves and longshore drift current. The long shore drift current is caused by the approach of waves to a coast at an angle. (American Geological Institute, 1997)
- Sedimentology - Sedimentology is the scientific study of sedimentary rocks and the processes that form them. (American Geological Institute, 1997)
- 'Soft' rock - Soft rock is unconsolidated rock fragment that overlies the bedrock, composed of muds and sands. (American Geological Institute, 1997)

- Soil - The upper layer of the earth in which plants grow, typically consisting of a composition of organic remains, clay and rock particles. This layer overlies the 'hard' and 'soft' rock layers, composed of consolidated and unconsolidated rock material. (Oxford Dictionaries, 2012)
- Soil creep - Creep is the slow movement of mineral, rock and soil particles down a slope due to gravitational forces. It may appear to be continuous, however it is the sum of numerous minute, discrete movements. This movement occurs when the gravitational forces become greater than those of the frictional forces between the slope surface and the material particles. (American Geological Institute, 1997)
- Sorting - The distribution of grain sizes of sediments in unconsolidated deposits. Particles of a similar size and low variance are referred to as well sorted, compared with sediment sizes that are mixed and have high variance, which are referred to as poorly sorted. (American Geological Institute, 1997)
- Talus - Talus is rock fragments that have been deposited at the foot of a cliff or steep, rocky slope. The material varies in size and shape, however it is typically coarse and angular. (American Geological Institute, 1997)
- Till - A till is a glacial deposit that consists of unconsolidated, unsorted and unstratified rock material deposited directly beneath a glacier. It consists of a heterogeneous mixture of clay, silt, sand, gravel and boulders, varying in size and shape. (American Geological Institute, 1997)
- Water column - A water column is a vertical distance or depth of water specified from the surface of the river, to the bottom of the sediments. (American Geological Institute, 1997)
- Weathering - Weathering is the physical disintegration and chemical decomposition of rocks, resulting in the eventual breakdown of a rock causing sediments to break off. (American Geological Institute, 1997)

Section I

Literature Review

The subject of this dissertation concerns the fine aggregate resources used in the construction industry in the Greater Cape Town area. Historically the bulk of resources used, consisted of naturally occurring sands, however due to extraction these reserves and their finite nature, they are becoming exhausted. The trend over the past few decades has been to move towards crusher sands, which have become increasingly popular. There are also several alternative resources that have been suggested as potential resources to supplement the future supply and ensure that the future demand is met.

In order to accurately evaluate this trend and future potential resources, it is important to develop an in-depth understanding of the fine aggregates, based on literature research. This section provides this background information, which offers an understanding of the current status of the aggregate industry and market to be achieved. This understanding is developed through the following chapters:

- Chapter 1: Introduction - This is the introduction of the research defining the subject of study
- Chapter 2: Origin of Fine Aggregate Resources - This phase analyses the different sources of naturally occurring fine aggregates and their rock characteristics,
- Chapter 3: Properties of Fine Aggregates - This chapter identifies the important properties of fine aggregates and their impact on the resulting concrete. The focus is initially on the end use of the concrete. This will give an explanation as to the important properties required for use and thus dictate the processing required of each resource, and lastly
- Chapter 4: Production of Fine Aggregates - This chapter discusses how the different sources of aggregates are exploited, and how the material is processed, so that the resulting aggregate has the necessary properties for concrete use.

Chapter 1

Introduction

1.1 Background to Study

Change is inevitable and is constantly occurring in the world. However, when this change occurs at a rapid rate it can result in an inability of the environment to accommodate the transformation, leading to detrimental impacts upon the environment. Such a situation developed when the global population grew from 1.5 billion people in the early 1900's to 7 billion people in 2011. Over the same period urbanisation has increased from 10% to nearly 50%. This dramatic increase in the global population and its urbanisation has resulted in larger pressures being placed upon the natural resources of the planet, and therefore the global ecological footprint continues to increase. This refers to the demand that humans place upon the Earth's ecosystems. (Mertha, 2002)

The increase in population is not the only factor contributing towards the pressure placed upon the planet's natural resources. The continued demand for economic growth within nations is also responsible. The economic activity level of a country is generally represented by its Gross Domestic Product (GDP), which is a measure of the total goods and services produced within a country over the period of one year. (Oxford Dictionaries, 2012) The annual growth of an economy can therefore be measured by the GDP increase. The GDP is often perceived to be an indicator referring to the standard of living within a country. Therefore, one of the factors contributing to the growth of GDP is the increase in buildings and development of the infrastructure so that there are better facilities to aid the nation in improving the quality of life. Economic growth is also an important factor in the alleviation of poverty. (Brundtland, 1987)

1.1.1 Impact of growth upon the Construction Industry

The effects of growth in the global population and economy have been noticeable in the Construction Industry, as there has been an increasing demand for buildings and infrastructure, to support the population increases. Construction of new structures to support this growth requires the use of building materials, which results in the consumption of non-renewable natural materials. According to a study of the US Geological Survey conducted in 2008, an estimated 60% of material flows in the US Economy (excluding fuel and food) are derived from the construction industry. (Atkins & Melton, 2004) It is also responsible for the consumption of vast amounts of energy through manufacturing and transporting these materials. According to Becchio and his fellow researchers in an article on improving the sustainability of concrete products, it is estimated that approximately 20–25% of the entire world energy is expended in the production of construction materials. (Becchio et al., 2009)

1.1.2 Impact of growth upon Construction Materials

The construction of buildings and infrastructure requires the use of construction materials, thus with the increase in growth of the Construction Industry, there has been an increase in the demand for building materials.

Concrete is the most widely used construction material around the world. More than 7.5 billion cubic metres of concrete are being produced annually and this output is steadily increasing. (USGS, 2007) However, the main constituents of concrete are non-renewable in nature, thus it is resulting in the depletion of natural resources. (Aïtcin & Mindess, 2011)

1.1.3 Impact of growth upon Civil Engineering

According to the Brundtland Commission sustainable development can be defined as “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs”. (Brundtland, 1987) In the case of civil engineering, the impacts upon the environment includes the depletion of natural resources, the carbon footprint of the construction industry and its consumption of energy, among other factors. Civil engineers should take their responsibility for the design and use of materials seriously and undertake the consumption of resources in a manner that does not leave a compromised legacy for future generations and minimises the impact. This is stressed in a definition of civil engineering according to the Institution of Civil Engineers (ICE), which stipulates that it is the responsibility of the Civil Engineer “ to create and maintain a sustainable natural and built environment”. (Institution of Civil Engineers (ICE), 2007)

1.2 Definition of Important Concepts

The physical parameters required of a fine aggregate are dictated by its use in a composite material, such as its use in concrete. Consequently it is important to understand the use of the composite material and its properties in order to better understand the function and requirements of the aggregate. The use of fine aggregates can be divided into two different categories consisting of building sands and concrete sands. Building sands are fine aggregates used as in mortar and plaster. However, discussion of fine aggregate resources often centres on its use in concrete. This is due to concrete being the most widely used construction material in the world. In this document, the concepts discussed focus on its use in concrete. It is however important to note that the concepts discussed are similar for mortar and plaster use. The only differences are that the requirements for concrete are more stringent due to its importance as a structural element, and as a result higher quality materials are required. (Aïtcin & Mindess, 2011)

1.2.1 Defining Concrete

Concrete is a composite material that is used predominantly for structural purposes in the construction industry. It is cast and cured to form structural and non-structural components in buildings and other structures. The main factors defining the selection of concrete compared with that of other structural materials, is the fact that it is a material of high strength and durability. It is thus able to sustain relatively high loads for the life of a structure, without being compromised by the processes of weathering that act upon it. (Grieve, 2009)

Concrete is composed of three major constituents: cement (binder), aggregate and water. Each constituent plays an important role in controlling the strength and durability of concrete. The aggregate component is especially important in achieving this, because it constitutes approximately 60 to 80% by volume of concrete mixes. Aggregates perform two roles within the concrete. Its primary function is to create the structural framework of the concrete matrix. This is created through the packing of the aggregate together to form an aggregate matrix, where the particles interlock thus giving a structure to

the concrete. The second function is achieved through the finer material (fines), which supplements the cement paste by acting as filler, which occupies the void space between the framework grains. (Alexander & Mindess, 2005)

1.2.1.1 Concrete as a Structural Material

Concrete, as previously mentioned, is an important structural material; therefore its strength and durability are its most important characteristics. These characteristics are influenced by two intrinsic factors: the porosity and permeability of concrete, and the mineralogy of the aggregate used in the concrete. (Grieve, 2009)

The porosity and permeability of the concrete refers to the void or pore space of the concrete and the connectivity of these voids. There is a correlation between these properties and the strength and durability of the concrete. The lower the porosity and permeability of the concrete, the more tightly packed the intrinsic framework and the greater the strength. This also has an impact upon the concrete's durability. With lower porosity and permeability, water ingress is considerably reduced. This will therefore limit the ability of water to penetrate the concrete, particularly if it contains deleterious constituents, which can react with the concrete, changing its chemical composition, and causing degradation of the structure. Consequently the concrete is able to maintain its strength for a longer period of time. (Grieve, 2009)

The other major impact on durability relates to the mineralogical composition of the aggregate and the subsequent effects, when used in concrete. It is essential to use chemically inert aggregates, as this will ensure that there is little or no reactivity between constituents in terms of grain weathering or chemical reactions. This could cause detrimental changes of the framework or filler grains over the life of the structure. (Grieve, 2009)

Although the intrinsic properties influence the strength and durability of concrete, the ideal situation in which the most optimal concrete is produced is not always achievable. This is since it is heavily dependant upon the aggregate resources used. There are certain intrinsic physical properties pertaining to an aggregate derived from a natural source, and so in order for these properties to be modified a degree of processing, post excavation, is required. This processing comes at an additional cost, which in some cases may not be economically viable. Consequently every concrete mix designed and used is created with a degree of balance and compromise. This is up to the discretion of the designer for any given situation. (Grieve, 2009)

1.2.2 Defining Aggregates

Aggregates are defined as mineral constituents, in granular or particulate form that are used in building and construction work in the construction industry. (Oxford Dictionaries, 2012) The purpose of the aggregate is to add strength and stability to the composite material in which it is used. They can be divided into two different categories based on particle size: fine and coarse aggregate. This dissertation is concerned with fine aggregates, which is the material that consists of finely divided rock and minerals that pass through a 4,75mm sieve. Fine aggregates are used in the construction industry mainly in concrete, however they are also used in mortar, plaster and for fill material. (Grieve, 2009)

1.2.2.1 Types of Fine Aggregate Sources

The properties of aggregates, as discussed previously, are important in influencing the properties of concrete. There are certain key properties that influence the strength and durability of the concrete produced. These properties can be grouped into three categories: particle size and distribution, mineralogy, and texture. (Grieve, 2009)

The source, from which an aggregate is obtained, has a significant influence upon its properties. In terms of fine aggregate resources, there are three primary sources used in the construction industry: natural aggregates, crushed aggregates, and site-derived and recycled aggregates. Natural aggregates are the most commonly used of these resources, however as these resources become depleted there has been a move towards the use of crushed material and to a much lesser extent recycled sources. (Grieve, 2009)

a) Natural Fine Aggregate Resources

Natural fine aggregates consist of sands that occur naturally in the environment. These aggregates are characteristically strong and relatively inert, due to their chemical constituents and origin. These characteristics are primarily dominated by the silica content (silicon dioxide - SiO_2), which constitutes the main component of any arenaceous deposit. This mineral commonly occurs in the form of quartz, which is an extremely hard and chemically stable mineral. (Grieve, 2009)

However, silica is not the only constituent found in these aggregates. Sands can also contain feldspars, lithic or rock fragments, as well as heavy minerals. The feldspars are less stable and easily weather, losing their strength and transforming into clays that are deleterious when used in fine aggregate. The lithic or rock fragments and heavy mineral component are normally chemically stable and strong. The heavy minerals are commonly found in the form of garnet, zircon, rutile or ilmenite. (Grieve, 2009)

Natural aggregates typically occur in deposits of material formed by natural sedimentation processes. Consequently they are found in four core depositional settings; alluvial or colluvial systems, fluvial or river setting, aeolian deposits in a dune or beach setting, and marine deposits. (Cole & Viljoen, 2001)

b) Crusher Sands

Crusher sands are sands that are derived through the crushing of rock, in crushing plants. They were initially introduced as an alternative to natural sand resources. However, they have become especially important in regions that have a shortage of natural sands of suitable quality. (Grieve, 2009)

Initially after the introduction of crushed sources, there was still the tendency to prefer natural resources due to their superior properties. The main concerns were the properties pertaining to particle shape and texture that impact upon the water requirement of concrete mixes. However, as crushing techniques have improved, the quality of the crushed product has improved. Consequently these resources are being used with increasing frequency. (Grieve, 2009)

There are also certain advantages of crushed aggregates that are not always widely appreciated. Modern crushing technologies can exercise great control on the grading and texture of the aggregate. This has resulted in the ability to produce a particle shape equivalent or even superior to that of natural sands. The aggregate producing plants also have a greater capacity to consistently produce uniform grading, compared with the natural sands are dependant on the stratum of the deposit being exploited at any given time. The sand produced is less likely to be contaminated with clay minerals and other deleterious components that are present in natural materials. Subsequently, higher fines content are often allowed

in specifications when derived from these sources. In addition, as the natural resources continue to be depleted and the crushing technologies are improved and become more efficient, the cost of the crushed resources will become more competitive with natural sources. (Alexander & Mindess, 2005)

A developing global trend exists, whereby the fine aggregate resources used are often from multiple sources, which are blended together to meet the desired composition and grading requirements for a specific use in the construction industry. This technique is becoming more important as natural aggregate resources are becoming exhausted. This blending depends on the material properties required by its use in concrete, mortar, plaster or fill. (Grieve, 2009)

c) Site Derived Aggregate Resources

Site-derived aggregates refer to the use of naturally occurring on-site material as an aggregate resource. This entails the use of soils obtained from the excavated material on site for construction purposes such as in concrete, mortar, plaster and filler applications. This is believed to be a sustainable method of construction as it involves the use of materials in the immediate vicinity, instead of using a virgin resource, thus reducing the amount of material wastage. In addition, the use of these resources helps to reduce the transportation incurred. This is reduced since the transport required for the removal of existing waste material and the delivery of virgin materials to the site are not necessary. (O'Neill-Williams, 2012)

However, in results represented in a study, conducted by O'Neill Williams, these observations were somewhat contradicted. Although his research confirmed the possibility of using site-derived aggregates as a resource, it was found to be not potentially as sustainable as initially believed. This is primarily dependent on the quality of the on-site materials, which can sometimes be inferior. The inferior quality typically can be attributed primarily to three factors: the micro-fines content, the clay fraction of the micro-fines content, and the organic content. In short these properties can have a deleterious impact on the concrete, causing high water demands, high shrinkage effects, retardation of the cementing reactions and subsequently a reduced overall strength and durability of the concrete. (O'Neill-Williams, 2012)

The results produced did however reflect a high degree of variability in the resulting effects on concrete, from similar specimens. This indicates that there is a high degree of variability of the geology within a given location and subsequently in each scenario the on-site material will require testing to determine its potential use. (For more information on the required aggregate properties, refer to Chapter 2: Fundamentals of Fine Aggregates)

In conclusion, the use of site-derived materials should be determined at the design phase of a project. This use will vary depending on the geological composition of the site in question. Considerations should be made with respect to the purpose for which the material is to be used. If the material is to be used in concrete, provisions should be made for on-site processing. This should comprise of grading of the aggregate to obtain the desired particle size distribution, and the removal of clay and organic contents. In theory the local site material could completely replace the aggregate from local quarries, however in practice it would often be necessary to supplement this material with aggregate from external sources.

d) Recycled Aggregates

The last source is that of recycled aggregates, which consist of material obtained from reclaimed concrete, derived in the demolition of pre-existing concrete structures. It is a resource that has only begun to become increasingly attractive as an aggregate source in the last decade. This can be attributed to the depletion of natural aggregate reserves and the problems associated with waste disposal sites. These problems include: the lack of available space for the disposal of construction waste, and the increased costs incurred through the transportation and disposal of waste material in dump sites, which now lie further away. (Evangelista & de Brito, 2004)

Traditionally, recycled aggregates have been used as coarse aggregates only. This was because it was believed that the fine proportion was unsuitable for use, due to the presumed high water absorption, which would consequently lead to a weakened performance of the concrete in terms of both its mechanical properties and durability. However, subsequent research conducted has suggested that blending of recycled fine material by up to 30% within the aggregate is acceptable without any diminution of concrete properties. (Evangelista & de Brito, 2004)

In conclusion recycled aggregate is becoming an increasingly used resource. It is generally used in concrete mixes of lower structural importance. However, providing the aggregate is of an adequate quality, it can be used as a partial replacement of fine aggregate, and used in concrete mixes of higher structural importance. It is an important resource in reducing the environmental impact placed upon the world by the construction industry. (Evangelista & de Brito, 2004)

1.3 Problem Description

In the Cape Town area there has been significant growth in the population and economic development, resulting in an expansion of housing, industry and infrastructure, met by an escalation of building activity. (Cole & Viljoen, 2001) This has directly impacted upon the demand for construction materials to meet this need. Concrete is the most important construction material due to its superior structural properties, versatility and cost. It is a composite structural building material that consists of cement, aggregate (both coarse and fine) and water. Approximately 70–80% of concrete is constituted by aggregates and thus the growing demand for them directly impacts upon aggregate resources. (Alexander & Mindess, 2005).

Fine aggregate was historically a relatively cheap, readily available commodity in the Greater Cape Town area. However, it has become clear for over a decade that a shortage of natural building sand, especially sand for concrete, is developing (Cole & Viljoen, 2001). These shortages are not only due to the lack of suitable sources but also due to the inability to access the identified resources due to environmental concerns or alternative land use. (Alexander & Mindess, 2005)

Many publications highlight this concern for the shortage of construction aggregates, however there is little literature that assesses the alternative sources of construction aggregate to meet future demand that are economically and environmentally feasible.

1.4 Significance of Research

Aggregates form an important component of the construction industry. They are used for fillers, in plaster, stabilised soil, mortar and concrete. Of these applications, their use in concrete is probably the most important and represents the highest volume, since concrete is the most commonly used material in the construction industry. As a fundamental part of the construction industry, it is imperative that there is an economically viable source that is available to meet future demand.

According to a study conducted in 2001 by Cole and Viljoen on the potential of building sands in the Greater Cape Town area, 2.2Mt of concrete was consumed annually. Cape Town had approximately 102Mt of reasonably assured fine aggregate, which would last approximately 46 years assuming no increase in the rate of consumption. However if only sand appropriate for concrete construction is considered, there is a reserve of only 32 Mt. At current levels of production the reserve life was approximately 35 years in 2001. (Cole & Viljoen, 2001)

These statistics indicate that the sand supplies, currently being accessed, will not be able to sustain the future demand; therefore it is important to assess the alternative sources and devise a plan of action that will most effectively meet the future demand in a manner that minimises the environmental impact.

1.5 Scope and Limitations of Research

The scope of this thesis document is to determine the long-term availability of fine aggregate resources in the Greater Cape Town area. This has been carried out through assessing the accessibility of the resources located within this region for fine aggregate production. To gain better understanding of the scope of the research discussed the following aspects are defined: the study region, the layout of the research conducted (plan of development), and limitations of the research.

1.5.1 Study Region

For the purpose of this dissertation it is important to define the region of study that is referred to as the Greater Cape Town area. This region the area of the Western Cape that has the largest urban population, thus accounting for the greatest demand on aggregate resources in the province. It is located on the western side of South Africa at its southern-most point. The area is constituted primarily by the Cape Town district, which is the region that extends from Table Mountain across False Bay to the East and up to Atlantis in the North. The Greater Cape Town area also includes the urban areas that lie just outside of the Cape Town district. These are the regions that border the Cape Town district, located along the borders of the West Coast, Boland (also referred to as the Cape Winelands) and Overberg districts. (See map represented in Figure 1.1)

1.5.2 Plan of Development

The research evaluates the long-term availability of fine aggregate resources in the Greater Cape Town area in a study conducted in a series of phases. These phases have been compiled into three sections:

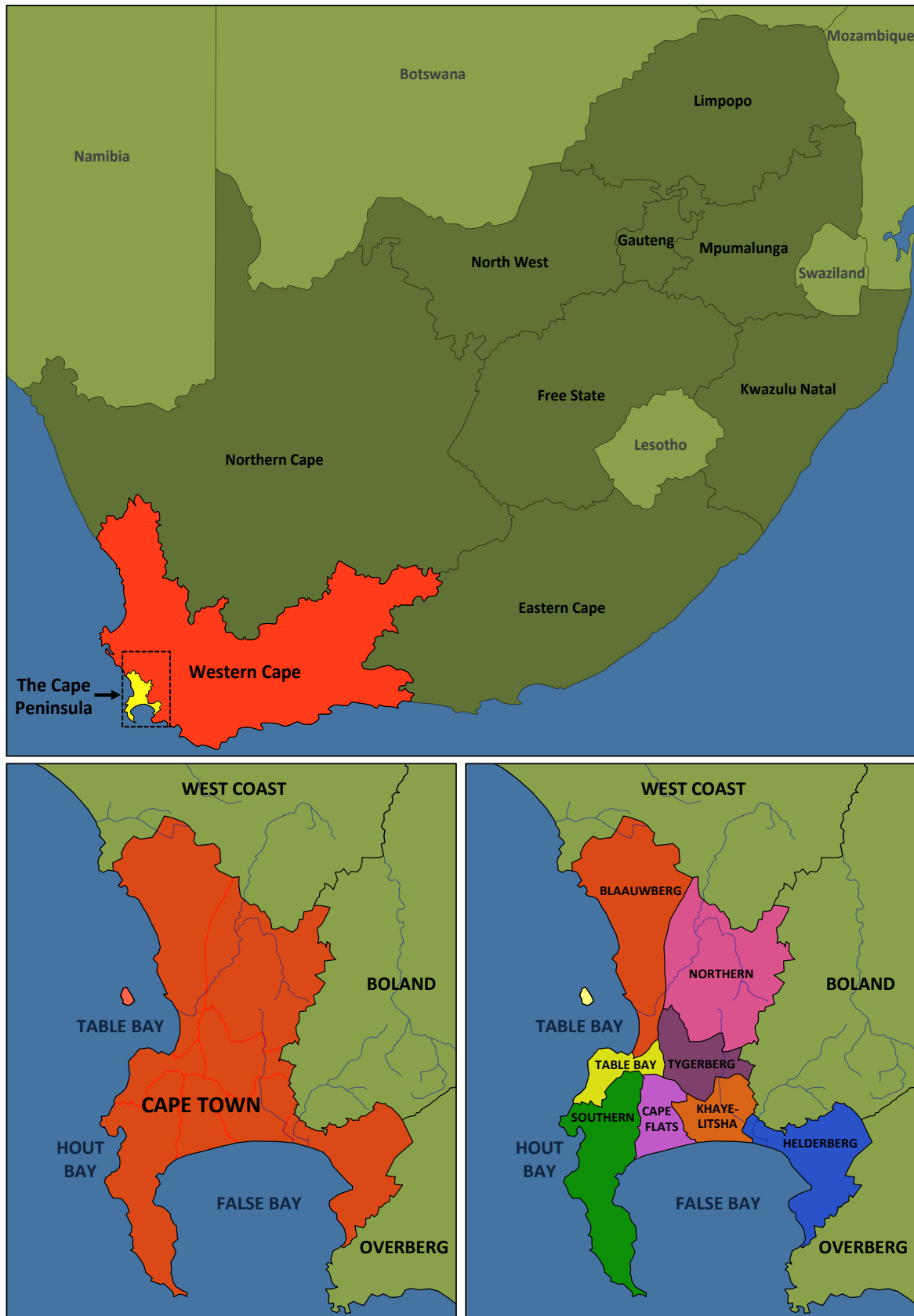


Figure 1.1 – Map representing the location of the Greater Cape Town area in South Africa

(1) the literature review, (2) a study of the geological composition of the Greater Cape Town area, and (3) discussion, conclusions and recommendations. The first section of the literature review was undertaken to develop a greater understanding of fine aggregates, where they are derived from, how they are extracted and processed, and the role they play in concrete. Once this core understanding was developed, a study of the fine aggregate resources in the Greater Cape Town area was conducted, in order to determine the existing reserves that are currently being extracted as well as future resources based upon their location and accessibility. This evaluation involved combining the literary information available, with information extracted from interviews conducted with personnel from the industry.

Lastly, after the fine aggregate resources were evaluated, conclusions were drawn as to the preferable future resources that can be used within the Greater Cape Town area. In this evaluation, they were briefly assessed with respect to economic and environmental considerations. Although the assessment was limited, it is clear that many aspects require more detailed evaluation before their feasibility can be confirmed. In addition, recommendations were also formulated to highlight further research that should be conducted as a result of findings produced in this thesis document.

1.5.3 Limitations of Research

As is the case with all research projects, there were certain limitations that should be considered when evaluating the results of this thesis. These limitations relate to the inability to access commercially protected data from the local aggregate producers of the Greater Cape Town area. This information is protected due to the value of the information within a company, in competing with the other aggregate producers. In addition, companies have become more protective of trade secrets due to collusion claims that have been rife within the industry over the past few years. Although this difficulty in obtaining information impacted upon the research, the trends could still be developed as to ascertain a good understanding of the current state of aggregate resources within the region.

Chapter 2

Origin of Fine Aggregate Resources

2.1 Introduction

The geological composition refers to the composition of the physical structure and substance of the earth. (Oxford Dictionaries, 2012) It can be divided into two components: ‘hard rock’ or bedrock and ‘soft rock’. The ‘hard rock’ is the consolidated rock that underlies the surface of the earth. The ‘soft rock’ overlies the bedrock material and is composed of sands and muds. This is then covered by soils at the surface. This classification is based upon geological terminology, however engineers typically refer to material of a granular composition as a soil, and the layer of material covering it referred to as the overburden material. These types of material constitute the two sources of fine aggregates that are predominantly used in the construction industry, namely: natural and crushed fine aggregates.

Soft rock deposits, comprising of sand, form naturally occurring fine aggregates. These deposits can be found in either land or marine environments. On land, the sand can be extracted from open cast pits, sand dunes or river sources, whereas the marine deposits are exploited through dredging operations. Crushed fine aggregates are composed of hard rocks derived from the artificial crushing of hard lithified rocks, into appropriate sizes for use. These sands are commonly extracted in rock form, from hard rock quarries before they are crushed. For a source to be used for fine aggregate in fill, mortar, plaster and concrete, it must have certain properties. These properties are discussed in Chapter 3 on properties of fine aggregates. (Alexander & Mindess, 2005)

In the subsections that follow, the origin of the fine aggregate resources is discussed. This is important, as the origin of the aggregate will influence the type and its subsequent properties. This information is vital in acquiring an understanding that will enable on to predict where these resources can be found.

2.2 The Rock Cycle

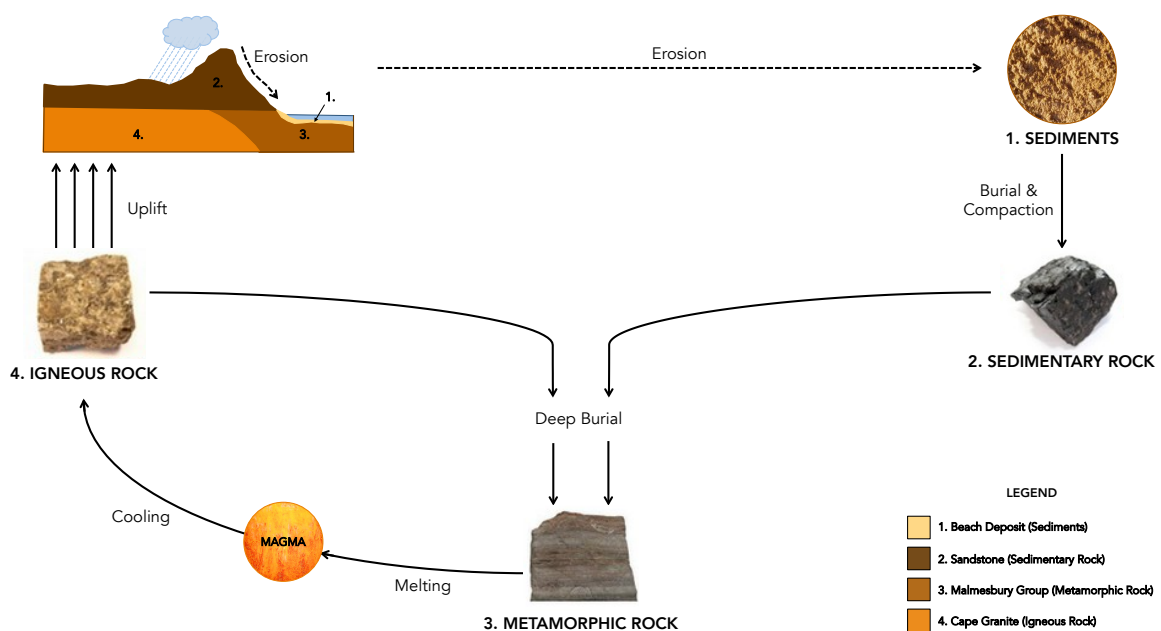


Figure 2.1 – Flow diagram of the rock cycle (Adapted from Compton, 2004)

The rock cycle is a description of the life cycle of rock that highlights its dynamic characteristics. There are three types of rocks reflecting their origin: sedimentary, metamorphic and igneous. Aggregates are a type of sedimentary rock that is derived from the erosion of igneous or metamorphic rocks, which as a result of later burial is transformed from a soft sediment into a hard rock. This cycle is represented in the Figure 2.1. (Compton, 2004)

2.3 The Formation of ‘Soft Rock’ Deposits

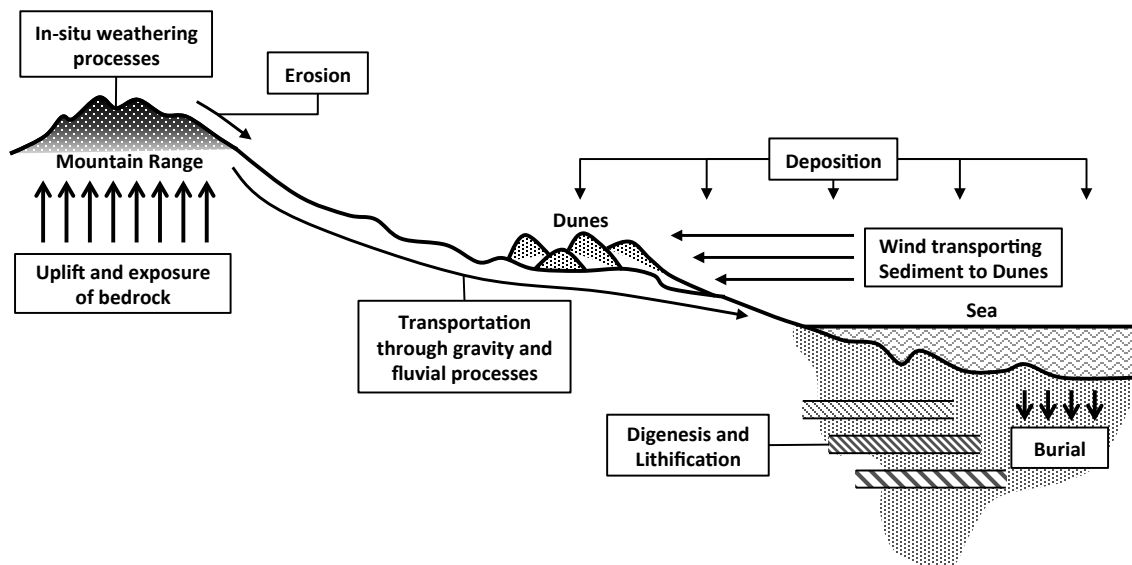


Figure 2.2 – Sedimentation Process (Adapted from Nichols, 1999)

The process of sedimentation describes the creation, movement and deposition of the sediments. The process begins with the erosion of pre-existing host rocks that have either an igneous, metamorphic or older sedimentary origin. Due to plate tectonics the rocks are uplifted and exposed at the earth’s surface. Over time this bedrock is eroded through mechanical and chemical processes called weathering. The products of this erosion can vary in size from rock fragments, called clasts, to individual grains. The material is then transported from the land towards the sea. If a distance exists between the source area and the sea, fluvial transportation processes are involved. The material that reaches the coast can be reworked by marine processes or in a beach setting by aeolian processes. Sand deposition can take place in these four settings where the depositional processes are different. This impacts upon the resulting composition, texture and thickness of the sands. Refer to Figure 2.2, for reference to the process of sedimentation. (Nichols, 1999)

2.3.1 Colluvium Deposits (Hillwash and Colluvial Sands)

Colluvium deposits are formed as a result of clastic material that has moved downslope under the influence of gravity and been deposited at the base of a slope by surface wash. This material is therefore typically found in mountain environments and is often referred to as talus material. The sediment is derived from a host rock through the processes of erosion and weathering. The rate of weathering and erosion of the parent rock and the resulting amount of material available for transportation is dependant on numerous factors of which the critical factor is the climate. (Nichols, 1999)

There are two forms of colluvium, hillwash sediments and colluvial sediments. Hillwash sediments are a type of colluvium that has been transported by the periodic movement of surface water as it runs downhill. As a result of this process, the sediment consists largely of the parent rock from which it was derived. Colluvial sediments are material that has been transported by mud/debris flows or soil creep processes. The colluvial material contains fine-grained particles from the viscous fluid that facilitated the transport of the sediments. This results in the deposits containing minerals such as clays and silt, which degrades the quality of the sand. (Cole & Viljoen, 2001)

The composition of the talus varies as a result of two factors. It is dependant both on the mechanisms of weathering and erosion, and the method of transportation of the rock fragments. However, these deposits typically consist of sands that are angular, coarse-grained and very poorly sorted, reflecting the relatively short distance that the material has been transported. For colluvium deposits that are at the edge of a river valley, they can be indistinguishable from alluvium deposits. (Nichols, 1999)

2.3.2 Alluvium Deposits (Fluvial Sands)

Alluvium is material that has been deposited by river processes, of which fluvial sands form part. The alluvium is derived either from colluvial material, or material that is eroded from the banks of the river channel, as a result of scouring by water with a high velocity. This material is transported within or at the base of the water column. The volume of the material carried depends on the speed and volume of the water within the river. The fluvial system evolves downstream from multiple fast flowing relatively straight channels that feed into a wider, broader, meandering system as the gradient of the land across which the river flows, decreases. As the gradient decreases and the system becomes more unconstrained, the water slows and its ability to carry the sediment load decreases, causing the river to change from erosional and transportational to become more depositional. (Perry & Taylor, 2007)

Sediments are deposited at any point along a river when the forces placed upon the sediments are less than that of the settling forces. This generally occurs where the water speed drops either as the river overflows its banks or where the velocity of the river is restrained. These alluvial deposits are more extensively developed in the lower part of the course of a river, particularly as one reaches the mouth of the river, as it enters the ocean. There are as a result many different settings for sand deposition that can exist along the length of the river. For a description of these depositional features refer to Table 2.1, Figure 2.3 and Figure 2.4. (Perry & Taylor, 2007)

In each of these depositional settings the composition of the sand varies. There are mainly three factors that control the textural and mineralogical composition of the sand: the climatic regime, the nature of the sediment source, and the processes of attrition and deposition that the sediment has undergone. (Perry & Taylor, 2007)

The coarser grained sediments and sands are associated with the highest energy flows, characteristic of the main channel with sand deposition occurring on the inner bank, within the point bar complexes. The thicknesses of the resulting sand bodies reflect the size and depth of the river channel, with larger deposits occurring at the end of a river's course where the river meanders greatest. Since the system is gravitational the ultimate output of the system is the sea and therefore the position of this interface point determines the length and extent of the system. (Nichols, 1999)

Table 2.1 – Fluvial Deposits

Type of Deposit	Description	Composition of Fluvial Deposit
<p>Alluvial Fan (Colluvial deposit)</p>	<p>An alluvial fan is alluvium that has been deposited by a stream or river, forming a mass of rock material in the shape of a cone or open fan. This occurs at a place where a river flows out of a narrow mountain valley onto a plain or broad valley, or at the junction or just before a tributary meets the main river.</p> <p>There are typically two different types of alluvial sand deposits:</p> <ul style="list-style-type: none"> • Debris Flow Deposits – this occurs when the formed is a dense mixture of water and sediment. These flows do not travel far and a small, relatively steep alluvial fan deposit is formed in the shape of a cone. • Sheetflow Deposits – this occurs when the material flows as traction currents that consist of a bedload of coarse sand and gravel, and finer material suspended in the water. These flows spread out into a large, wide deposit. 	<p>Mixture of sand and gravels in different geological forms</p> <p>Debris Flow Deposits</p> <ul style="list-style-type: none"> • Poorly sorted, • Randomly orientated clasts, and • Thin, wide deposits. <p>Sheetflow Deposits</p> <ul style="list-style-type: none"> • Moderately sorted, • Normally graded, and • Thin wide deposits.
<p>Overbank deposit (in the Floodplain)</p>	<p>Overbank refers to the type of alluvial deposit that occurs at the where the flow is not constrained in the channel of a rivers watercourse. It is the fine-grained material that is suspended in the water, which is deposited on the floodplain.</p>	<p>Blanketlike deposits of fine-grained particles of clays and silts, overlying coarser grained sands.</p>
<p>Channel Bar</p>	<p>A channel bar is an elongated deposit of sand or gravel that forms in a ridge in a braided channel of the river. These bars may be temporary because they suffer from reworking. However they can last for years depending on numerous factors such as the flow velocity past the bar and if vegetation begins to grow. The roots of plants would hold the sand together resulting in the bar becoming a semi-permanent deposit.</p>	<p>Channel Bar</p> <ul style="list-style-type: none"> • Consists of sand or gravel deposits, • Generally coarse grained, and • Contain little to no mud. <p>Top of the Channel Bar</p> <ul style="list-style-type: none"> • Fine-grained silts, clays and sands

Information obtained from: American Geological Institute, 1997, Nichols, 1999, Perry & Taylor, 2007, Smith & Collis, 2001, and Pidwirny, 2006

Table 2.1 (Continued)

Type of Deposit	Description	Composition of Fluvial Deposit
Point bar complex	<p>A point bar is a depositional feature in the course of a river that refers to one of a series of curved ridges of sand and gravel, formed on the inside of a growing meander in the rivers lower watercourse. It is caused by the migration of the channel towards the outer bank that is accompanied by the slow deposition of sediments.</p> <p>If there is continual deposition occurring by the point bar deposits on the edge of a channel, it will result in the formation of levées. A levee is a bank of sediment at the edge of the channel, which is higher in elevation than that of the floodplain.</p>	<p>Thin beds, normally graded from very fine-grained particles of clays and silts on top, to fine grained to medium grained particles consisting of sands at the bottom.</p>
Delta Fan	<p>A delta is an alluvial deposit developed at or near the mouth of a river that is typically in the shape of delta (Δ), the fourth letter of the Greek Alphabet, which resembles a triangle or a fan-shaped plain. (It can be seen as both a Marine and Fluvial Deposit)</p> <p>There are three types of deposits in a delta, that are differentiated according to the relative strengths of the tide or wave action and the fluvial outflow and this dictates the geometry of the sand bodies:</p> <ul style="list-style-type: none"> • Fluvial Deposits - If the energy of the tides or waves is greater than that of the water flowing out of the river mouth, then the sediment is trapped in the mouth of the river, in a fluvial environment. • Beach Deposits - This occurs when the strength of the river system is equal to that of the tides or waves the sediment is trapped close to the fluvial output in a beach or barrier bar setting. • Marine Deposits - This occurs when the energy of the water flowing out of the river mouth is greater than that of the tides or wave action and the sediment can be dispersed into the marine environment. 	<p>Fluvial Deposits Sands are developed in a channel as mouth bar complexes orientated parallel to river flow. If the tidal currents are strong channel bar complexes are well developed. Away from the channel complexes the sediments is clay rich.</p> <p>Beach Deposits Beach deposits are laterally extensive sand rich complexes orientated parallel to the shoreline.</p> <p>Marine Deposits The sand in this setting is dispersed and interbedded with clays. Offshore bar complexes can be developed if currents on the shelf rework the sand.</p>

Information obtained from: American Geological Institute, 1997, Nichols, 1999, Perry & Taylor, 2007, Smith & Collis, 2001, and Pidwirny, 2006

Due to attrition, the clastic material that is deposited at the lower point of a river is more mineralogically mature. The sand associated with the river channels is more texturally developed, with a better sorting and rounding than that of the sands further upstream and therefore has the best quality. However, within the fluvial depositional system there is significant sediment heterogeneity, with the sediment deposits comprising of silts, clays, gravels and sands. It also often contains high quantities of organic material, due to deposition in low energy settings away from the main channel. (Nichols, 1999)

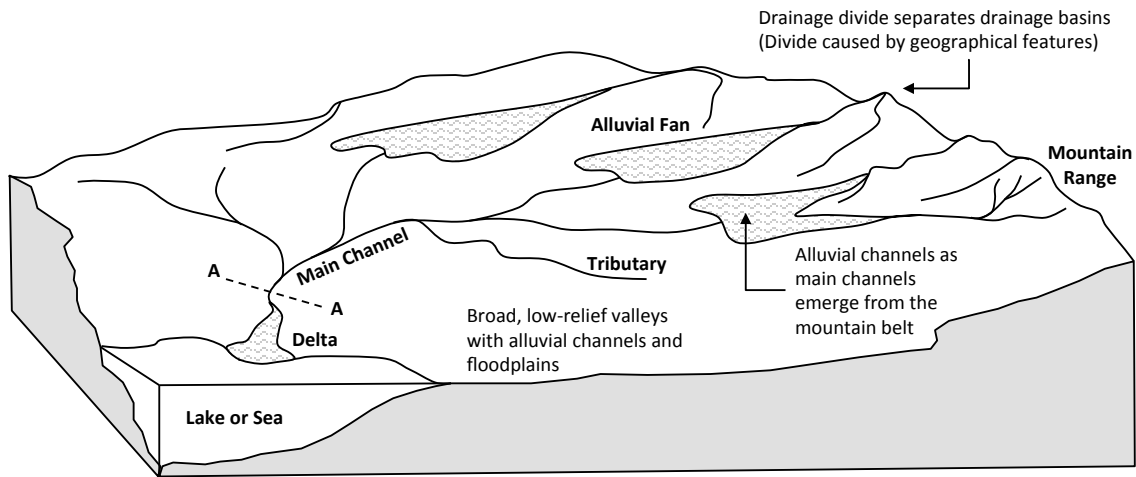


Figure 2.3 – Depositional features of a fluvial river system (adapted from Perry & Taylor, 2007)

Today's river systems represent a snapshot in time. As a result of past global sea level changes as well as changes in the climate, the extent of fluvial deposition can be much more extensive than expected based on the current day situation. In particular the significant sea level drops associated with the recent glaciation episodes meant that the river systems extended across the continental shelf, resulting in the deposition of fluvial sands in a current marine setting. Evidence of these palaeo-fluvial systems is also seen in the presence of river terraces. An important control is also the climate and the resulting amount of water run-off. The palaeo-climate was different from the current dry setting of today and this is reflected in the different thickness and texture of the sand. (Nichols, 1999)

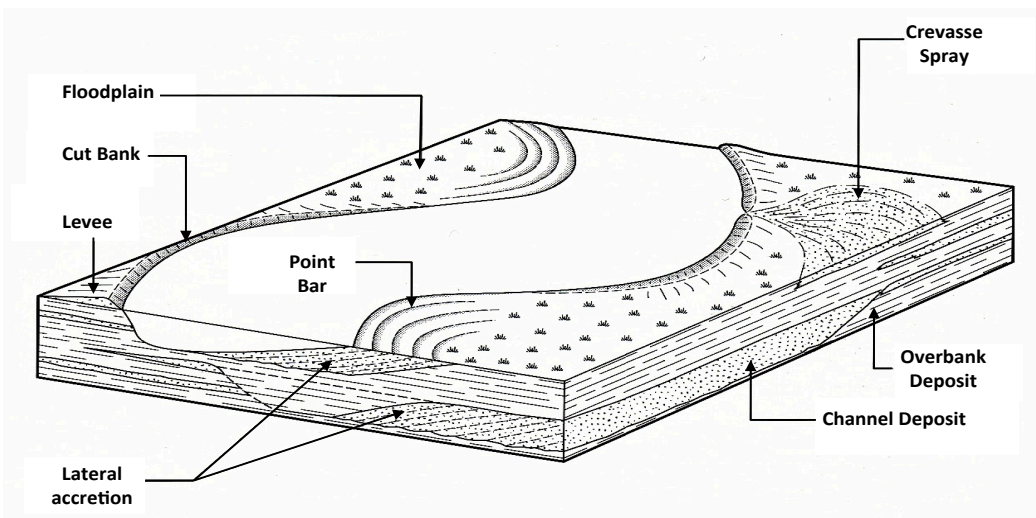


Figure 2.4 – Cross-section of a river indicating the main geographical features (Section A-A from Figure 2.3) (adapted from Nichols, 1999)

Due to post-depositional diagenesis, the sands can be cemented, resulting in a variation in the rock's hardness. It is a rule of thumb for geologists that the longer the rock is exposed the greater the chances it can be subjected to change (e.g. fluid movement) and therefore the greater the chance that it becomes lithified. (Perry & Taylor, 2007)

2.3.3 Marine Sands

Marine sands refer to the deposits of sedimentary material that form in coastal environments. This generally occurs along the interfacial region between the ocean and the land, marked between the boundaries of the lowest tidemark and the top of the storm beach. These sediments are generally carried through the fluvial networks towards the sea, and then upon reaching these environments, the sediment load is released. This forms depositional features such as deltas, as described in Table 2.1. This sediment is then subjected to the tidal or wave actions of the sea. (Smith & Collis, 2001)

Once fluvial processes have transported the sediment towards the sea, the sands are often trapped and deposited at the river mouth. However, depending on the amount of sediment, the power of the tidal and wave forces can transport sands along the coastline by processes such as longshore drift. (Smith & Collis, 2001)

The coarser grained clastic material in the marine realm comes either from the fluvial systems or via marine reworking of older coarser grained sediments. Due to the erosive and sorting action of the waves upon the shoreline, the coarser sediments tend to be swept high onto the coast (back-shore) and trapped close to the coastline in beach or barrier complexes. These sands are more homogeneous and laterally continuous and often perpendicular to fluvial transport direction, than in a fluvial setting. In the higher energy settings, coarser grained material is deposited, which is generally better sorted with a consistent textural and mineralogical composition. (Smith & Collis, 2001)

However in the beach setting, the sediment can also be derived from marine organic sources such as shell or reef debris. This shell debris can be reworked to form coarse-grained calcareous sand. Depending on the amount of calcareous material, it can be dissolved and re-deposited in a cemented form and can result in the early lithification of the sands. (Smith & Collis, 2001)

With the sea level changes of the recent past, the position of the shoreline has varied significantly, therefore the beach complexes, with some of the best sands, will have migrated across the area. As a result some of the sand deposits that were created in a setting along the shoreline in the past, are now found offshore in deeper marine settings. (Nichols, 1999)

2.3.4 Aeolian Sands

Aeolian sands refer to sands found in deposits that are formed as a resultant of erosion, transportation and deposition by the wind. Air has a very low viscosity by comparison to water, thus consequently much higher velocities are required to achieve a sufficient uplift force to move the sediments. Therefore, where sufficient sand exists and the wind speed is fast enough, the sand can be picked up and laterally transported. The size of the sand grain that can be transported depends on the wind speed. Coarse-grained material is transported short distances, whereas finer grained material (e.g. clays) can be transport further distances. This action results in a strong sorting of the sand bodies, thus the deposits are well sorted, and due to strongly attritional nature of the air movement, the sand grains are also well rounded.

The easiest place for the development of aeolian deposits to take place is adjacent to the beach setting, resulting in the formation of dune complexes. The extent of these complexes is dependant on the availability of the sand. The greater the size of the sand source, the greater the extent of the associated dune field. The wind speed is a major determinant on the size of the individual dune. Between the dunes where the wind eddies and speeds drop, finer grained material can accumulate, but this represents a small portion of the overall complex. It is clear that the changes in climate of the recent past and the change in the position of the shoreline means that the palaeo aeolian deposits are likely to be developed away from the present day coastline.

2.4 Summary of Fine Aggregate Deposits

Fine aggregates can be obtained from many different sources, however they can be categorised into three primary categories, which are defined according to their origin. These consist of: (1) Natural fine aggregates, also referred to as building sand, originating from 'soft' rock deposits, (2) Crushed fine aggregate, also known as crusher sand, originating from 'hard' rock deposits, and (3) Recycled fine aggregate, originating from recycled materials. 'Hard' rock deposits refer to tough, consolidated material deposits that underlie the surface of the earth, compared with 'soft' rock deposits which are unconsolidated material that overlies this bedrock material, composed of muds and sands.

In terms of natural fine aggregate resources, they can be further sub-divided into four categories. These groupings are defined according to their stage in which they are extracted from in the sedimentation process. These are defined as follows: hillwash and colluvial sands obtained from colluvium deposits, alluvial and fluvial sands obtained from alluvium deposits, marine and beach sands obtained from marine deposits, and aeolian sands obtained from aeolian sand deposits. Each of these sand deposits vary in grading, geometry and composition of the sand. There are many different factors that dictate these properties, however there are conclusions that can be drawn. (Refer to Figure 2.5)

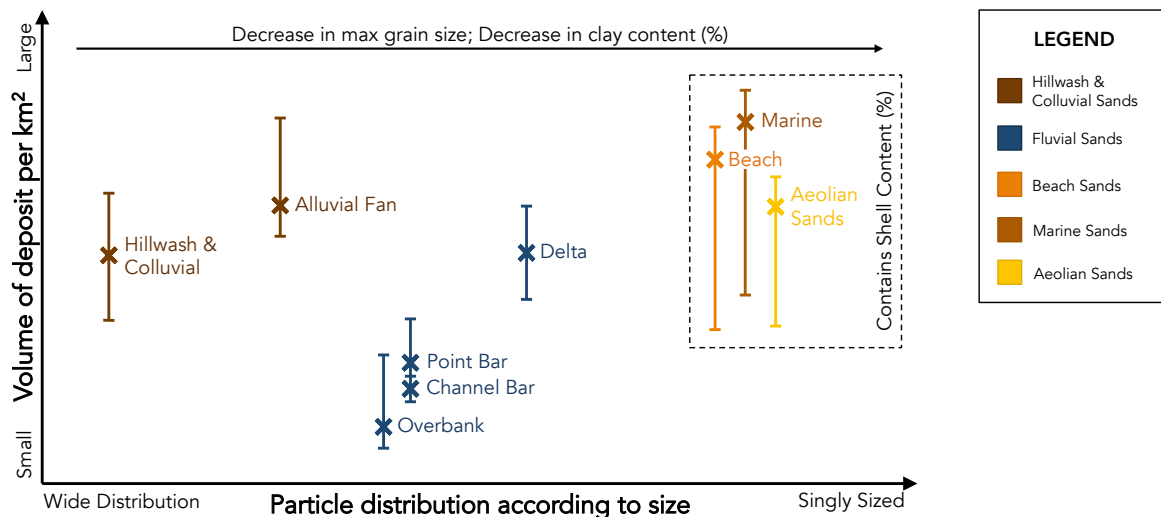


Figure 2.5 – Summary of the sand deposit properties

As sediment is transported towards the coast it is subjected to a greater amount of reworking, which consequently results in the following:

- **Reduced particle size and distribution of the sand** – Sands found closer to the coast in aeolian, beach and marine deposits are typically more single sized and finer than that of hillwash and colluvial deposits.
- **Increasing mineralogical maturity** – Sands found closer to the coast become dominated by harder and more stable minerals that are normally more quartz rich.
- **Decreasing maximum grain size** – Coastal sands show a more limited grain size range compared with sands found at the start of the sedimentation process (hillwash and colluvial sands), which have larger maximum grain sizes.
- **Improved deposit volumes** – The sands closer to the coastal setting typically have greater volumes, and higher reserves per square kilometre.
- **Shell Content** – The calcium carbonate content, also known as the shell content, is normally a factor only in marine sands.

Chapter 3

Properties of Fine Aggregates

3.1 Introduction

Fine aggregates are defined as granular materials where 90% of its mass passes through a 4,75mm sieve and is retained by a 0,075mm sieve, in which the apertures of the sieves are square. The aggregates account for approximately 60 to 80% by volume of concrete mixes, and therefore they are a fundamental component of concrete and play a huge part in dictating its resulting properties. (Alexander & Mindess, 2005)

As previously mentioned, the key criteria of concrete are: its strength, and durability to last over its design life. Aggregates have a strong influence upon this through the following:

- The aggregate matrix creates the structural framework and subsequent core strength,
- The porosity and permeability of the concrete is influenced by the amount and connectivity of the void space between the aggregate particles, and
- The mineralogical composition of the constituents used in the concrete mix.

3.1.1 The Structural Framework of Concrete

The structural framework refers to the composition of concrete from where it derives its core strength and provides the rigidity of the concrete structural element. This framework consists of the arrangement of the aggregate particles, which forms the aggregate matrix. A closer arrangement of the particles corresponds to a higher packing density and subsequent reduction of void space between the particles. This arrangement is the most beneficial in obtaining higher strength concrete. This is primarily because there is a greater contact surface area between aggregate particles. As a result there will be a higher friction content, which creates higher tension forces, which resist any movement between the particles. The greater these tension forces, the greater the strength of the aggregate matrix and therefore the greater the strength of the aggregate matrix. (Alexander & Mindess, 2005)

Another factor contributing to the frictional forces between the aggregate particles is created by the texture of the aggregate. The rougher and more angular an aggregate will result in a greater contact surface area and subsequent friction potential between aggregate particles. However, there is a problem associated with this property as it influences the plastic properties of concrete. This primarily relates to the balance between the workability and cohesiveness of the mix. With a greater friction content it will lead to a reduced workability of concrete in its plastic state. This concept is discussed in greater depth in section 3.2.1. (Alexander & Mindess, 2005)

3.1.2 The Porosity and Permeability of Concrete

The porosity and permeability are two different concepts relating to the void spaces of the concrete. The porosity relates to the quantity of the void space. It is the percentage that relates the volume of the internal pores to the total volume of the solid. By comparison, the permeability is a function of the connectivity of the void spaces, which refers to the ability of a fluid or gas to flow through a solid. These

are important characteristics of concrete as there is a correlation between the porosity and permeability of concrete and its strength and durability. (Grieve, 2009)

The strength is influenced by these properties because of two factors. The first factor relates to the previous concept, where a greater packing density will result in a lower permeability and porosity and subsequently higher internal frictional forces. Secondly the cement paste influences the porosity and permeability. With a lower porosity and permeability, the greater the density of the cement paste, therefore there will be greater adhesion between the aggregate particles. This is important as the concrete will fail at its point of weakness and typically this is the inter-facial transition zone (ITZ), which is the interaction zone between the aggregate and the concrete paste. (Grieve, 2009)

The durability will also be improved with a lower porosity and permeability, because this will reduce the ability for water and other solutions from entering the concrete. Consequently this reduces the potential for deleterious reactions occurring, which could influence the concrete's strength over time. (Grieve, 2009)

3.1.3 Mineralogical Composition

The last property influencing the strength and durability of concrete are the mineral constituents of the aggregate used in the concrete mix. These constituents must be strong and chemically inert, thus enabling them to withstand the high forces placed upon them and preventing any deleterious reactions occurring within the concrete, over the life of the structure. (Grieve, 2009)

In conclusion there are important criteria that a source of aggregate must possess in order to be used in the production of concrete. These properties consist of: the grain size and distribution, mineralogical composition and texture of aggregates. The next sections discuss these properties, relate them to their impact upon concrete and stipulate specifications that they must adhere to as defined by the South African National Standards.

3.2 Particle Size and Distribution

As discussed in the introduction, the grain size and distribution are important aggregate properties. Particle size and distribution refers to the distribution of the individual particles according to their occurrence with respect to particle size, within the aggregate. In engineering terms it is referred to as the grading of an aggregate. It is a useful analysis of a given source as it helps to provide a means of predicting the likely performance of the source material when used in concrete, mortar and plaster. (Grieve, 2009)

3.2.1 Grading

Grading is most effectively represented on a grading curve. It represents the cumulative percentage of the particles mass passing through sieves of standard aperture sizes. For fine-aggregates this consists of the following nominal sieve sizes: 4,75mm, 2,36mm, 1,18mm, 0,6mm, 0,3mm, 0,15mm and 0,075mm. Therefore, fine aggregates are less than 4,75mm in size. However, this is only a guideline and does allow for small fractions of material to fall outside providing that at least 90% the mass lies between these limits. (Grieve, 2009)

3.2.1.1 Impact on Concrete

Grading is an important feature of an aggregate as it influences the void content of concrete. Therefore it influences two aspects regarding the cement paste: the void space available for the cement paste to fill, and the surface area of the aggregate that needs to be coated. Both components are related to the amount of fines material, and the cement paste used. The amount of these constituents is determined through obtaining a balance between the cohesiveness and workability of fresh concrete, related to its application. This must essentially produce concrete of adequate strength, whilst not containing an excess amount of either fines or cement paste that could lead to problems occurring, such as shrinkage. Therefore, the grading of an aggregate is classified according to a spectrum, ranging from a good to poor grading. The lower the voids and subsequently the cement paste required, the better the grading of a resource. (Alexander & Mindess, 2005)

a) Plastic Properties of Concrete

The plastic properties of concrete are the properties of concrete in its fresh state. This is the state of the concrete in the mixing phase before the hydration reactions occur, causing the concrete to harden. The important plastic properties of concrete in which the grading has an impact upon, consist of: the workability, cohesiveness and bleeding of fresh concrete. It is more specifically the finer material fractions (minus 0,300mm, 0,150mm and 0,075mm aggregate sizes) that impact upon these properties the most. Of these sizes, the fines content (minus 0,075mm fraction) has the greatest impact. This is attributed to its grain size and mineralogical composition. The mineralogical composition is discussed later in Section 3.2.2. (Alexander & Mindess, 2005)

The grain size refers the ability of the finer material to fill the void space when compacted in a concrete mix, due to its size. As a result the finer material is able to reduce the void spaces in the concrete, which also causes a reduction in the concrete's porosity and permeability. As a result, with a reduction in void space, the paths allowing water to be transported through the concrete are more tortuous or blocked. Subsequently this reduces the amount of bleeding in the concrete.

The reduction in void space also contributes to increasing the cohesiveness of the concrete mix. This is because as there are a greater amount of particles; there is a greater total surface area of the aggregates. This more commonly will contribute to a greater internal friction within the mix, making it more cohesive, and less workable. This property is closely linked with particle shape and surface texture. (For more information, refer to the section on texture of fine aggregate) It is important to achieve a careful balance, as an overabundance of fines may cause stickiness resulting in an increase in handling difficulties. Yet if there is a lack of this fraction of material, it will result in a lack of cohesiveness and consequently segregation could occur. For further explanation of the impact of the finer material upon the workability, cohesiveness and bleeding, refer to Table 3.1. (Alexander & Mindess, 2005)

However, these effects are not experienced unless the aggregate has a good distribution of particle sizes, and thus the aggregate is well graded. This is because with a lack of material that is slightly larger than the fines content; there will not be a sufficient aggregate matrix holding the fines in place. Consequently the fines may be transported with the mixing water out of the concrete during settlement and bleeding.

Table 3.1 – Influence of fine aggregates on plastic properties of concrete (adapted from Alexander & Mindess, 2005)

Concrete Property	Definition	Effect on Concrete	Influence of Grading on Property	
			'Coarser' Sand (FM > 2,9)	'Finer' Sands (FM < 2,0)
Bleeding	Bleeding is a form of segregation that occurs in concrete in its fresh state. It refers to the process in which a portion of the mixing water rises to the surface of the concrete, or is trapped beneath large aggregate particles or reinforcement bars. It occurs when the materials begin to settle after placement.	Bleeding is an important component that needs to be controlled. Without proper control it can lead to detrimental effects upon the structural integrity of concrete. This includes the occurrence of cracking, caused by plastic shrinkage and settlement.	Higher bleeding	Lower bleeding (providing there are adequate fines)
Workability	Workability refers to the handling of a concrete mix. This is the ease of mixing, transporting, placing, compacting and finishing of fresh concrete, without segregation of its constituents occurring.	The cohesiveness and workability of concrete are closely related. They impact upon the homogeneity of the concrete. This refers to the uniformity of the concretes properties. In order to achieve homogeneity in concrete, whilst ensuring that the concrete is sufficiently easy to use, the workability and cohesiveness of a concrete mix need to be balanced. Should this not be achieved, there are two resultant effects that can be experienced: High workability, Low cohesiveness¹ This concrete will be more easily manipulate, however it will contain a greater content of free water in the cement paste, this will result in greater settlement and bleeding. Consequently settlement and shrinkage could occur resulting in potential plastic cracking. This will reduce the homogeneity and strength of the concrete. Low workability, high cohesiveness Conversely if the mix is very cohesive, yet lacks workability, it results in difficulty of handling. Consequently contributing to difficulty of transportation and handling and may result in zones of incomplete compaction and honeycombing.	Higher workability	Lower workability
Cohesiveness	Cohesiveness refers to the 'stickiness' of the concrete mix, thus it is the property of concrete referring to its tendency to resist segregation and bleeding.		Lower cohesiveness	Higher cohesiveness (More fines content the higher)

FM = Fineness Modulus

¹ Note with a reduction in cohesiveness in the mix, the workability will increase until segregation occur, at which point the mix will no longer be workable.

Therefore, although the fines have a large impact upon the plastic properties of concrete, without sufficient other sizes of aggregate, the hardened properties of the concrete are adversely affected. It is thus important to have a relatively well-graded aggregate. This is even more important in mixes of low cement content where this effect is much greater. (Grieve, 2009)

b) Hardened Properties of Concrete

As mentioned, the ability of fine material to fill the void spaces also contributes to an increased strength of concrete in its hardened state. This phenomenon is referred to as the fine-filler effect. (Alexander & Mindess, 2005)

This strength is attributed to the additional fine particles. These fine particles are well dispersed in the fresh paste and are of a mineralogical composition that results in them being less reactive than the cement particles. Subsequently, they are able to help create a better microstructure and improve the interfacial transition zone (ITZ) through filling the micro-void spaces in between the cement products. Consequently the concrete’s microstructure is more homogenous with an improvement of strength and a reduction in the permeability of the concrete. (Grieve, 2009)

In conclusion, the influence upon the properties of concrete caused by fine aggregate grading is less in rich concrete mixes, compared with that of lean mixes. The influence is also increased with increasing workability or decreasing cement content. However, grading is not a fundamental property governing the quality of the concrete. Good concrete can be made with aggregates consisting of a poor particle shape and grading, as long as the mix properties are matched between the requirements of the concreting operations and the structural application. (Grieve, 2009)

3.2.1.2 Classification of Grading

The grading of an aggregate is defined according to a spectrum, ranging from a well-graded to poorly-graded aggregate. This classification is based on two factors: the range of the grain sizes and the continuity between the amount of aggregate of each grain size within the range. Therefore a well-graded aggregate will have a particle distribution that has a greater variety and more continuous range of particle sizes. With a greater variety of particle sizes, there is a greater range of particles able to fill the voids in the mix. By comparison, poorly graded aggregates, which lack certain sizes of aggregates, will not have the range to be able to fill all of the voids. (Alexander & Mindess, 2005)

In the grading spectrum, there are typically four characteristic types of aggregate gradings. These gradings are characterised by a lack/excess of a particular size of aggregate. (Refer to Table 3.2 for a description, and Figure 3.1 for a diagrammatic and graphic representation, of the characteristic gradings)

Table 3.2 – Characteristic aggregate gradings

Type of Grading	Description	Quality
Continuous grading	Aggregates comprising of a wide range of particle sizes such that the volume of voids between particles is low. As a result the paste requirements are lower.	Good Grading
No-fines grading	Aggregates consisting of a lack of fine material (fines content). The fines content is material that passes through a 0,075mm sieve.	Problematic grading

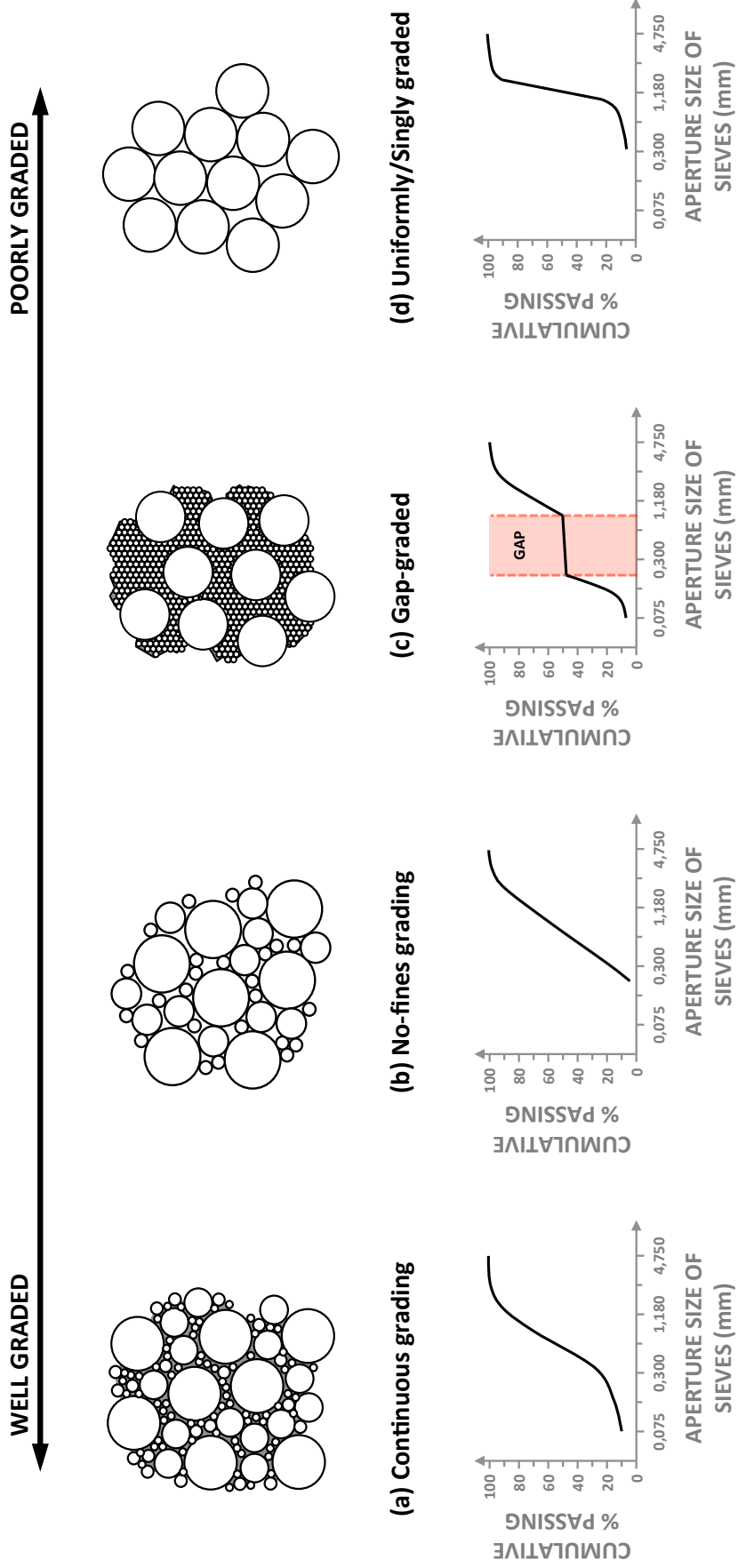


Figure 3.1 – Diagrammatic and graphical (grading curve) representation of aggregate gradings (aggregate diagrams adapted from Alexander & Mindess, 2005)

Table 3.2 (Continued)

Type of Grading	Description	Quality
Gap-graded	Aggregates lacking one or more intermediate sized particles. This occurs more commonly in an analysis of the total aggregate particle distribution (both fine and coarse aggregates), of which the 5-10mm (smaller) coarse aggregates are omitted.	Moderate to good grading
Uniform/singly graded	A particle distribution where the majority of the aggregates are of a similar size. When these aggregates are used in a concrete mix, there is a lack of material being able to fill the voids, thus this represents a poor aggregate grading.	Poor grading

3.2.1.3 Classification according to SANS Specifications

The South African National Standards specify properties to classify grading through the use of two measurements: the fineness modulus and grading envelopes. These specifications are discussed in the following section.

a) Fineness Modulus

The grading of an aggregate produces data stipulating the percentage of mass falling within a certain envelope size. This data can then be analysed to determine the fineness or coarseness of the resource. This measure is expressed in terms of an index referred to as the fineness modulus (FM). It is calculated through summing the cumulative percentages of material retained on each standard sieve, excluding the 0,075mm sieve, which is then divided by 100. This value will not describe the grading of the fine aggregate, as an aggregate that is single sized could have the same FM as a well graded aggregate. Therefore the FM is purely a representation of the fineness or coarseness of an aggregate resource. The classification of the aggregate coarseness according to the FM value is represented in Table 3.3. (Addis et al., 1995)

Table 3.3 – Fineness Modulus (FM) Classification

Classification	Fineness Modulus (FM)
Very Fine	FM < 1,0
Fine	1,0 < FM < 2,3
Medium	2,4 < FM < 2,9
Coarse	2,9 < FM < 3,5
Very Coarse	3,5 < FM

$$FM = \frac{\Sigma (\text{total cumulative \% of material retained on the sieves}^*)}{100}$$

* Sieves include: 150-micron sieve and greater

According to SANS 1083:2006, a sand resource tested in accordance with SANS 201:2006 should have a FM between 1,2 and 3,5. This range provides a useful guide for allowable concrete sands, however sands that fall outside of this range could also be used providing careful adjustment to concrete mix proportions. Sands with a FM range of 2,0 to 3,0 are preferable for sands used for the manufacture of high quality concrete. (Addis et al., 1995)

b) Grading Envelopes

Despite extensive investigation into the grading of aggregates, it has not been possible to determine the optimal grading for each particular case. Suitable gradings are thus empirically derived through applying the principles previously stipulated and conducting trial mixes. However, there are certain trends that have been developed according to the factors such as the contribution of fines towards the plastic properties of concrete. These trends were used to develop fine aggregate envelopes. These are suggested limits that the grading of the aggregate should fall within to ensure that the plastic properties of concrete are not compromised. These specifications are laid out in the South African National Standards (SANS). Refer to for these values Table 3.4 and Figure 3.2 and Figure 3.3 for the respective grading envelopes. (Addis et al., 1995)

Table 3.4 – Grading envelopes of fine aggregates for concrete, mortar and plaster

Aperture size of sieves (mm)	Concrete				Plaster	Mortar
	SANS 1083 Code Limits	SANS 1083 Suggested Outer Limits	SANS 1083 Preferred Limits	C&CI Limits	SANS 1090 Code Limits	SANS 1090 Code Limits
4,750	90 - 100	85 - 100	90 - 100	90 - 100	100	100
2,360	-	60 - 100	75 - 100	75 - 100	90 - 100	90 - 100
1,180	-	40 - 100	60 - 90	60 - 90	70 - 100	70 - 100
0,600	-	30 - 75	40 - 60	40 - 60	40 - 90	40 - 100
0,300	-	15 - 45	20 - 40	20 - 40	5 - 65	5 - 85
0,150	5 - 25	5 - 20 (25)	10 - 20	10 - 20	5 - 20	5 - 35
0,075	0 - 5 (10)	0 - 12 (20)	3 (6) - 6 (15)	5 - 10 (20)	0 - 7,5	0 - 12,5
FM	1,20 - 3,50	1,00 - 3,65	2,00 - 3,00	-	-	-

Note: All values are represented as a total percentage passing the given sieve size, and the values in brackets represent limits for crushed aggregate sources

In reference to these values, there are four different limits for concrete, namely:

- SANS Code Limits – Values represented in SANS 1083:2006,
- Suggested Outer Limits – Values for concrete use according to Commentary on SABS 1083:1994².
- Preferred Limits – Recommended values for use in high quality concrete use, according to Commentary on SABS 1083:1994.
- C&CI – The limits recommended by the Cement and Concrete Institute of South Africa. (Addis et al., 1995)

The limits specified according to SANS 1083:2006 are extremely general, as they provide no range for aggregates between the sieves with an aperture size of 2,36mm to 0,30mm. The other values stipulated in the commentary consist of preferred limits and suggested outer limits. The preferred limits are a representative a narrower envelope for fine aggregate use in concrete of higher quality. This entails

² Note: SABS 1083:1994 has subsequently been superseded by SANS 1083:2009, however the values remain the same.

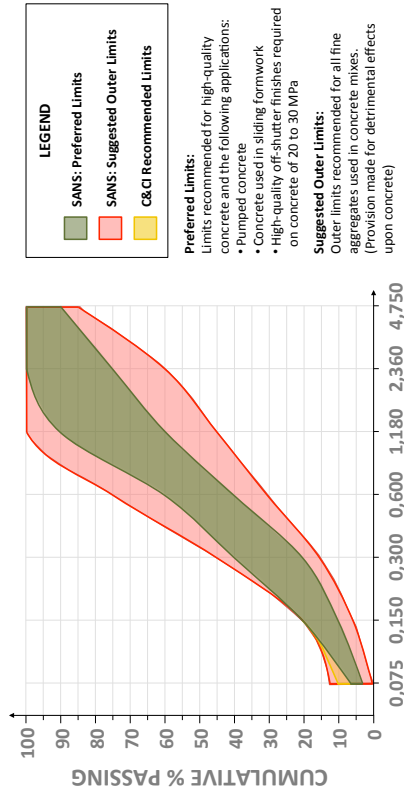
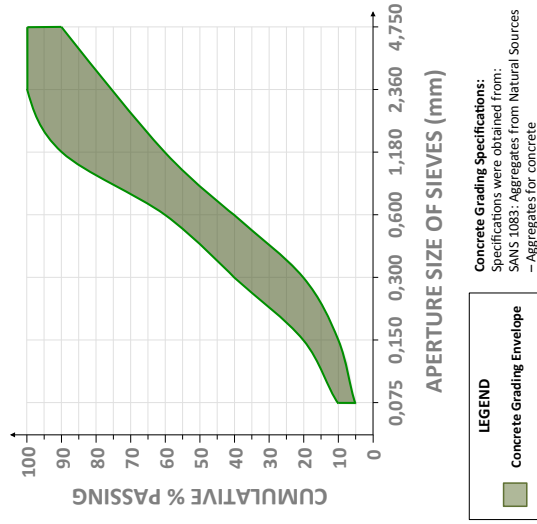
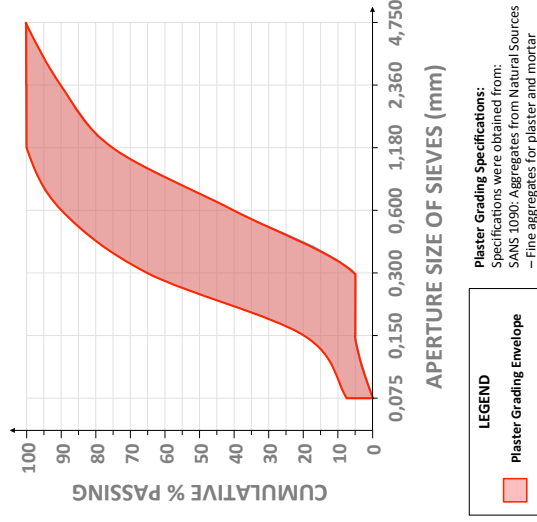


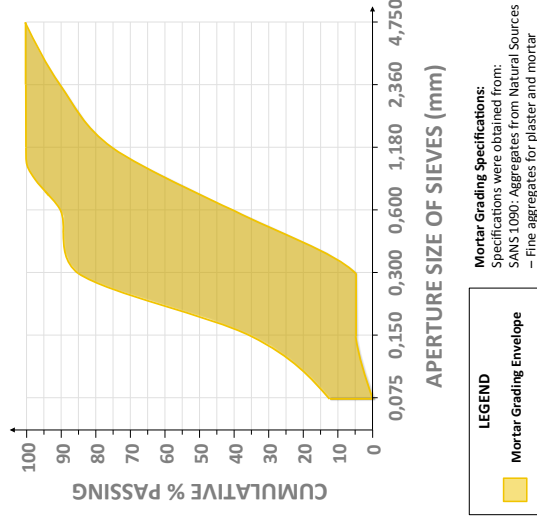
Figure 3.2 – Comparative fine aggregate grading envelopes for concrete according to SANS and the C&CI



(a) Fine aggregate grading envelope for concrete



(b) Fine aggregate grading envelope for plaster



(c) Fine aggregate grading envelope for concrete

Figure 3.3 – Comparative fine aggregate grading envelopes for concrete, plaster and mortar according to SANS specifications

pumped concrete, concrete used in sliding formwork, or high quality off-shutter finishes on concrete with a strength of 20 to 30MPa. The suggested outer limits are representative of the limit between aggregates suitable for concrete and aggregates that would cause a detrimental impact upon the properties of the concrete. (Addis et al., 1995)

The Cement and Concrete Institute (C&CI) of South Africa have produced their own preferred limits of fine aggregates used for concrete mixes. These limits are similar to that of the preferred limits stipulated in the SABS 1083 commentary, however it makes provision for a greater amount of fines. (Grieve, 2009)

3.3 Mineralogical Composition

The mineralogical composition of the aggregate is an important property that influences the strength and durability of concrete. It refers to the mineralogy of the aggregate material used in the concrete mix. It is essential that the aggregate is strong and chemically stable; as to ensure the structural integrity of the concrete element is not compromised. There are three factors influencing the mineralogy of aggregates:

- The rock and mineral constituents,
- The chemical constituents that coat the aggregate, and
- The organic matter.

These factors are discussed in the sections to follow. Due to the fines content accounting for the largest concern regarding the reactive rock and mineral constituents in aggregate, it is discussed under a separate heading in section 3.3.2.

3.3.1 Reactive Rocks and Minerals

Aggregates exhibit properties reflected by the chemical composition of their constituent materials. The composition of aggregate used in concrete consists of minerals varying from light-coloured felsic minerals, primarily in the form of quartz and feldspar, to relatively dark-coloured mafic minerals, consisting primarily of pyroxenes and amphiboles. Certain minerals in the aggregate can be unstable, thus when exposed to the atmosphere or concrete environment, chemical reactions occur. These reactions consist of oxidation, hydration and carbonation reactions, which are potentially associated with effects that are detrimental to concrete. As the minerals are embedded in the concrete the damage is usually limited to the surface resulting in surface pop-outs, due to volume changes, and unsightly staining. (Alexander & Mindess, 2005)

It is not only the chemistry of the aggregate that contributes to these reactions from taking place. The nature of the constituent minerals and crystals can also contribute. An example of this is strained quartz, which is an unstable form of the quartz mineral. This mineral has an unstable lattice, with higher thermodynamic energy, thus increasing its potential to react with the cement paste causing an alkali-silica reaction (ASR). This is a well-known reaction that occurs due to the unstable silica content in aggregate and the high alkalinity of the pore water solution in the concrete paste. (Alexander & Mindess, 2005)

Upon analysing the reactive minerals, it is normally not possible to stipulate the precise quantities that will result in an adverse effect. However, reactive minerals enclosed or finely dispersed within the aggregate matrix, compared with those free to interact with the water or cement paste, should have a

lesser detrimental effect. As a result in each case the interpretation of these effects for finely milled aggregate samples, should be left up to the discretion of the engineer. (Alexander & Mindess, 2005)

In conclusion there are certain rocks that can cause a detrimental impact upon the structural integrity of concrete. This detrimental impact is caused by the reactions occurring due to the unstable minerals that occur within the aggregate. It is important to identify these materials, to ensure that their use can be minimised or avoided. This section identifies the rocks and minerals that are deleterious in concrete, discussing their impact and their classification according to SANS specifications. (Refer to Table 3.5, Table 3.6, Table 3.7, and Table 3.8) (Grieve, 2009)

3.3.2 Fines Content (Dust and Clay Content)

The fines content, also referred to as dust and clay content, is defined according to SANS as the fraction of material that passes through a 0,075mm sieve. This fraction of fine aggregate is comprised of three components:

- Very small rock fragments – These fragments can be mineralogically heterogeneous, comprised of the same mineralogy as the parent rock from it originated.
- Silt – This is commonly quartz-dominated material that is defined according to its size, which ranges somewhere between sand and clay. This ranges from approximately 0,005mm to 0,020mm in dimension.
- Clay – This is commonly phyllosilicate dominated material that contains variable amounts of water trapped in their mineral structure. They also constitute the smallest material in the fines content, which is smaller than 0,005mm in dimension. Clay is also potentially the most deleterious constituent.

A high percentage of the fines content is comprised of clay and silt particles. These particles, in particular clay, can have a deleterious impact upon concrete. As a result there have been limits placed upon their quantity, which is achieved through limiting their mass as a percentage by total volume of the total fine aggregate content. This percentage is however defined as the limiting factor for fines, therefore it fails to differentiate between the deleterious (active clays) and non-deleterious fractions. Therefore it is a convenient measure yet not completely meaningful. Recall section 3.2.1, it is highlighted that there is a certain quantity of fines important in assisting with the strength and durability of concrete, providing it is not reactive. As a result, alternative measures have been developed that distinguish between these components by means of both size and mineralogy. (Refer to SANS specifications for more information) (Addis et al., 1995)

3.3.2.1 Impact on Concrete

As mentioned in the previous section, the clay content presents problems in a concrete mix. This is due to it contributing towards possible high shrinkage or swelling, and/or an increased water requirement in the concrete mix. It is therefore important to limit the amount of clay material in a concrete mix; otherwise this mineralogical content will contaminate the concrete. The impacts that the clay content has upon concrete are discussed further, in the sections on shrinkage and water requirement, which follows. (Addis et al., 1995)

Deleterious Rocks and Minerals in Aggregates

Table 3.5 – Undesirable rocks and minerals containing sulphides (metallic ores) in aggregates (adapted from Alexander & Mindess, 2005)

Deleterious Rocks/Minerals	Impact on Concrete	Minimization/Avoidance and Specifications
<p>1. Sulphide Minerals</p> <ul style="list-style-type: none"> • Iron Pyrite (FeS_2) • Marcasite and Pyrrhotite • Copper Pyrite 	<p>The sulphides present in these minerals can oxidise to form sulphates. These sulphates then decompose, resulting in sulphate expansion, or unsightly iron staining.</p> <ul style="list-style-type: none"> • Sulphate expansion is a product of the sulphates reacting with cement compounds causing expansion. This could result in surface pop-outs. • The unsightly iron staining is caused in the oxidation process, where the minerals such as marcasite and iron pyrite oxidise to form a brown hydroxide, which stains the concrete. <p>These effects cause local deteriorations in the concrete and are worse in warm, humid conditions.</p>	<p>Iron pyrite, marcasite and pyrrhotite according to Alexander and Mindess is recommended not to exceed 0,25–0,4% and copper pyrite is to be avoided.</p> <p>SANS 5850-1:1998 – Sulphates content of fines in aggregates Part 1: Water soluble sulphates in fines in aggregates</p> <p>The suggested limits for the total water-soluble sulphate content are (according to SANS 10100-2:1992):</p> <ul style="list-style-type: none"> • 0,4% by mass in fine and coarse aggregates, and • 4% by mass in concrete
<p>2. Sulphate Minerals</p> <ul style="list-style-type: none"> • Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), • Aluminite ($\text{K}_2\text{Al}_6(\text{OH})_{12}(\text{SO}_4)_4$), • Epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) 	<p>At higher sulphate levels a reaction between calcium aluminate hydrates, sulphate and water occurs. This consequently results in the formation of ettringite, which is an expansive gel paste. Thus disruptive expansion occurs resulting in a local volume change.</p> <p>Ettringite has the potential to form strong hydraulic cement, however in hardened concrete it expands causing cracking.</p>	<p>Gypsum is restricted to 0,25% by mass of the coarse aggregate, restricted by the USA Bureau of Reclamation.</p> <p>SANS codes are the same as above in sulphide minerals</p>

Information obtained from: Addis et al., 1995, Alexander & Mindess, 2005, Grieve, 2009, O'Neill-Williams, 2012, and Smith & Collis, 2001

Table 3.6 – Undesirable minerals due to physical characteristics in aggregates (adapted from Alexander & Mindess, 2005)

Deleterious Rocks/Minerals	Impact on Concrete	Minimization/Avoidance and Specifications
<p>1. Chalk and other friable particles</p> <p>Occur in the form of chalk or clay lumps in rocks</p>	<p>These materials can result in a strength reduction and consequently induce cracking. This is caused through the breakdown of these friable particles into smaller grains through the processes of transportation and mixing.</p>	<p>ASTM C 33-93</p> <p>ASTM Limits constrain the amount of chalk and other friable material to 3% by mass of fine aggregate and 2–10% by mass of coarse aggregate. It is also recommended that it not be used in concrete subject to abrasion.</p> <p>SANS 6246:2006 – Trenton impact value of aggregates</p> <p>There is no specific standard for friable material, however the Trenton Impact test determines the hardness of a material. Thus as friable particles are weak and lacks strength it can be used. The ASTM values should be used.</p>
<p>2. Clays and altered minerals</p> <p>Highly active clays consist of:</p> <ul style="list-style-type: none"> • Active smectite clays, • Montmorillonites, and • Illites <p>(Refer to section 3.3.2 for more information)</p>	<p>These minerals result in the increase in the water requirement in fresh concrete and they cause dimensional instability in hardened concrete. This leads to effects experienced such as excessive shrinkage in concrete resulting in cracking. They also contribute to weaker and more permeable concrete.</p>	<p>SANS 201:2006 – Sieve analysis, fines content and dust content of aggregates</p> <p>Natural and crushed aggregate resources are allowed to have 5% and 10% of the material may pass through the 0,075mm sieve, respectively.</p> <p>SANS 5838:2006 – Sand equivalent test (SET)</p> <p>SET is a field test that is used to determine the fraction of sand that is comprised of silts and clays. There are not limits for this test.</p> <p>SANS 6243:2002 – Deleterious clay content of the fines in aggregates (methyl blue absorption indicator test)</p> <p>Primarily used to determine whether further testing would be required. The premise of the test is that the more of the solution absorbed, and the darker the colour on the filter paper, and thus higher the active clay content. (Maximum methyl blue absorption value = 0,7%)</p> <p>SANS 6244:2006 – Clay Content Test</p> <p>Material (less than 5-microns) < 2% by the mass of the aggregate</p>

Table 3.6 (Continued)

Deleterious Rocks/Minerals	Impact on Concrete	Minimization/Avoidance and Specifications
<p>3. Coal and lignite Bituminous coals and lignites are present in coal deposits which can occur in certain natural sands and gravels</p>	<p>It may result in a decrease in the strength of the concrete due to softness and swelling. Lignite can also cause unsightly staining, which occurs on exposed surfaces in the presence of water.</p>	<p>ASTM C 12392 Coal and lignite fall under low-density particles. ASTM limits the amount of material, with a relative density of 2,0 or lower to 0,5% in sand.</p> <p>SANS 5837:2008 – Low-density Particles It is a similar method, however it does not specify limits, thus the ASTM values should be adhered to.</p>
<p>4. Shells (CaCO₃) Shell content are associated with sea-dredged, beach, dune and marine sand deposit</p>	<p>The shell content is generally not problematic providing that it is not in excessive quantities. However, due to the shells being flaky and hollow in shape, it impacts upon the workability of concrete in its fresh state.</p>	<p>SANS 5840:2002 – Shell content in fine aggregates According to SANS, the broken shell content should be limited to 30% of the mass of fine aggregates. This percentage should be less for unbroken shells.</p>
<p>5. Slate and Schist</p>	<p>Rocks contain cleavage plains that are relatively low in strength, thus reduce the strength of the concrete.</p>	<p>Avoid weaker aggregates (Refer to part 1 of this table for code requirements)</p>

Information obtained from: Addis et al., 1995, Alexander & Mindess, 2005, Grieve, 2009, O'Neill-Williams, 2012, and Smith & Collis, 2001

Table 3.7 – Undesirable minerals according to chemical composition in aggregates (adapted from Alexander & Mindess, 2005)

Deleterious Rocks/Minerals	Impact on Concrete	Minimization/Avoidance and Specifications
<p>1. Alkali-susceptible minerals</p> <p>Reactive Minerals</p> <ul style="list-style-type: none"> • Opal • Tridymite • Chalcedony, cryptocrystalline, microcrystalline or glassy quartz • Coarse-grained quartz, which is intensely fractured, granulated or strained internally, or rich in secondary inclusions. <p>Reactive Rocks</p> <ul style="list-style-type: none"> • Refer to Table 3.8 <p>Reactive Substances</p> <ul style="list-style-type: none"> • Synthetic glass, and silica gel 	<p>Alkalisilica reaction (ASR) occurs between the alkaline pore solution of a concrete and metastable forms of silica. These reactants produce expansive products in the form of alkali-silica gels. These expansive gel products result in local volume change, which can cause cracking.</p> <p>ASR can also cause a loss of bond between the aggregate, cement past interface, thus weakening the concrete.</p>	<p>Avoid the use of reactive aggregates and minimise the effect through the use of cement extenders.</p> <p>(Refer to Table 3.9 for code requirements)</p>
<p>2. Minerals with a large amount of ferrous iron</p> <p>Certain igneous rocks</p> <ul style="list-style-type: none"> • Granites with biotite mica, • Some dolerites containing olivine 	<p>Effects on concrete may vary ranging from:</p> <ul style="list-style-type: none"> • Cracking caused by the ferromagnesian minerals oxidising. This causes a volume increase and expansion and thus consequently cracking occurs • Unsightly staining caused by the oxidation 	<p>Avoid deleterious varieties, such as Olivine (Highly ferrous fayalite olivine degrades to black chlorophaeite)</p>
<p>3. Hornblende</p> <p>Found in certain metamorphosed dolerites</p>	<p>Certain ferrous hornblende degrade in the presence of moisture, especially moist saline conditions. As a result it produces a reddish limonitic material, which forms a coatings on the aggregate.</p>	<p>Avoid deleterious varieties, such as certain metamorphosed dolerites</p>

Table 3.7 (Continued)

Deleterious Rocks/Minerals	Impact on Concrete	Minimization/Avoidance and Specifications
4. Micas		
Muscovite and Biotite (Occurs in granites, gneisses and sandstones)	<p>Muscovite Mica Muscovite mica can occur as flaky grains in sand resulting in an increased water requirement and a reduction in strength and durability. The strength reduction experienced can be up to 5% for every 1% by mass of muscovite.</p> <p>Biotite Mica Biotite can be altered rapidly to form sericitite and illite clay, through the process of weathering. (Sericitite is a fine-grained variety of hydro-muscovite) Muscovite micas are more harmful than biotite</p>	Micas according to Alexander and Mindess is recommended not to exceed the limit of 3-5%

Information obtained from: Addis et al., 1995, Alexander & Mindess, 2005, Grieve, 2009, O'Neill-Williams, 2012, and Smith & Collis, 2001

Table 3.8 – Rocks that are potentially deleteriously reactive with alkalis in concrete (Addis et al., 1995)

Potentially Reactive Rocks		Reactive Component		
Igneous Rocks	Granodiorite Charnockite Granite	Strained quartz; microcrystalline quartz		
	Pumice Rhyolite Andesite Dacite Latite Perlite Obsidian Volcanic tuff	Silicic to intermediate silica-rich volcanic glass; devitrified glass; tridymite		
	Basalt	Chalcedony; cristobalite; palagonite; basic volcanic glass		
	Metamorphic Rocks	Gneiss Schist	Strained quartz; microcrystalline quartz	
		Quartzite	Quartzite Strained and microcrystalline quartz;	
		Hornfels Cataclasite Mylonite Argillite	Phyllite Strained quartz; microcrystalline to cryptocrystalline quartz	
		Sedimentary Rocks	Sandstone	Strained and microcrystalline quartz; chert; opal
			Greywacke	Strained and microcrystalline to cryptocrystalline quartz
			Siltstone Shale	Strained and microcrystalline to cryptocrystalline quartz; opal
	Tillite		Strained and microcrystalline to cryptocrystalline quartz	
Chert Flint	Cryptocrystalline quartz; chalcedony; opal			
Diatomite	Opal; cryptocrystalline quartz			
Argillaceous dolomitic limestone and alligarious calcitic dolostone Quartz-bearing argillaceous calcitic dolostone	Dolomite; clay minerals exposed by de-dolomitisation			

a) Shrinkage of Concrete

Clays, due to their absorptive properties, expand and contract with varying water contents. As a result this causes local shrinkage and swelling. Subsequently this causes local volume changes, which produce tension forces within the concrete. These resultant tension forces often are greater than the tensile strength of concrete, resulting in cracking occurring in zones of the concrete. This effect reduces the concrete's structural integrity, by reducing its strength and durability. (Grieve, 2009)

This effect is more prominent in clays, which are termed 'active'. This is because of their ability to absorb water molecules into their crystalline structure when wetted, but to expel water when dried. The 'activity' of the clays is particularly high with clays that are rich in smectite or montmorillonite. Consequently active clays result in more excessive shrinkage and swelling and subsequently higher impacts upon concrete. (O'Neill-Williams, 2012)

An additional problem with 'active' clays is that they can retard the rate of hydration of the cement particles. This occurs through their tendency to break down in highly alkaline environments, such as in concrete, which has a highly alkaline pore water solution. To explain this concept, during the hydration process, there is an excess of hydroxide (OH) ions, which react with the active clays forming an expansive gel paste. As the hydroxide ions have been consumed through the reaction with the 'active' clays, there are fewer available for the cement's hydration reactions. This consequently retards the rate of hydration of the cement. Due to the reduced rate of hydration, a smaller quantity of cement paste is produced, which reduces the strength of the concrete. (O'Neill-Williams, 2012)

b) Water Requirement

The amount of active clay, not the total clay content, is the fundamental factor dictating the deleterious impact of clays on concrete. This has been proved through extensive testing conducted by the C&CI. (Grieve, 2009) Their findings showed that fine aggregate resources with a higher proportion of non-active clay produced a higher strength concrete. This result can be attributed to the fine-filler effect, in which the finer clay particles are able to fill the gaps between the larger particles, providing strength, but also impeding the flow of water and improving the interfacial transition zone (ITZ). However, with an increase in the fines content, the water requirement will increase, subsequently reducing the workability of the fresh concrete. This subsequently makes transportation and handling more difficult. (For a discussion on the influence of the fines content on a concrete mix, refer to section 3.2.1 on grading) (Grieve, 2009)

3.3.2.2 Classification according to SANS Specifications

According to SANS 1083:2006, the dust or fines content is defined as material passing through the 0,075mm sieve. This specification focused upon the size of the particles being the important factor preventing the contamination of concrete due to clay. However, as discussed in the impact upon concrete in this section, it is also important to identify the mineralogy of the fines material, and establish the activity of the clay content. As a result there are three separate components of the SANS codes, that specify the quantity of fines material. They are differentiated as follows: (Grieve, 2009)

- Fines content
- Clay content
- Active clay content

a) Fines Content (SANS 201:2008)

The values for this test are specified in SANS 1083:2006, with the procedure for determining the amount specified in accordance with SANS 201:2008. This code specifies different values for natural and crushed aggregate resource, which are 5% and 10% by mass of the fine aggregate, allowed to pass through a 0,075mm sieve respectively.

It is preferable that the dust content for normal grades of concrete be as close to these limits as possible. This is to ensure an acceptable control of the amount of bleeding. In certain circumstances these limits may be increased providing that the aggregate resource has a negligible, or zero active clay content. (Grieve, 2009)

b) Clay Content (SANS 6244:2006)

The pipette method detailed in SANS 6244:2006 is used to determine the clay content present in an aggregate resource. The method determines the proportion of material that is between 5 to 20-microns in diameter. This is achieved indirectly through sedimentation of the particles in water. Then the content of each particle size is determined with the aid of Stokes Law, which relates the settling velocity to the particle diameter. Silt has a particle size of less than 20-microns and clay less than 5-microns. The limits of this test are specified in SANS 1083:2006 stipulate material (less than 5-microns) should be less than 2% by the mass of the aggregate. (Addis et al., 1995)

c) Mineralogy of Dust Content (SANS 6243:2002)

The methyl blue absorption test detailed in SANS 6243:2002 was introduced to test for the smectite/montmorillonite content. This test works on the premise that the active clays absorb the indicator. Only once all of the particles are coated, the indicator colour becomes evident. This colour becomes apparent in the form of a halo on the filter paper. This test is primarily used to determine whether further testing would be required. The limits of this test are specified in SANS 1083:2006, stipulate a maximum methyl blue absorption value of 0,7%. (Addis et al., 1995)

3.3.3 Deleterious Chemical Constituents

The impacts of chemical reactions occurring within the concrete are not solely restricted to the mineral constituents that form the composition of aggregates. There are also deleterious chemical constituents that can contribute to these chemical reactions. This is as a result of many natural sources containing substances that coat the aggregate. These coatings can be categorised into five effects, as listed as follows: (Alexander & Mindess, 2005)

1. Soluble substances that dissolve in water causing efflorescence,
2. Soluble substances interfering with the hydration of cement,
3. Substance that react directly with the cement paste, being destructive to the hydration products,
4. Substances that react with the alkali constituents of the cement paste, and
5. Substances causing corrosion of the reinforcement steel.

The categories mentioned above are in Table 3.9, which discusses their impact upon concrete and their classification according to SANS specifications.

Deleterious Chemicals in Aggregates

Table 3.9 – Undesirable soluble salts and chemicals in aggregates (adapted from Alexander & Mindess, 2005)

Deleterious Soluble Salts/Chemicals	Impact on Concrete	Minimization/Avoidance and Specifications
<p>1. Salts causing efflorescence</p> <p>Soluble chlorides and carbonates e.g. Common table salt (NaCl – Sodium Chloride)</p>	<p>These substances mix with water in the concrete mix and leach out forming unsightly white deposits on the concrete surface. When they leach out, they weaken the aggregate resulting in cracking or increasing the voids in the aggregate.</p>	<p>SANS 5849:2006 – Total water soluble salts content of fines in aggregates Limit the amount of soluble material or avoid altogether</p>
<p>2. Salts effecting cement hydration</p> <p>Acceleration of the hydration reactions e.g. Chlorides (Cl)</p> <p>Retarding the hydration reactions e.g. Humic acid or sugars (product of organic material)</p> <p>Increase in the reactive alkali content e.g. Common table salt (NaCl – Sodium Chloride)</p>	<p>The substances cause an accelerated process of hydration, resulting in the concrete hardening more quickly and rapid strength gain. This can cause subsequent issues such as higher temperatures in the hydration process leading to thermal expansion and contraction causing cracking. They can also cause subsequent efflorescence, or steel corrosion.</p> <p>These substances react in the concrete mix causing the retardation of the hydration process. Consequently resulting in slow strength gain. It can be very detrimental to construction and may reduce later strength gain.</p> <p>The sodium chloride in concrete contributes to an increase in the reactive alkali content. This may exacerbate ASR or potential ASR.</p>	<p>Limit the amount of soluble material or avoid altogether (Refer to part 5 of this table for code requirements)</p> <p>Limit the amount of soluble material or avoid altogether (Refer to Table 3.11 for code requirements)</p> <p>Limit the amount of soluble material or avoid altogether (Refer to part 4 of this table for code requirements)</p>

Table 3.9 (Continued)

Deleterious Soluble Salts/Chemicals	Impact on Concrete	Minimization/Avoidance and Specifications
<p>3. Salts destructive to hydration products e.g. Sodium sulphate (Na_2SO_4) and magnesium sulphate (MgSO_4)</p>	<p>The sulphates in the aggregates can react with the hydration products and destroy their properties. This occurs through either expansive reactions (ettringite formation) or ion-exchange reactions, resulting in the destruction of the binding ability of the hydrates, softening, cracking and weakening of the concrete.</p>	<p>Limitation of the total sulphate content from the cement, aggregate and mixing water. Ensure that there is not more than twice the amount of sulphate present solely in the cement. (Refer to Table 3.5 for code requirements)</p>
<p>4. Aggregates containing releasable alkalis Releasable alkalis that occur in certain aggregates such as in some granites and volcanic rocks.</p>	<p>Alkali-silica reactions are deleterious in concrete. They occur as a result of silica minerals in the aggregates react with the alkali content in the pore solution. This results in the formation of an expansive gel paste, which results in cracking and a reduction in strength. Alkalis are naturally present in concrete due to the cement content. Additional alkalis, which are derived from certain aggregates, can be problematic as they increase the overall alkali content in the pore solution. This only occurs in concrete with aggregate containing releasable alkalis.</p>	<p>Avoidance of aggregates containing releasable alkalis is recommended. SANS 6245:2006 – Potential reactivity of aggregates with alkalis (accelerated mortar prism methods) Results after 12 days are as follows:</p> <ul style="list-style-type: none"> • 0,00% – 0,10% = Aggregate is innocuous • 0,11% – 0,20% = Aggregate is slowly reactive or inconclusive • > 0,20% = Aggregate is deleteriously reactive and rapidly expansive
<p>5. Salts causing steel corrosion Chlorides that typically occur in unwashed aggregates obtained from sea-dredged sources, beach sands and dune deposits. (e.g. Common table salt (NaCl))</p>	<p>The chlorides in aggregates and concrete are highly problematic. They are highly aggressive to the embedded reinforcement steel, causing corrosion, cracking and spalling. The corrosion of the reinforcement steel is of huge concern, because it can lead to early failure in the concrete due to a loss of strength in the reinforcement.</p>	<p>SANS 202:2006 – Chloride content of aggregates The maximum allowable chloride content (Cl^-) by mass in aggregates are:</p> <ul style="list-style-type: none"> • Prestressed concrete = 0,01% • Normal reinforced concrete = 0,03% • Non-reinforced concrete = 0,03%

Information obtained from: Addis et al., 1995, Alexander & Mindess, 2005, Grieve, 2009, O'Neill-Williams, 2012, and Smith & Collis, 2001

3.3.4 Deleterious Organic Material

Lastly as aggregates are natural material that is extracted from the ground, they can contain organic material. This is especially the case for natural sources, by comparison to crushed and recycled sources where it is less likely. This material is also a cause of deleterious reactions in concrete, therefore it is important that this material is identified in order to minimise or avoid these detrimental effects.

Organic material is matter that has been derived from an organism, as a product of decay, or composed of organic compounds. This organic matter can be divided into three broad categories: non-humic matter, humic matter, and organic contaminants. These three categories are discussed in Table 3.10. (O'Neill-Williams, 2012)

Table 3.10 – Types of Organic Matter (Tremblay et al., 2002)

Category	Definition	Examples
Non-humic Matter	The non-humic proportion consists of the decaying organics, where organic molecules are released from cells of fresh residues.	<ul style="list-style-type: none"> • Proteins • Amino Acids • Sugars • Starches
Humic Matter	The humic proportion consists of non-humic matter that has been broken down by organism through the process of weathering, or transformed.	<ul style="list-style-type: none"> • Alcanes • Fatty Acids • Humic Acids • Fulvic Acids • Humins
Organic Contaminants	Organic contaminants comprise of the remaining organic material. This is most of the time anthropogenic, thus is a form of pollution or pollutant. This includes a variety of organic compounds originating from human activity.	<ul style="list-style-type: none"> • Fertilisers

The impact of these deleterious organic materials are categorised according to organic material consisting of humic matter and organic contaminants, and sugars, which is a non-humic matter. These categories are discussed in Table 3.11 with respect to the impact that they have upon concrete and their respective SANS specifications.

3.4 Texture

An aggregate's texture is not technically a property, but more of a characteristic. It refers to an aggregate's particle shape and surface texture, which in combination with an aggregate's grading, influences the plastic properties of concrete. These plastic properties include the workability and cohesiveness of the concrete mix. Subsequently these properties have an impact upon the aggregate matrix and thus the overall strength of concrete. This section discusses the two characteristic textures of aggregate, identifying their impact upon concrete and their classification according to SANS specifications.

Deleterious Organic Material in Aggregates

Table 3.11 – Undesirable organic matter in aggregates (adapted from Alexander & Mindess, 2005)

Deleterious Organic Matter	Impact on Concrete	Minimization/Avoidance and Specifications
<p>1. Organic Material</p> <p>Organic matter comprises of three categories:</p> <ul style="list-style-type: none"> • Humic matter • Organic contaminants <p>They typically occur in natural sands, and less likely in crushed sources. (Refer to section 1.1.1 for more information)</p>	<p>Organic material has two significant effects upon concrete:</p> <ul style="list-style-type: none"> • Retards the hydration process – Some organic matter tends to coat the binder, thus interfering with hydration of the cement from occurring. This can result in an adverse effect upon the strength of the concrete. • Discolouration of the concrete – Some organic matter may react with the constituents within a concrete mix, discolouring the concrete. 	<p>Avoid contaminated sources as even very small amounts (typically less than 1% of the mass) may have a significant impact upon the concrete.</p> <p>SANS 5832:2006 – Organic impurities in fine aggregates</p> <p>The colour of the liquid above the fine aggregate should not be darker than the reference solution. However, the result is not applicable if in accordance with soluble deleterious impurities.</p> <p>SANS 5834:2006 – Soluble deleterious impurities in fine aggregates (limit test)</p> <p>Strength of specimens must be at least 85% of strength of specimens made after aggregate has been washed. However, the result is not applicable if in accordance with soluble deleterious impurities.</p>
<p>2. Sugars</p> <p>Sugars may be present in natural sources of sand, originating from plant matter, and form part of the non-humic matter.</p>	<p>Sugars can have severe effects upon the chemical reactions within a concrete mix, retarding the setting and hardening. Consequently the setting times are extended for days, or as the percentage of the sugars reaches 1% by mass of the cement, the reaction can be completely inhibited. Sugars that ferment to form alcohols can result in similar effects.</p>	<p>It is preferable to avoid the presence of sugar.</p> <p>SANS 5833:2006 – Detection of sugar in fine aggregates</p> <p>The fine aggregates must be free from sugar, unless it complies with the requirement of both organic impurities and soluble deleterious impurities in fine aggregates.</p>

Information obtained from: Addis et al., 1995, Alexander & Mindess, 2005, Grieve, 2009, O'Neill-Williams, 2012, and Smith & Collis, 2001

3.4.1 Particle Shape and Surface Texture

Particle shape and surface texture are important characteristics of aggregates that impact upon the plastic properties of concrete. These characteristics in fine aggregates have the greatest impact in this regard. The particle shape refers to the external form, outlining the profile of the aggregate, whereas the surface texture is the feel, appearance and consistency of the surface of the aggregate. These two properties are represented in Figure 3.4. (Alexander & Mindess, 2005)

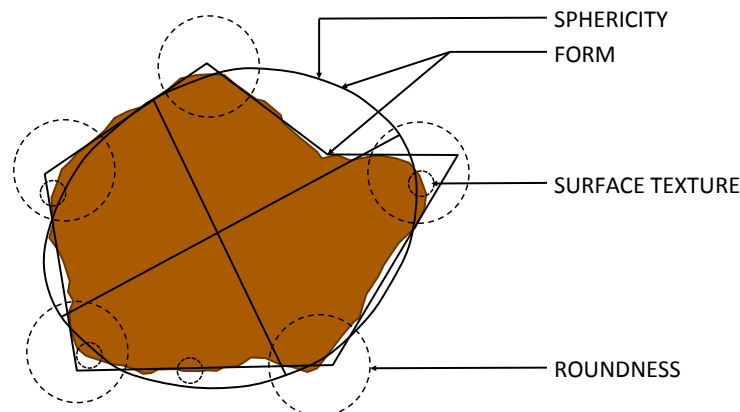


Figure 3.4 – Particle shape terminology (Barrett, 1980)

The particle shape of fine aggregates can be classified according to three functions consisting of the sphericity, roundness and form of the particles. These three functions are defined as follows:

- **Sphericity** – A measure of how closely the particle reaches a spherical shape (Sphericity = nominal diameter/maximum intercept)
- **Roundness** – The sharpness of the edges and corners (Roundness = average radius of the corners and edges/radius of maximum inscribed circle)
- **Form** – A function describing the relative proportions of the three axis (also known as shape factor)

These three functions of particle shape are highly dependant upon the source and nature of the aggregate. The nature of the aggregate refers its original geological depositional setting, and this dictates the material's strength and abrasion resistance. The source of the aggregate refers to the location in which the aggregate is obtained and thus suggests the degree of wear it is subjected. The further the aggregate has been transported, the greater the degree of wear. Therefore resulting in aggregates that are more spherical and rounded and have a smoother particle texture. (Alexander & Mindess, 2005)

a) Classification of Particle Shape

According to these functions of particle shape, aggregate shapes have been defined according to BS 812:102:1989. This classification ranges from rounded, well-shaped aggregates, to flaky, elongated and angular aggregates, which are regarded as poorly shaped aggregates. These classifications are represented in Figure 3.5 and Table 3.12. (Alexander & Mindess, 2005)

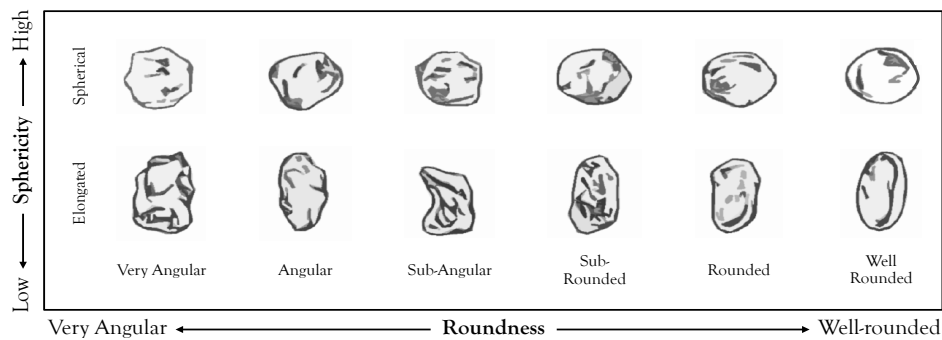


Figure 3.5 – Visual classification of the particle shape based upon morphological observations (Alexander & Mindess, 2005)

Table 3.12 – Particle shape classification (Alexander & Mindess, 2005)

Classification	Description	Examples
Rounded	Water-worn or completely shaped by attrition	Natural sands derived from alluvial, marine or aeolian sources
Irregular	Naturally irregular, or partly shaped by attrition and having rounded edges	Pit sand sources, such as fluvial sands found in terrace deposits
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Hillwash and colluvial sands, or crushed rocks of natural or artificial origin
Flaky	Material in which the thickness is small relative to the other two dimensions	Poorly crushed sands, particularly if derived from laminated or bedded rocks
Elongated	Material, usually angular, in which the length is considerably larger than the other two dimensions	
Flaky and Elongated	Material having the length considerably larger than the width, and the width considerably larger than the thickness	Poorly crushed sands, particularly formed through the use of poor processing techniques

Original source: BS 812:102:1989

b) Classification of Surface Texture

The surface texture as previously mentioned refers to the feel, appearance and consistency of the aggregates surface. This is classified in the BS code according to six different categories, ranging from glassy and smooth to rough surface textures. Aggregates with a rougher surface texture, have a more uneven the surface, consequently this results in a greater surface area for the aggregate. These classifications are represented in Table 3.13. (Alexander & Mindess, 2005)

Table 3.13 – Surface texture classification (Alexander & Mindess, 2005)

Classification	Description	Examples
Glassy	Conchoidal (curved) fracture	Glassy or vitreous materials such as slag or certain volcanics
Smooth	Water-worn or smooth due to fracture laminated or fine-grained rock	Alluvial, glacial or aeolian sands, fine grained crushed rocks such as quartzite, dolomite etc.
Granular	Fracture showing more or less uniform size rounded grains	Sandstone, coarse grained rocks such as certain granites etc.
Rough	Rough fracture of fine or medium grained rock containing no easily visible crystalline constituents	Andesite, basalt, dolerite, felsite, greywacke
Crystalline	Containing easily visible crystalline constituents	Granite, gabbro, gneiss
Honeycombed	With visible pores and cavities	Brick, pumice, foamed slag, clinker, expanded clay

Original source: BS 812:102:1989

3.4.1.2 Impact of Particle Shape on Concrete

Particle shape is an extremely important property of fine aggregates, contributing strongly towards the plastic properties of the concrete and mortar mixes. The main impact is upon the workability of a concrete mix, and this impacts upon the water requirement. As known in the industry, greater amounts of water lead to two results. If the same amount of cement is used, then the water-binder ratio is increased, which results in a reduction of the strength of the concrete. Alternatively if the cement content is increased, to maintain a constant water-binder ratio, there is a higher volume of cement paste in the concrete, which contributes towards higher porosity. As the main component of porosity is in the paste and if these pores are highly interconnected, the permeability would increase. This would then either contribute to a lower strength or increase the shrinkage and other such factors in the concrete. It also makes the concrete mix less economical and less sustainable as there is a greater amount of cement used. It is therefore important to reduce the water requirement of a concrete mix. (For more information refer to Fulton's Concrete Technology) (Grieve, 2009)

Rounded and more spherical particles are able to roll and slide over each other in a plastic mix with greater ease and less resistance thus making the mix more workable. The poorly shaped particles of flaky and angular shape also induce aggregate interlocking, thus resisting compactive efforts. If proper compaction is not achieved it can lead to greater number of voids, and may even result in honeycombing of the mix. This results in substantially reduced strength in the concrete in its hardened state. This is more of a concern with poorly shaped coarse aggregates. (Alexander & Mindess, 2005)

The particle shape also impacts upon the hardened properties of concrete mixes, however this is not as much of a factor. A degree of angularity is good for hardened concrete as it creates a higher internal friction caused by the interlocking of aggregates with each other. This will result in increased concrete strengths, however only if full compaction is achieved. This is because cracking typically occurs in the cement paste, except in the case of extremely high strength concrete. Thus the cracking is forced to follow a more tortuous and complex path around the aggregates. (Alexander & Mindess, 2005)

A balance has to be made between the shape of an aggregate used in concrete and mortar mixes. If the particle is poorly shaped it will result in more difficult compaction, an unacceptable water demand, and a higher cement paste content, which is uneconomical and environmentally unfriendly. However, conversely providing it is fully compacted, it can increase the strength of the concrete. (Alexander & Mindess, 2005)

3.4.1.3 Impact of Surface Texture on Concrete

This property, like particle shape, has an impact upon the water requirement and consequently the workability of mortar and concrete mixes, which is controlled by the surface area of the aggregate. The rougher the aggregate surface, the more likely it is to cause an increase in the water requirement, because a greater surface area requires wetting. The roughness of the surface will contribute to the internal friction, resulting in a mechanical interlock between particles, that impacts its workability. (Grieve, 2009)

The surface texture will also have a similar effect upon concrete in its hardened state. The roughness of the surface texture will increase the internal friction of the concrete, thus resulting in greater internal forces resisting the external forces placed upon the member. (Grieve, 2009)

3.4.1.4 Classification according to SANS Specifications

The classification of the particle shape and surface texture is difficult to determine. This is especially difficult for fine aggregates which are small and difficult to examine unless under a microscope. Therefore the visual classification according to the diagrams and tables represented in the British code (BS 812:102:1989) are not commonly used. The more commonly used methods are indirect, as they are based upon the effects caused by the particle shape and surface texture on concrete. These effects experienced are as follows:

- The estimation of the effect of fine aggregate on water requirement
- The bulk density and voids content of fine aggregates

The results obtained are not necessarily conclusive in determining the particle shape and surface texture, since these effects can also be caused by other properties such as the grading of aggregate. However, it serves a purpose as it describes the necessary impact that aggregate has upon the resulting fresh concrete.

a) The estimation of the effect of fine aggregate on water requirement (SANS 5835:2006)

The particle shape and surface of fine aggregates have a large impact upon the water requirement of concrete and mortar mixes. Therefore a test of the water requirement gives an indirect indication of the particle shape and surface texture of aggregates. However, this test has been proven to limit applicability, according to the C&CI. This is because although particle shape and surface texture has a significant impact upon the water requirement, it is not the only factor. Other factors include the mineralogy and fines content. (Addis et al., 1995)

This experiment requires a control specimen with a specified water requirement. This is to provide a reference from which the aggregate being tested can be assessed. The water requirement will vary according to the resource used; however a preferable water requirement is below 200 litres per cubic metre of concrete. (Grieve, 2009)

b) The bulk density and voids content of fine aggregates (SANS 5845:2006)

The bulk density and void content of aggregates test is a useful technique that can be used to determine the particle shape of fine aggregates. It is an indirect method based upon the observation that particle shapes that have an angular, elongated shape will pack less, and thus contain a greater void content than that of a well-shaped, rounded particle. The experiment requires a controlled reference specimen against which the bulk density and void content are measured. (Addis et al., 1995)

3.5 Summary of Fine Aggregate Properties

Aggregates account for approximately 60-80% by volume of concrete mixes, half of which is constituted by fine aggregate. They provide the structural framework of concrete through the interconnectivity of the aggregate particles that form a matrix. As a result they are highly influential in dictating the overall properties produced in a concrete mix. It is thus important that the aggregate contributes towards ensuring that the concrete maintains sufficient strength and is durable from deterioration over its design life.

In analysis of aggregate used in concrete mixes, there are three main properties that dictate the potential use of an aggregate resource. These consist of: (1) the particle size and distribution, (2) the mineralogical composition, and (3) the particle shape and surface texture of aggregates. These properties and their impact upon concrete are summarised briefly in Table 3.14.

Table 3.14 – Summary of fine aggregate properties

Name of Property	Significance of Property	Impact on Concrete
Particle Size and Distribution	The particle size and distribution refers to the grading of an aggregate resource. This is representative of the range of particle sizes, indicating the maximum particles size and fines content. These factors are fundamental to concrete as a 'bound conglomerate'. It directly impacts upon: <ul style="list-style-type: none"> Aggregate packing density Void content, and Required cement paste content to achieve desired strength 	Plastic properties of concrete: <ul style="list-style-type: none"> Bleeding (Major) Cohesiveness (Major) Workability (Major) Water Requirement (Minor) The fines content (minus 0,075mm fraction) is crucial to cohesiveness and control of bleeding.
Mineralogical Composition	The mineralogical composition refers to the mineralogy and chemical constituents of the aggregate material. It is essential that the aggregate is strong and chemically stable (inert); as to ensure that the aggregate is able to withstand the high forces placed upon them, preventing any deleterious reactions from occurring.	The mineralogical composition can compromise the strength and durability of concrete through chemical reactions that occur in both concrete's plastic or hardened state. The most common impacts experienced include: <ul style="list-style-type: none"> Shrinkage and subsequently cracking, Retardation of the cementing reactions resulting in loss of strength, and Corrosion of the reinforcement steel.

Table 3.14 (Continued)

Name of Property	Significance of Property	Impact on Concrete
Particle Shape and Surface Texture	<p>The particle shape refers to the angularity, and spherical shape of the aggregate particle. The surface texture refers to the surface roughness and form of the aggregate particle. These factors influence the following:</p> <ul style="list-style-type: none"> • Particle packing and • Aggregate interlock in the concrete mix, and • Frictional surface properties in a mix, and thus the 'harshness'. 	<ul style="list-style-type: none"> • Workability and water requirement, and • Strength and aggregate bond.

3.5.1 Fine Aggregate Properties according to Resource

When identifying a potential resource, it is important to understand the more desirable properties for fine aggregate used in concrete, however this will vary depending upon the use of the concrete mix. Typically a fine aggregate with a well-graded particle distribution, consisting of greater variety of sizes, a more rounded particle shape, smoother surface texture, and a strong and inert mineralogical composition, is most desirable for concrete of moderate strength and high durability. The particle shape and surface texture are properties that will least inhibit a resource's potential use, as compared to the mineralogical composition of strong, inert material, that is essential for all concrete mixes.

As previously discussed, these properties vary according to the origin of the resource. Each resource of fine aggregate is mentioned in Figure 3.6 and Table 3.15, highlighting their typical aggregate properties as discussed in this chapter.

Table 3.15 – Source and production of fine aggregates (adapted from Alexander & Mindess, 2005)

Source	Sand Production	Influence of source and production on aggregate properties		
		Particle Shape	Surface Texture	Grading
Natural Sand Resources				
Pit or Quarry Sands	Yes	Rounded to Angular	Smooth to Rough	Graded
River Sands	Yes	Rounded	Smooth	Graded to Single-Sized
Beach Sands	Yes	Rounded	Smooth	Graded to Single-Sized
Dune Sands	Yes	Rounded	Smooth	Single-Sized
Marine Sands	Yes	Rounded	Smooth	Graded to Single-Sized
Crushed Sand Resources				
Hard Rock Quarry	Yes	Normally Angular *	Normally Rough *	Graded

Table 3.16 (Continued)

Source	Sand Production	Influence of source and production on aggregate properties		
		Particle Shape	Surface Texture	Grading
Recycle Sand Resources				
Rock Dumps	Potentially	Normally Angular *	Normally Rough *	Graded
Demolition Sites	Potentially	Normally Angular *	Normally Rough *	Graded

* May vary depending on the resource

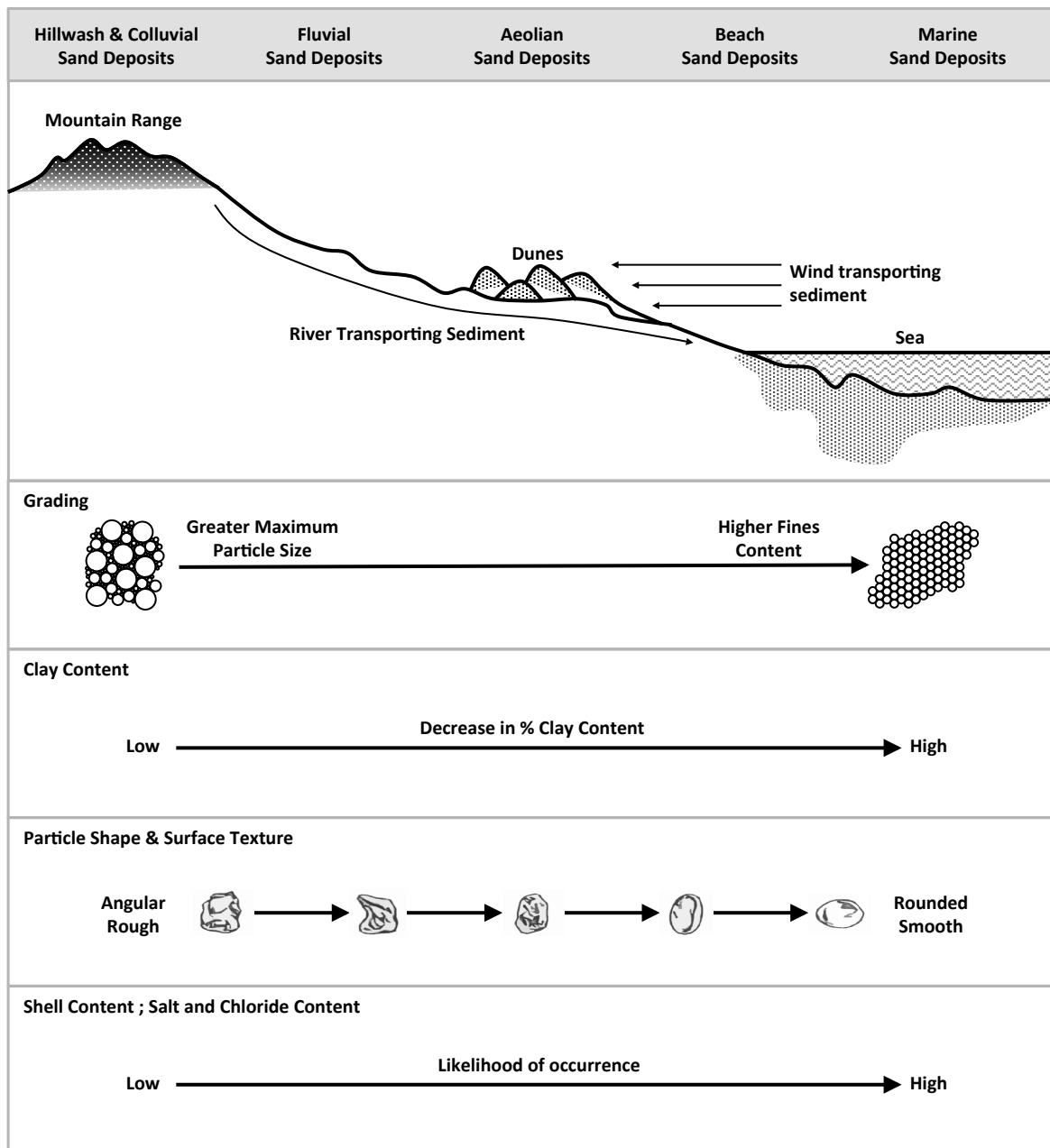


Figure 3.6 – A representation of natural fine aggregate deposits

Chapter 4

Production of Fine Aggregates

4.1 Introduction

The subject of production of fine aggregates involves the extraction and processing of the raw rock material into a form, suitable for use in the Construction Industry. The processes used are developed to achieve the properties discussed in the previous chapter, relating to particle size and distribution, mineralogical composition, and particle shape and surface texture. This chapter will assess the industrial processes used to achieve this, as well as discuss the important considerations that need to be addressed in the design and planning phase of the quarry and processing plant.

4.2 The Production Cycle

The production cycle of fine aggregates refers to the set of operations implemented to transform rock material into a form, which possesses properties suitable for use in the construction industry. In the context of this dissertation its use is for concrete production. The production cycle is in two stages: extraction and processing. The method of extraction and processing used are dependant upon the source from which the aggregate was obtained. (Archibald, 1991) As mentioned in the previous chapter, these sources can be grouped into five main groups:

- Onshore sand deposits – Hillwash/colluvial, fluvial and aeolian sands,
- Offshore sand deposits – Marine sands,
- Excavated site material – Site-derived aggregates,
- Hard rock deposits – Crusher sands/dusts, and
- Construction and demolition waste (C&DW) – Recycled aggregates.

4.2.1 Extraction

The extraction phase is the removal of rock, sand, or gravel from the earth, and its delivery to a processing plant. The techniques used depend on nature of the deposit, which is either compact and hard rock, or soft and friable rock. For hard and compact deposits, explosives are required to break up the material into appropriate sizes for processing. By comparison the soft and friable deposits are already of appropriate size for processing, therefore they will only require to be dug out. The resources mentioned previously, along with the extraction technique used to exploit them, are listed as follows. (Smith & Collis, 2001)

- Onshore sands (soft rock) – quarrying of open-cast mines,
- Offshore marine sands (soft rock) – dredging of marine deposits on the sea floor,
- Site-derived aggregates (hard or soft rock) – excavation of site material,
- Crushed Aggregates (hard rock) – extraction from open-cast quarries,
- Recycled aggregates (hard rock) – crushing and processing of construction and demolition waste.

The extraction procedures vary, however the techniques used all aim to achieve the same outcome. This is to obtain rock material in a form suitable for processing. In general, this is achieved in five steps:

(1) Site preparation, (2) Resource extraction involving environmental impact minimization strategies, (3) Secondary fragmentation of hard rock, to process the material into an optimal size for processing, (4) Stockpiling or storage of the aggregate material, (5) Loading, and transportation. (Refer to Table 4.1 for an explanation of these phases and their applicability to each resource) However, for recycled fine aggregate the extraction procedures are different as it involves the use of construction and demolition waste products obtained from construction or landfill sites. (Smith & Collis, 2001)

4.2.2 Processing

After the material has been extracted it is transported to the aggregate processing plant. The purpose of this plant is to prepare the rock material and change its properties so that it can be used as an aggregate. This preparation uses mechanical processes to refine the following properties: particle size and distribution, mineralogical composition, and particle shape and surface texture. (These properties are discussed in Chapter 3)

The processing is in five phases: (1) comminution, (2) washing and scrubbing, (3) screening and sorting, (4) beneficiation, and (5) dewatering. In order to move the material through each of the mechanical processes, the aggregate is handled and transported using a system of conveyors and feeders. Once the aggregate has been processed it is stockpiled, ready for use. When required the fine aggregate is collected and loaded onto a dump truck and transported to a required location for use in concrete. This is typically a ready-mix plant. (For an explanation of these categories and the mechanical operations used, refer to Table 4.2. Figure 4.1, which follows, is an example of a typical crushed aggregate processing plant) (Smith & Collis, 2001)

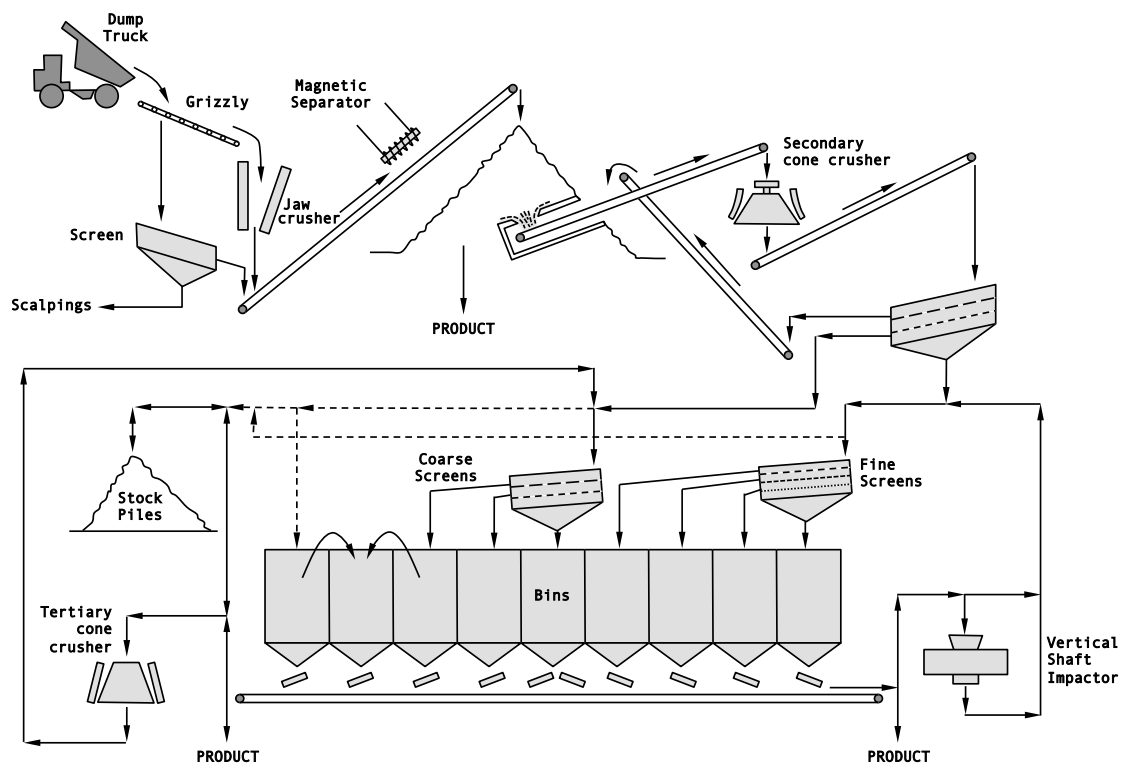


Figure 4.1 – Flow diagram representing a typical crushed aggregate processing plan (Smith & Collis, 2001)

Table 4.1 – Extraction procedures

Extraction Operation	Natural Fine Aggregates			Crushed Aggregates
	Onshore Sands	Offshore Marine Sands	Site Derived Aggregates	
<p>1. Site Preparation</p> <p>Overburden Removal – The removal of the top layer of soil, which overlies the deposit that has been defined for fine aggregate use. This overburden material is removed as it typically consists of soils or weathered, weaker rocks that are generally unconsolidated and are often sand rich. It also typically contains a high organic content due to the biological activity that occurs in these soils. This material is commonly stored on-site to help with site restoration, upon closure of the quarry.</p>	✓		✓	✓
<p>2. Resource Extraction (Primary Fragmentation and Removal)</p> <p>Drilling – Drilling refers to the boring of rock material to produce a hole in which the explosives can be placed. These holes are referred to as blast holes.</p> <p>Blasting – Blasting is the controlled use of explosives, used for the breakdown and removal of rock material in a hard rock quarry. This is done to reduce the material into a more manageable size for removal to the processing plant.</p> <p>Digging – Digging is the breakup and removal of rock material or sand in a quarry. This mechanical operation is conducted through the use of a hydraulic shovel excavator.</p> <p>Dredging – Dredging is the removal of sand from marine environments. It typically is conducted through the use of suction equipment attached to a ship vessel, which trawls the coastline, sucking the marine sands from the sea floor. (This procedure can also be used in fluvial sand deposits, such as rivers, and lakes)</p>				✓
		✓		✓
	✓			✓

Table 4.1 (Continued)

Extraction Operation	Natural Fine Aggregates			Crushed Aggregates
	Onshore Sands	Offshore Marine Sands	Site Derived Aggregates	
<p>3. Aggregate Preparation</p> <p>Secondary Breakage - This refers to the additional breakage of the rock material excavated from a hard rock quarry. This is undertaken for rock material exceeding the maximum size, which can be processed. This is typically conducted through the techniques of drilling and blasting, using smaller quantities of explosives.</p>				✓
<p>4. Stockpile or Storage</p>	✓		✓	
<p>5. Loading and Transportation</p> <p>Hauling - Hauling is the loading and removal of raw aggregate material using dump trucks, which transport the rock material from the excavation site to the processing plant.</p> <p>Conveying - Conveying is the transportation of the raw aggregate, through a set of conveyor belts to an on-site processing plant. This transportation procedure is only undertaken if the processing plant is on-site, and is typically only used in natural sand deposits, however it can be used on-site for the production of site derived material, using temporary conveyors.</p>	✓	✓		✓
	✓		✓	

Information adapted from Smith & Collis, 2001, Oxford Dictionaries, 2012, and Archibald, 1991

Table 4.2 – Processing procedures

Processing Operation	Concrete Property Affected	Soft and Friable Rock	Hard and Compact Rock
<p>1. Comminution</p> <ul style="list-style-type: none"> - Comminution is the breakdown of rock material into smaller fragments. This is to produce rock material that is of a more suitable size for fine aggregate use. This is achieved by progressively crushing the rock in a series of phases. Primary crushing is the crushing of large boulders and rock material to create smaller, more manageable material for processing. The equipment used typically comprises of jaw or gyratory crushers. Secondary and tertiary crushing is conducted to crush the rock material into increasingly smaller sizes, appropriate for use in concrete. This is conducted through the use of cone and vertical impact crushers. These machines also produce an aggregate with a better particle shape and surface texture. 	<p>Particle Size and Distribution, Particle Shape and Surface Texture</p>		✓
<p>2. Washing and Scrubbing</p> <ul style="list-style-type: none"> - Washing and scrubbing of fine aggregates is conducted to remove the unwanted materials, such as excessive silts and clays and soluble salts that may be present. These processes are consist primarily of: <ul style="list-style-type: none"> (1) Washing of the aggregate occurs by jetting the particles during the screening phase, or passing the material through a washer barrel, and (2) Scrubbing the aggregate to achieve a more vigorous wash, which is implemented to remove resistant clay lumps. 	<p>Particle Size and Distribution, Mineralogical Composition</p>	✓	✓
<p>3. Screening and Sorting</p> <ul style="list-style-type: none"> - Screening and sorting is conducted to achieve a particle grading that is more consistent. (The grading of fine aggregate for concrete use is stipulated in the SANS code) This can be achieved through using two different mechanical processes consisting of: <ul style="list-style-type: none"> (1) Screening, which uses a series of vibrating sieves, or (2) Classification, which is a water-settling process. 	<p>Particle Size and Distribution, Mineralogical Composition</p>	✓	✓

Table 4.2 (Continued)

	Processing Operation	Concrete Property Affected	Soft and Friable Rock	Compact and Hard Rock
4. Beneficiation	<ul style="list-style-type: none"> - Beneficiation is the selective removal of undesirable constituents from an aggregate resource. These undesirable constituents comprise of unsound, lightweight or deleterious materials. This process is conducted to improve the overall mineralogical composition and thus quality of the aggregates. This is achieved through primarily two processes: (1) gravity settling, and (2) centrifugal separation. 	Mineralogical Composition	✓	✓
5. Dewatering	<ul style="list-style-type: none"> - Dewatering is the last process that is implemented to remove the water from the aggregate. This is conducted through the use of drainage techniques using screens and then the aggregate is typically stockpiled where it is left to dry out. 	Water Content	✓	✓

Information adapted from Smith & Collis, 2001, Oxford Dictionaries, 2012, Archibald, 1991, and Alexander & Mindess, 2005

4.3 Exploitation of Fine Aggregate Resources

Before exploitation of a resource can be undertaken, a series of studies needs to be conducted. This work is to ensure the resource can be exploited economically. The mechanical operations and infrastructure to be used in the exploitation need to be determined and the environmental impact upon the surrounding area has to be assessed. The major determinant in the exploitation of available resource, relates to its locality. This is because this effects both the economics but also and its environmental impact. (Archibald, 1991)

The planning phase of exploiting a new resource is conducted in three phases: (1) Definition stage, (2) Feasibility stage, and (3) Design stage. Each phase should be conducted taking into consideration the entire life cycle of the project from the construction of the infrastructure, its subsequent operation and maintenance, and finally the decommissioning of the quarry and processing plant. This should also include consideration of the environmental implications of the facility through the project's life cycle, especially the impact of the quarry, processing plant and production cycle upon the surrounding region. Brief discussions of each of these phases are discussed in the sub-sections that follow. (Refer to Figure 4.2 for a flow diagram of these phases)

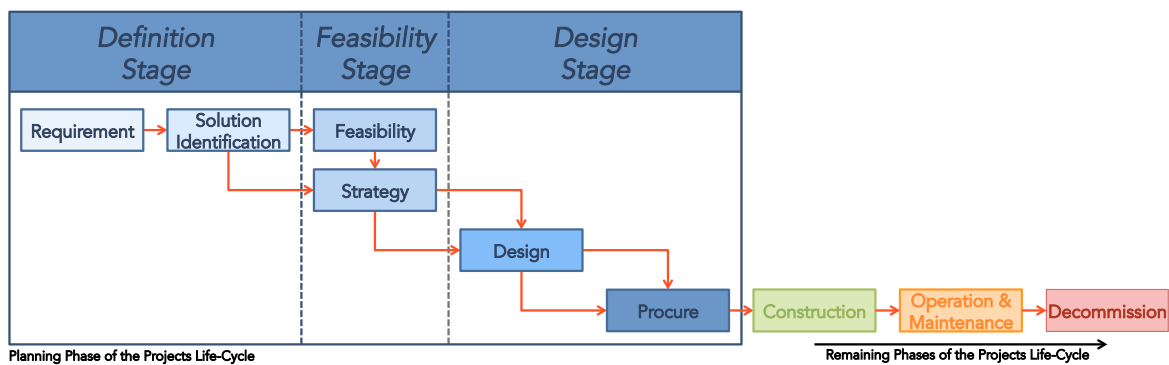


Figure 4.2 – Flowchart representing the phases of a project's life-cycle, focusing on the design stage

4.3.1 Phase 1: Definition Stage

The definition process is the initial phase and is initiated when a shortage of fine aggregate is identified and the size of the market shortfall is defined. This process is continually on going within a company, through the continual monitoring of their quarries and their estimated reserve life and annual production outlook. This is assessed in conjunction with the projected demand of the construction industry.

Commonly, there is a department in a company responsible for the development of future resources. This forms part of the solution identification, whereby a series of geological surveys are conducted as to ascertain potential future resources. This is an on-going process as acquisition of land for mining purposes is time consuming, thus there is great uncertainty on the timing of quarry start up.

The geological surveys and assessment of resources in determining new site locations will involve the following assessments: (1) size of the resource, (2) quality of the material in the resource, and (3) accessibility of the resource in terms of extraction. This assessment is conducted on a range of resources in different locations, to determine the most attractive sites.

4.3.2 Phase 2: Feasibility Stage

The feasibility analysis forms the next stage of resource development. Once a series of potential resources have been identified, an evaluation based on the reserve estimate is required. This evaluation will form the basis to determine the feasibility of extracting and processing the aggregate material, as well as to estimate the cost of building and running the facility. (Smith & Collis, 2001)

A feasibility estimate is calculated in terms of the return on the investment made to produce the resource, measured as the cost per ton of aggregate produced. The major costs involved in the production of a resource includes: the initial capital investment to secure the site and the building of the infrastructure to extract and process the aggregate (CAPEX), the operating and maintenance costs (OPEX), and the transportation costs for transporting the material during the production cycle. The OPEX and transportation costs are referred to as the production costs. (Archibald, 1991)

Transportation is an important cost to consider in the production cycle. An aggregate is a high bulk, low unit cost commodity, thus a large proportion of the costs incurred are for the transportation of the resource. The transportation costs are all those costs incurred from transporting the aggregate from the extraction location to the processing plant and then from the processing plant to its end use. As a result the location of the resource with respect to its proximity to the market is a critical factor. (Cole & Viljoen, 2001)

After this feasibility assessment is complete, a decision is made as to whether the project should proceed further. Following the decision to proceed, legal work is undertaken to secure access to the resource and obtain the appropriate mining licences. (Pullan, 2012)

4.3.3 Phase 3: Design Stage

The next phase is the design phase, in which all aspects of the project are evaluated in detail. This includes detailed planning of the quarry and processing facilities. In order to achieve this, the following factors are taken into consideration (Smith & Collis, 2001):

- Definition of the excavation area – refers to the demarcated area of the deposit that can be technically and economically worked in relation to property boundaries and surrounding topography. (For example, factoring in the major constraints that have greatest impact)
- Definition of the overburden material – determining the quantity of overburden material, waste and non-saleable material which define the basic economics of the excavation, and hence determine any cut-off limits
- The geological structure and tectonic features – Faults, joint sets and interbedded material can determine the orientation and dimensions of the quarry faces, angles of stable slopes, which define the safety limits to the excavation and the preferred direction of working.
- The regional hydrology – Helps to determine the requirement of dewatering systems and thus the equipment required.
- The lithology of the rock types – Influence the selection equipment required and the costs of production.
- The location of the processing plant and infrastructure – In many cases the processing plant is located alongside the quarry and thus the location of the processing plant and the infrastructure required in transporting the material between the two needs to be determined.

4.3.4 Environmental Issues

The need for protection of the environment and the creation of a safe and healthy workplace for the employees, has a profound effect upon the establishment and subsequent operation of quarries and processing plants. Measures must be taken to ensure that the workplace is safe and healthy for the employees, as well as minimizing the impact of the operations upon the surrounding countryside. This is a critical consideration that must be appropriately considered during the definition and planning phases of a new Greenfield site. (Smith & Collis, 2001)

The key factors that need to be considered are Visual Impact as well as the local ecology before site construction, with noise, dust and ecology impact during operation. Consideration of truck movements both during the construction and normal operations will need to be evaluated in detail. Plans for full site restoration at the end of the project's life need to be developed before project commencement.

A series of environmental impact studies are undertaken at the feasibility stage and are submitted to Local Authorities for their approval in the form of an Environmental Impact Assessment (EIA). The EIA will cover all aspects of the project's life, including site restoration, and will detail strategies to address issues raised by the studies. (Refer to Table 4.3 for the environmental impacts that require consideration during the production cycle)

4.4 Summary of the Production of Fine Aggregates

The purpose of this chapter is to provide an understanding as to the factors considered in the exploitation of a fine aggregate resource. This was undertaken by developing a greater understanding of the production cycle of fine aggregates. This set of operations is fundamental to the considerations upon which the potential of an aggregate resource is based.

The production of fine aggregate is the process implemented to transform rock material into a form, such that it possesses properties suitable for use in concrete. The production cycle is comprised of two primary processes, consisting of extraction and processing. Extraction is the removal of the rock material from its original deposit and its transportation to the processing plant. At the processing plant the rock material undergoes a series of mechanical operations, which shape the material into a form suitable for its end use.

Each resource undergoes a similar set of operations, which have been refined according to the specific deposit, and the required output properties. This is achieved through controlling the following important properties of aggregates: grain size and distribution, mineralogical composition and texture of the aggregate material. The grain size and distribution, and mineralogical composition of aggregates are fundamental in achieving the strength and durability in concrete. The processes used to obtain these properties are well understood and form an integral part of aggregate production. By comparison, the texture of aggregates is seen as a desirable attribute, and is an inherent property that is specific to the resource from where the aggregate is obtained. As a result a cost benefit analysis needs to be conducted in determining the benefit of processing of aggregate to improve its texture.

In conclusion, the procedures to exploit and process need to make a resource economically viable whilst ensuring the least impact upon the environment. As a result the properties of the material, the financial costs associated with aggregate production and the resource's locality, are fundamental in the determination of the viability of a potential resource.

Table 4.3 – Environmental impacts to be considered in the production cycle

Minimization Strategies	
Environmental Impact	Minimization Strategies
<p>Noise</p> <ul style="list-style-type: none"> - The impact of noise is a nuisance upon the surrounding region, causing annoyance for people. In some cases the sound of the extraction and processing operations can reach levels causing damage to a persons hearing. 	<ul style="list-style-type: none"> • Location of the quarry and processing plant should be sufficiently far from a settlement as to not compromise the sound quality within local settlements, thus ensuring that there is no noise nuisance, • Protective equipment (ear protectors) is to be worn by all personnel working around operational machinery, • In the design and construction phase, implement measures to contain the noise within the quarry and processing facility. This can be achieved through use of quieter, more modern machinery, and encapsulating loud machinery with flexible curtains or sound absorbent walls. • Frequently conduct noise surveys to ensure that the noise exposure does not exceed 130db in any part of the facility, and 85db in the working areas of the facilities.
<p>Dust</p> <ul style="list-style-type: none"> - The impact of dust can compromise the air quality, which is detrimental to the health of the personnel working in the facilities and fauna and flora of the surrounding areas. 	<ul style="list-style-type: none"> • Implement dust suppressing measures such as water sprays. This is to be implemented in the quarries along the roadways, on the drilling rigs, and in the stockpiled materials. • Suspend operations of the quarry and processing plant in exceedingly dry or windy conditions. • In sections of the facilities where excessive dust content is released into the air, protective equipment should be worn to ensure that it is not inhaled by employees.
<p>Visual Impact</p> <ul style="list-style-type: none"> - This impact refers to the unattractive properties of the quarry and processing facilities, which can cause discomfort for a neighbouring settlement, impacting upon their view. 	<ul style="list-style-type: none"> • Location of the facility factors in the visual impact upon the surrounding regions, which includes obtaining the required permissions from the surrounding landowners. (In many cases this can be unavoidable) • Implement screens, promote vegetation growth, and orientate the working face to help mask the view of the facility from onlookers (this also helps noise suppression).
<p>Restoration</p> <ul style="list-style-type: none"> - The restoration refers to the process of returning the land back into its original state after the plant has been decommissioned. This is important to ensuring that there are no long-term detrimental impacts to the land, compromising it for future generations. (It is important that this is taken into consideration during the design and planning of the quarry and processing plant) 	<p>The restoration of the facility is incredibly important and measures taken to ensure that the impacts upon the environment are minimised are dependant upon the type of deposit, topography and geohydrology. However, there are a few considerations that are common throughout:</p> <ul style="list-style-type: none"> • Upon initial construction the overburden material should be stored for the restoration phase since it contains the pollen and spores of the native vegetation. • The quarry and processing plant area should be filled and re-vegetated after decommissioning, with the land used for facilities such as: agricultural, landfill, water sport leisure activities, nature conservation parks or urban development. • For deep hard rock and limestone quarries, the facility could be used for water storage such as reservoirs and dams.

Information adapted from Smith & Collis, 2001, and Archibald, 1991

Section II

Fine Aggregate Resources of the Greater Cape Town Area

The subject of this dissertation concerns the fine aggregate resources within the broader Cape Town area. In the previous section, a generalised overview of the fundamentals of fine aggregates and their production cycle was discussed. This included a discussion of their origins, the required properties for their use in the construction industry focussing upon their use in concrete, and the processing techniques used to achieve them.

In this section, this knowledge is used to identify the current and future fine aggregate resources in the Greater Cape Town area, and their ability to meet the demand placed upon them in the future is discussed. The analysis of the resources is discussed whilst considering the environmental impact that they place upon the earth. This study is developed through the following chapters:

- Chapter 5: Geological Composition of the Greater Cape Town Area
- Chapter 6: Current and Potential Fine Aggregate Resources

For the purpose of this section the Greater Cape Town area refers to the Cape Town district and the areas that border it. The focus is upon the ability to meet the demand within the Cape Town Municipality, however it will discuss resources that are located in the regions surrounding the area.

Chapter 5

Geological Composition of the Greater Cape Town Area

The geological composition refers to the composition of the physical structure and substance of the earth. (Oxford Dictionaries, 2012) This is important as it provides an understanding as to the geology of the region and creates a context in which the current and potential fine aggregate resources can be assessed. As mentioned in Chapter 2, there are two components that form the geological composition: hard rock and soft rock. These two constituents are discussed, with respect to the Greater Cape Town area, in the sections that follow.

5.1 'Hard Rock' Geology of the Greater Cape Town Area

The Greater Cape Town area has a complex geological history. A large proportion of its landscape is comprised of the vast mountain range, which extends approximately 700km in distance, known as the Cape Fold Belt. This mountain range is primarily composed of hard sandstone rocks, which overlie a series of granite hills running from Cape Agulhas to Cape Columbine. The lower regions that form the valleys between the mountains are comprised of softer shales. (This is represented in Figure 5.1) (Compton, 2004)

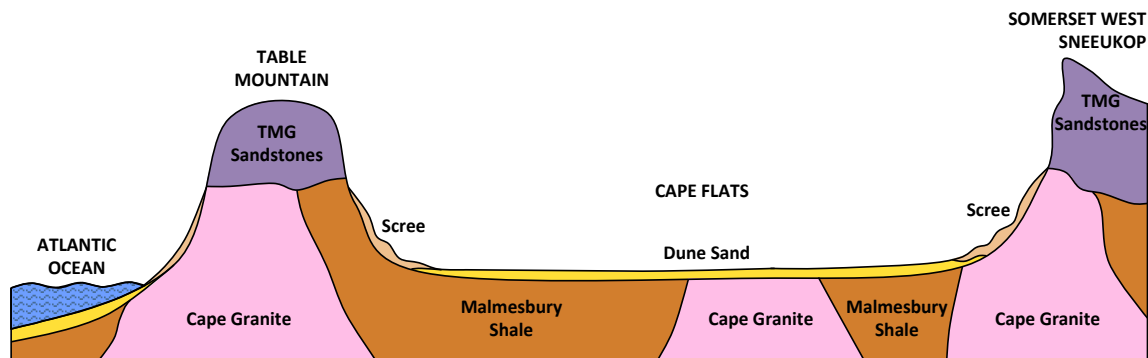


Figure 5.1 – Geological cross-section of Cape Town (Compton, 2004)

There are typically three prominent geomorphological features present in the Greater Cape Town region reflecting the underlying geology. These are comprised of the underlying granite forming the rounded hills, sandstone forming the tightly jointed cliffs, and the shale deposits constituting the flatter regions. Consequently these geomorphological features form the basis of the three major rock formations present, namely the Malmesbury Group, Cape Granite Suite and Table Mountain Group. These rock formations are discussed in the sub-section that follows. This information includes: their formation, their location and the characteristic rocks associated with them. (A map showing their distribution is shown in Figure 5.2, and the characteristic rocks present in each of the rock formations are discussed in Table 5.1) (Compton, 2004)

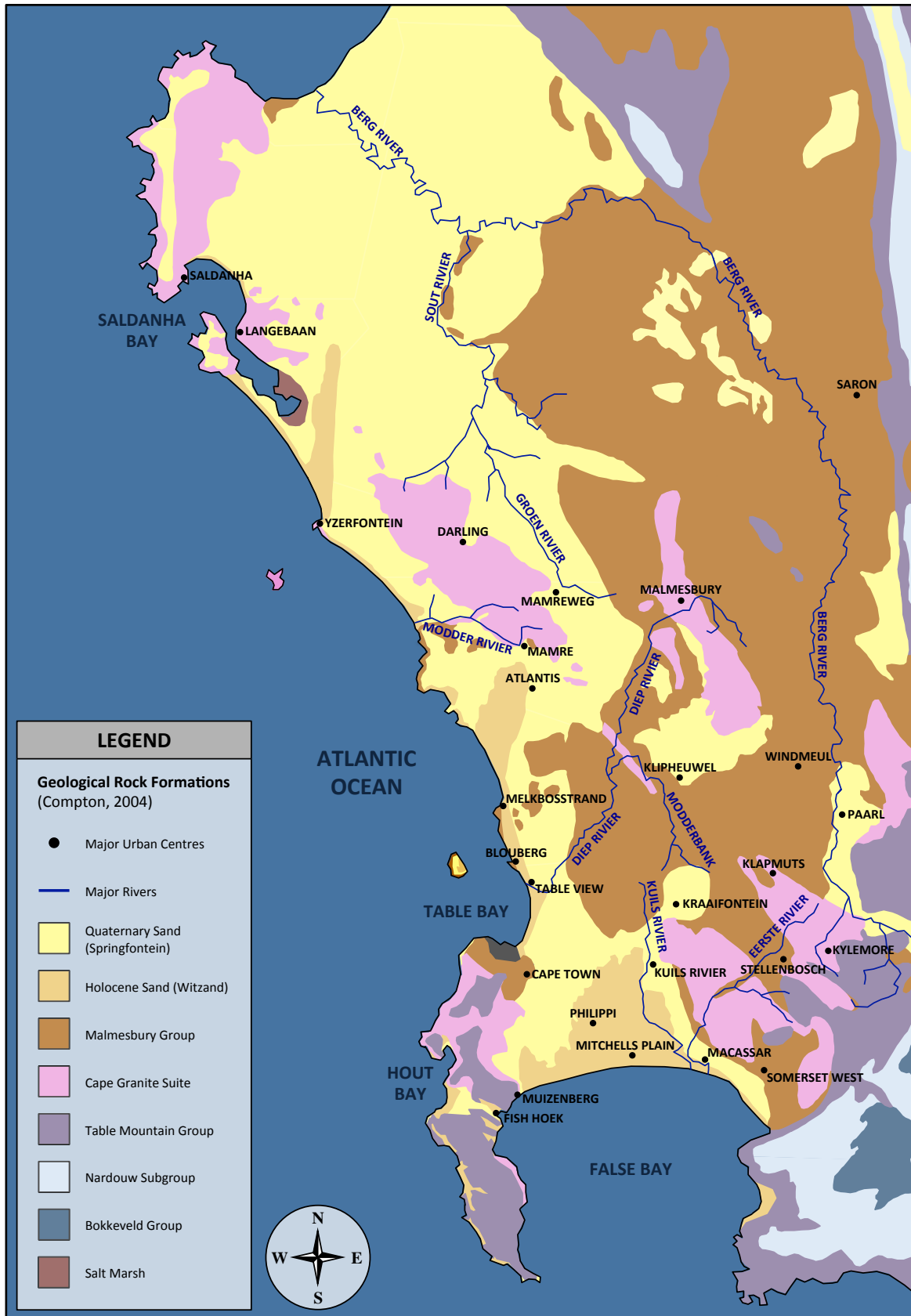


Figure 5.2 – Geological map of the Greater Cape Town area (Adapted from Compton, 2004)

5.1.1 Malmesbury Group

The Malmesbury Group is the oldest formation of rocks in the Greater Cape Town area, dating to about 630 million years old. It received its name from the location where it was first described, however it can be found throughout the region, in the vicinity of Table Mountain and east of Malmesbury running along the span of the Berg River. (Refer to Figure 5.2) It comprises of a diverse set of indurated rocks that originated from muddy sand and marine mud deposits, which today consists of predominantly shale, greywacke, siltstone and hornfels. They are dark coloured, fine grained, heavily fractured rocks that are found in deposits that are covered by soils and wind-blown sands in most areas. The dark colour of the rocks indicates an abundance of organic matter. (Compton, 2004), (Department of Geological Sciences UCT, 2012)

5.1.2 Cape Granite Suite

The Cape Granite Suite consists of a series of large granite intrusions into the Malmesbury Group Formation over 560 million years ago. The contact zone between the Cape Granite Suite and the Malmesbury Group has resulted in rocks from the Malmesbury Group undergoing metamorphic processes resulting in the formation of hard rocks known as hornfels. (Compton, 2004), (Department of Geological Sciences UCT, 2012).

Initially the granites were intruded at great depths, resulting in the formation of the Cape Granite basement. This formed the foundation on which the younger sedimentary rocks of the Table Mountain Group were deposited. Subsequently the Cape Town landscape was subjected to prolonged erosion, resulting in the granite surface becoming increasingly exposed. This caused regions characterised by large round granite boulders, which outcrop along the coastline. (Compton, 2004).

5.1.3 Table Mountain Group

The Table Mountain Group is the rock formation situated on Table Mountain, overlying the eroded surface of the granite basement. It dates back to approximately 450 million years ago. It is sub-divided into three further formations known as the Graafwater Formation, Peninsula Formation and Pakhuis Formation, which consist of predominantly sandstone and mudstones. These rocks have been produced as a result of the lithification through pressure, of sand, silt and mud deposits, which were then folded to form the Cape Fold Belt. (Compton, 2004), (Department of Geological Sciences UCT, 2012)

5.1.3.1 Graafwater Formation

The Graafwater Formation is the oldest unit in the Table Mountain Group, which are approximately 510 million years old. It forms the basal part of the Table Mountain Group and overlies the Cape Granite. This formation consists of interlayered rocks ranging from current-bedded, pale brown sandstones, to increasing proportions of fine-grained, dark maroon coloured shales that overlie them. This is a consequence of deposition cycles occurring in flood plains and lagoons (Compton, 2004), (Department of Geological Sciences UCT, 2012)

Table 5.1 – Hard rocks commonly used in the Greater Cape Town area for crushed aggregate

Engineering Rock Name	Rock Type	Major Constituents	Description of the Rock
Cape Granite Suite			
Granite	Igneous Rock	Quartz, Feldspar	Granite is a coarse-grained igneous rock formed by the crystallization of silica rich, molten magma, within the earth's crust. It consists of quartz, feldspars, with variable amounts of micas, amphiboles and iron oxides. It is a homogeneous rock that is extremely hard and thus is particularly resistant to weathering. The granite found in the Greater Cape Town area typically has a white or pink colour, due to the feldspars prevalent in the rock. Due to its hardness and resistance to weathering, it is a good source of material for aggregate use.
Malmesbury Group			
Greywacke/ Malmesbury Shale/ Hornfels	Metamorphic Rock	Quartz, Feldspar, Mica, Iron Oxides	Greywacke, often referred to as Malmesbury Shale are typically fine-grained rocks consisting of a mosaic of quartz, feldspar, mica and iron oxide minerals and are interbedded with shales, with little quartz content, to form the Malmesbury Group. They were developed by the metamorphism of the initially argillaceous and sandy sedimentary rocks of the Malmesbury Group during the Cape Orogeny. The rocks were also subject to thermal metamorphism due to the intrusion granite plutons and this has resulted in the formation of hornfels. As a result of the thermal aureole around the granite there is a transition form hornfels to the greywackes and shales of the host rock of the Malmesbury Group. Due to the transitional nature of the rocks and the lack of sharp contacts much of the material affected by the thermal aureole are called greywacke or Malmesbury shale.
Table Mountain Group			
Quartzitic Sandstone/ Quartzite	Sedimentary Rock	Quartz (Silica Minerals)	Sandstone is a clastic sedimentary rock that consists of grains of sand, which are cemented together forming a rock matrix. The sandstones grains can be composed of quartz, feldspars or rock fragments. Its grain size, sorting and composition differentiate the type of sandstone. The composition of sandstones found in the Table Mountain Group vary. Sandstones rich in quartz are called arenite sandstones and are characteristic of the Peninsula Formation. The Table Mountain Group sandstone rocks are one of the main sources contributing to the quartz rich sands found in the Greater Cape Town area.

Information obtained from Alexander & Mindess, 2005, Compton, 2004, Grtieve, 2009 and Cairncross, 2004

5.1.3.2 Peninsula Formation

The Peninsula Formation consists of hard, light grey, pebbly, well-sorted, coarse sandstone rocks that overlie the Graafwater Formation of the Table Mountain Group. The rocks consist almost entirely of quartz rich sands and a minor component of iron, manganese oxides and other minerals such as zircon. Through analysis of the current bedding and pebble layers it is suggested that this formation forms part of deposits resulting from previously existing migrating sand bars in broad river channels. (Compton, 2004), (Department of Geological Sciences UCT, 2012)

5.1.3.3 Pakhuis Formation

This is the last formation forming part of the Table Mountain Group. It consists of rocks that are unusual due to their poorly sorted nature, which ranges from fine-grained mud to coarse-grained gravel and boulders. The rocks were deposited as a glacial tillite and are found at the highest points of Table Mountain. (Compton, 2004), (Department of Geological Sciences UCT, 2012)

5.2 'Soft Rock' Geology of the Greater Cape Town Area

The soils are unlithified sands, shales and silts derived from the erosion of the underlying bedrock. Where exposed at the surface for some time, a thin soil covering, referred to as the overburden material, can be developed derived from soils modified by biological processes. (Pullan, 2012) (Cairncross, 2004) The soil deposits constitute the bulk of fine aggregate resources. This is a result of these deposits having a richer sand content, thus are more suitable for use as a resource. However, there are many other important criteria that must be met before the resource is deemed to be useable. These criteria were discussed in Chapter 2 on the 'Fundamentals of Fine Aggregates'.

Maps of soils give insight into the underlying geology, of the Greater Cape Town area. This information was attained from the Agricultural Geo-Referenced Information System (AGIS) website. This information is represented in the two maps displayed in Figure 5.3. The descriptions of the soil classifications are categorised for agricultural purposes, typically referring to the overburden material, thus making it difficult to draw conclusions. However, they do serve a purpose as a few outcomes that can be deduced, confirming trends developed in other sources.

The coastal soils have a richer sand content compared with the soil located in the interior regions. The soils inland are commonly composed of a higher silt and clay contents. This can be attributed to the weathering of the hard rock formations. In general, the weathering of the granite from the Cape Granite Suite results in the breakdown of the feldspar and biotite minerals to form kaolinite clay, and thus clay rich soils. These clays have then been washed into the low-lying regions of Cape Town. In the areas of greater topography, along the mountain slopes, the soils are quartz rich, owing to weathering of the sandstones from the Malmesbury and Table Mountain Groups. (Compton, 2004)

The coastal regions comprising of a higher sand content, have been the major source of fine aggregates used in the Cape. These regions are typically composed of large aeolian sand deposits, of Holocene (Witzand Formation) and Quaternary (Springfontein Formation) origin. These sands have contributed towards the greyish, imperfectly drained, sandy soils represented in Figure 5.3. (Cole & Viljoen, 2001)

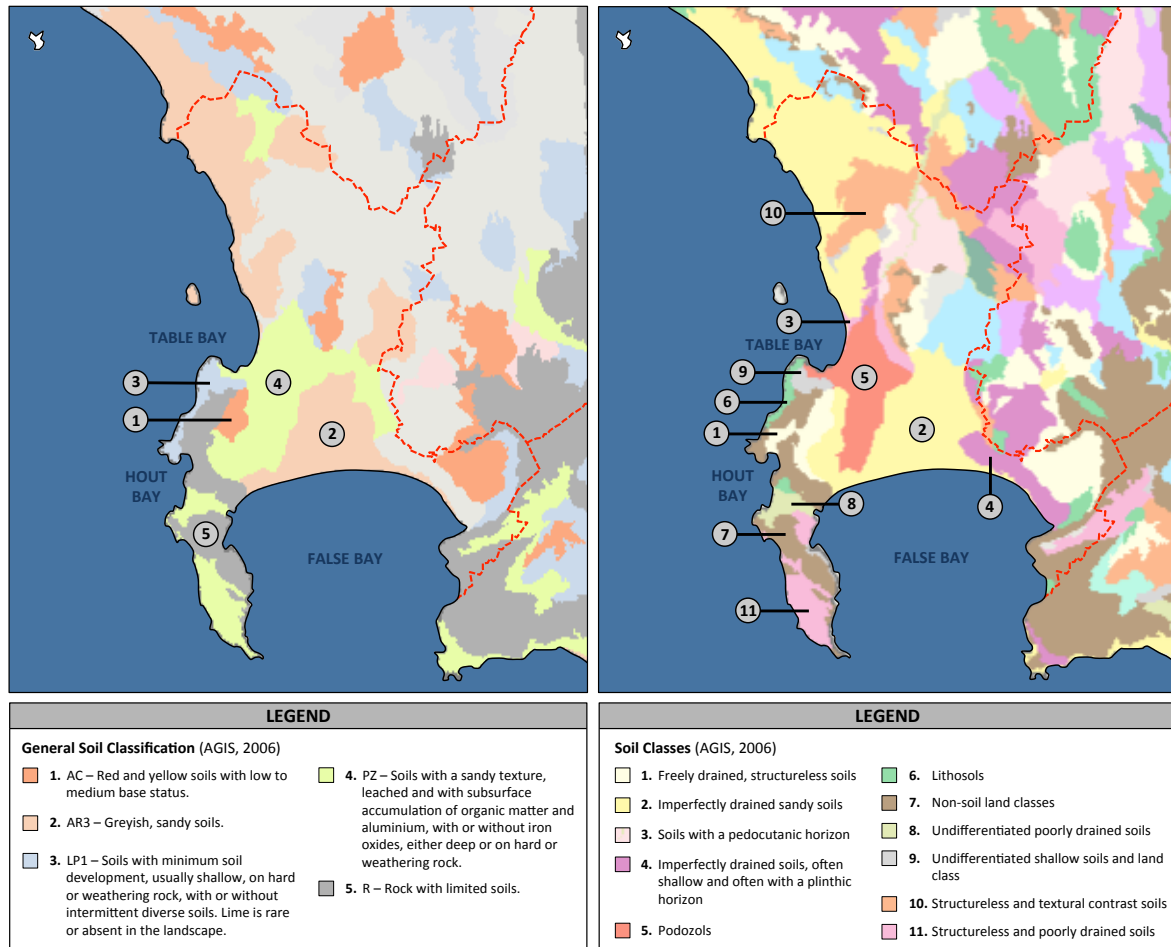


Figure 5.3 – Agricultural classification of soils in the Greater Cape Town area

Since there is a trend of these aeolian sand deposits being exploited for fine aggregate use, the remaining unutilised resources could potentially be used as a site derived source. This can be deduced from the soil maps represented in Figure 5.3, which represents a proxy for the underlying geology, as previously discussed. Further testing would be required to ensure that these soils are of high enough quality for use. (For further discussion of site-derived resources, refer to section 1.1)

5.2.1 Distribution of Sand Types

As mentioned, there are a wide variety of sand deposits that exist in the Greater Cape Town area. These deposits are responsible for the majority of fine aggregate resources used in the construction industry, over past century. They can be divided into five categories according to their genesis. These comprise of:

- Colluvial/Hillwash Sands,
- Alluvial Sands,
- Fluvial Sands,
- Aeolian Sands, and
- Marine Sands.

5.2.1.1 Hillwash and Colluvial Sands

Hillwash and colluvial sands, also known as colluvium, are sediments typically accumulating at the foot of a slope. This deposited material is formed as a result of geological processes, which erode and weather the local rock geology. This material is normally deposited relatively close to its origin. In engineering terminology these sands are more commonly referred to as residual sands. For more information on their origin and formation refer to Chapter 2. (Alexander & Mindess, 2005)

The colluvial and hillwash sands in the Greater Cape Town area are most commonly derived from weathered granites of the Cape Granite Suite (CGS), and to a lesser extent sandstones of the Table Mountain Group (TMG). The TMG sandstones typically occur in mountainous locations that have steeper slopes. Consequently, the scree material, which consists of coarse gravel that covers these slopes, is primarily attributed to streams that have reworked rocks. Consequently, the material produced is more commonly fluvial sands, rather than hillwash and colluvial sands. (Cole & Viljoen, 2001)

The most extensive hillwash and colluvial sand deposits originate in the Malmesbury-Klipheuwel region. This is located south and south-west of Malmesbury and is derived from the erosion of weathered granite. There are also smaller deposits of colluvial and hillwash sands that occur in the Darling, Kuils River, Klapmuts, Franschhoek, Stellenbosch, Paarl and Somerset West areas. (Cole & Viljoen, 2001)



Figure 5.4 – Hillwash/colluvial sand deposit located on the western side of the Paardeberg Mountain, south of Malmesbury (Image courtesy of Google Earth, 2013)

The hillwash sands occur more abundantly in the Greater Cape Town area as compared to the colluvial and typically consist of very fine grained to coarse grained, gritty sands that have a pebbly composition in part. The deposits have a tabular shape, which is a consequence of their derivation by sheetwash processes. The areal extent of the deposits is small, typically about 1km². (Cole & Viljoen, 2001)

By comparison the colluvial sands are restricted to sites close to their bedrock source, particularly the granitic material of the Cape Granite Suite, which has been subjected to erosion and weathering. These sands have a silty to pebbly composition, with variable clay content. This clay content is a consequence of the viscous flow depositional processes such as soil creep, mud flows and debris flows. The deposits are normally at higher elevations and on steeper slopes than the hillwash sands. The size of the deposits are also smaller by comparison, with a typical areal extent of about 0,5km². (Cole & Viljoen, 2001)

5.2.1.2 Alluvial Sands

Alluvial sand refers to rock material that is a product of in situ weathering of bedrock associated with floodwater deposits. (Oxford Dictionaries, 2012) There is a limited amount of this resource present within the Greater Cape Town area. There are isolated deposits that occur on the flat surfaces overlaying the Table Mountain Group and Cape Granite Suite. However, these deposits are generally chemically unstable and are often further reworked through colluvial and fluvial processes. (Cole & Viljoen, 2001)

The alluvial deposits occur in small deposits with an areal extent of approximately less than 0,1km². These deposits exist on the plateau surfaces of Cape Fold Belt Mountains on the eastern side of the Greater Cape Town area, between Grabouw and Saron, but are difficult to distinguish with absolute certainty from the hillwash and colluvial deposits. The sands are typically are fine to coarse sand in grain size with a reasonable clay content. (Cole & Viljoen, 2001)

5.2.1.3 Fluvial Sands

Fluvial sands are sediments that are a product of weathered rock material transported and deposited as a result of water action. There are typically two types of fluvial deposits in the Greater Cape Town region; fluvial terrace gravels and fluvial channel sand deposits.



Figure 5.5 – Quarry located on the western bank of the Berg River, near Saron (Image courtesy of Google Earth, 2013)

The fluvial sands in the Greater Cape Town region are most commonly found along the more prominent rivers in the region, namely the flood plains of the Berg River and its tributaries. Other rivers with these deposits include: the middle reaches of the Eerste River, and proximal portions of the Mosselbank, Diep, Modder, Sout and Groen Rivers. These deposits typically form deposits parallel to the flow direction in a geomorphological form called a bar. (Cole & Viljoen, 2001)

The sands are derived from the sandstones of the Table Mountain Group and to a lesser extent the Cape Granite Suite. In many cases these sands are a product of the re-working and erosion of hillwash, colluvial, and alluvial sediments. The resulting sand deposits are typically less than 2m thick consisting of fine to very coarse-grained material with varying silt and clay contents. Particularly in the more proximal reaches of the rivers the sands become more gritty and pebbly in composition. (Cole & Viljoen, 2001)

The other type of fluvial deposits are the fluvial terraces which exist along the Eerste river, between Stellenbosch and Faure, and the Berg River and a few of its eastern tributaries, between Kylemore and Saron. Fluvial Terraces are flat or gently inclined geomorphic surfaces often called a tread and represent a palaeo floodplain of a river. These deposits occur 2 to 30m above the height of the current level of the rivers. (Cole & Viljoen, 2001)

The clasts found in these deposits consist of sediments almost entirely of quartzitic sandstone derived from the Table Mountain Group, are well rounded and can be up to approximately 3m in diameter. These deposits are located above weathered bedrock and form tabular deposits with an areal extent of up to approximately 5km². (Cole & Viljoen, 2001)

The problems associated with the fluvial sands, from an aggregate perspective, are that the deposits are thin, laterally inconsistent sand deposits typically extending over several hundred metres. Thus any deposit is limited and sparsely distributed requiring greater effort for extraction. (Cole & Viljoen, 2001)

5.2.1.4 Aeolian Sands



Figure 5.6 – Macassar sand dunes, region in which a large proportion of the natural sand resources of the Greater Cape Town area originates (photo courtesy of John Silander, UConn)

Aeolian sands are sediments found in deposits that are formed as a result of erosion, transportation and deposition by the wind. They are some of the more common types of sands deposits present within the Greater Cape Town area. These sands can be categorised into two formation groups: the Springfontein and Witzand Formations. (Cole & Viljoen, 2001)

The Witzand Formation is a coastal aeolian sand, which commonly forms part of the partially vegetated parabolic dunes that occur in coastal areas of the Greater Cape Town region. These coastal locations consist of: south-east of the Cape Peninsula in the Macassar area, south of Bloubergstrand in the Table Bay area and south-west of Atlantis. (Cole & Viljoen, 2001)

The Witzand aeolian dunes consist of well-sorted, fine to medium grained, cross-stratified, quartzose sand, containing a fraction of comminuted marine shell fragments. These dunes are typically orientated parallel to the prevailing summer winds that occur. They were formed as a result of the deflation of the sandy beaches, and their re-transportation by wind action. (Cole & Viljoen, 2001) (Refer to Figure 5.7 for a map representing the deflation of sands in the Greater Cape Town area) This typically occurred through the south-easterly wind, commonly referred to as the Cape Doctor, which has caused their migration from the Cape Flats through to the Table Bay and Melkbostrand areas. (Compton, 2004)

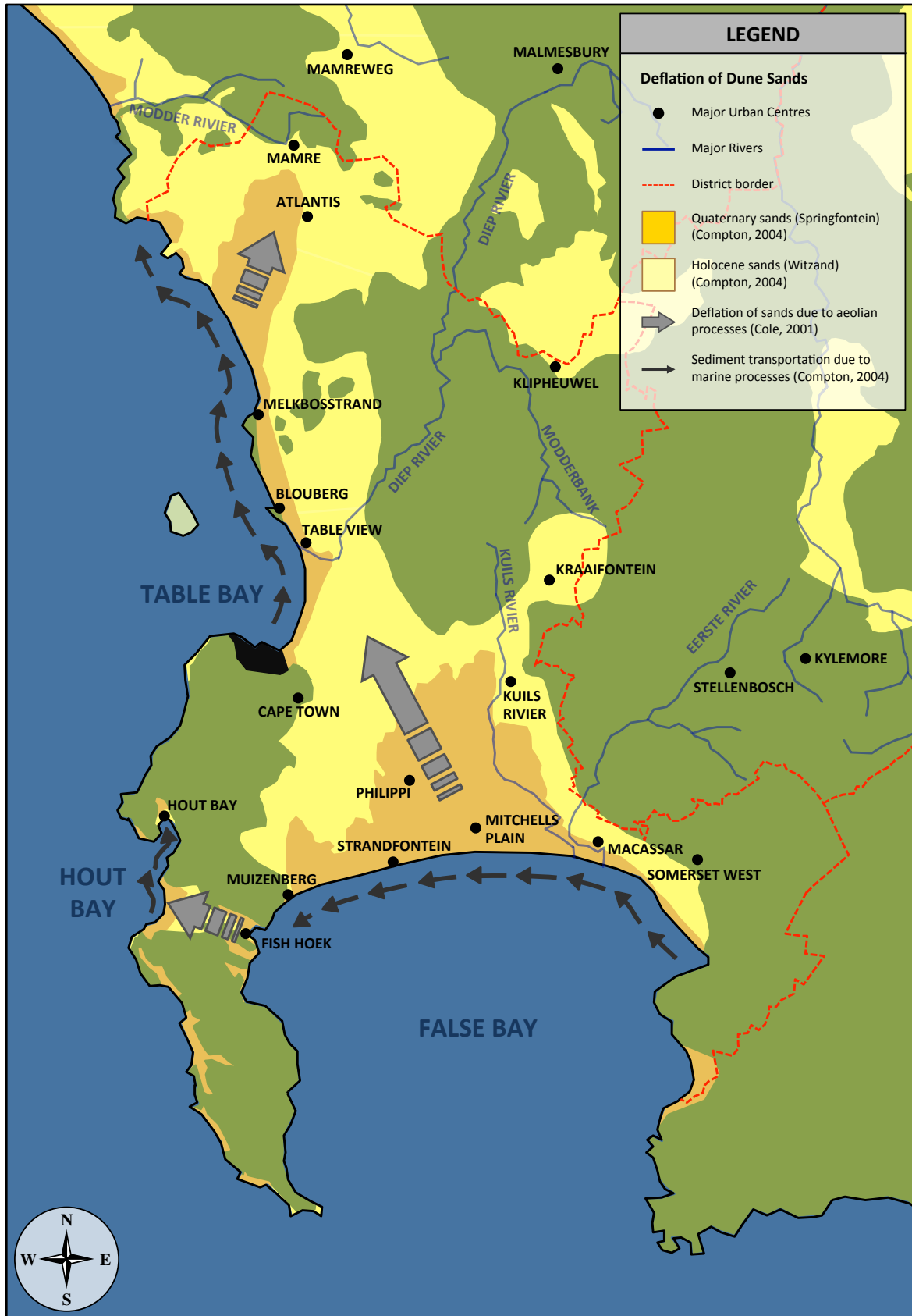


Figure 5.7 – Map representing the deflation of sands in the Greater Cape Town area

The second aeolian sand formation is that of the Springfontein Formation. These sands are characteristically composed of well-sorted, fine to medium grained, unconsolidated, structureless quartzose sands. Although the deposits do not have typical dune forms or geometries, they have the typical aeolian characteristics of the high degree of quartz rounding and mineralogical maturity. Although formed by similar processes to that of the Witzand sands, there is an absence of shell fragments due to the decalcification of these sands as a result of the passage of acidic groundwater. (Cole & Viljoen, 2001)

The Springfontein sands are mainly located in deposits close to the coast such as in the Cape Flats and slightly further up north along the West Coast in the Blouberg, Melkbosstrand, and Atlantis areas. There are also deposits located near Stellenbosch, Paarl, Malmesbury and Darling. These deposits have been formed as a result of the deflation and reworking of the hillwash, colluvial and fluvial sands, of eroded Cape Granite or Table Mountain Sandstone origin. (Cole & Viljoen, 2001)

The Springfontein sands located in the Philippi area are more commonly known for their high silica content, therefore these sands are in high demand for glass manufacture.

5.2.1.5 Marine Sands



Figure 5.8 - Marine sand dredger ship, dredging sand (photo courtesy of the Asian Tribune)

The marine sands refer to the sedimentary material that forms in a coastal environment, and in terms of this section, on the seafloor. There is very little information regarding these deposits in terms of their engineering properties. The sands are currently unexploited, however, according to Dr. Cole from the Council for Geoscience, these sands are known to be present in False Bay. (Cole & Viljoen, 2001)

These sands are thought to be derived from river systems that fed the area in the past. Geological studies suggest that this occurrence in the False Bay area is not unique but other systems will exist to the north of Cape Town as a result of palaeo-rivers feeding into the offshore. There is also sand believed to be offshore in the Table Bay area, which forms a tombola, which extends from the shore through to Robben Island. (Cole, 2012)

The characteristics of these sand deposits are similar to the sand deposits that exist in the coastal areas onshore being well-rounded, fine to medium-grained, quartzose sands. However it will have a substantial fraction of comminuted shell fragments and salts (chloride content). (Alexander & Mindess, 2005)

5.3 Summary of the Sources of Fine Aggregate in the Greater Cape Town Area

Natural fine aggregate resources are commonly derived from two types of geological deposits consisting of 'soft and hard rock'. In the Greater Cape Town area, there are a wide variety of 'soft and hard rock' deposits present, as summarised below.

'Hard Rock' Deposits

'Hard rock' deposits, composed of hard consolidated material, are constituted by three main rock formations in the Greater Cape Town region, namely: the Cape Granite Suite, Malmesbury Group and Table Mountain Group. Of these deposits the following 'hard rock' deposits offer the greatest potential for fine aggregate use in this region: (1) the granite rocks of the Cape Granite Suite, located in the Mamre and Malmesbury region, and (2) the greywacke (Malmesbury Shale) rocks of the Malmesbury group, primarily locate in the Tygerberg Hills. Their potential use can be attributed to their composition that is hard, relatively inert and durable thus having a low potential for degradation that could affect the quality of concrete produced.

'Soft Rock' Deposits

'Soft rock' deposits, composed of sediments that have been formed as a result of the weathering of the bedrock material, are in high abundance within the Greater Cape Town area. There are a wide variety of deposits consisting of five types of sands, namely: hillwash and colluvial, alluvial, fluvial, aeolian and marine sand deposits. The hillwash, aeolian and marine sand deposits are in greatest abundance within the region in terms of on-land resources.

There are extensive hillwash deposits located in the Malmesbury/Klipheuwel region, with additional minor deposits scattered in the region spanning from Kuils Rivier through to Somerset West and as far north as Paarl. The aeolian sand deposits cover a greater areal extent than that of the hillwash deposits, however by comparison they are thinner. This can be attributed due to their wind-blown origin. Additionally, there appears to be an abundance of marine sands located off the south and west coastlines in the region. However the true extent of these resources is unknown, due to the relatively limited data available on these deposits. All of these sand deposits possess properties that lend themselves towards use as fine aggregate.

In conclusion, the Greater Cape Town area has a high abundance of 'soft and hard rock' deposits with properties suggesting that many could potentially be exploited for fine aggregate use. Although these resources have been identified, further investigation is required to determine the remaining extent of these resources and those of which are appropriate for use as fine aggregate in concrete. This investigation has been undertaken and is discussed in Chapter 6.

Chapter 6

Current and Potential Fine Aggregate Resources

The fine aggregate resources of the Greater Cape Town area have historically been available in abundance with the market dominated by natural sands. These natural sands originated from the aeolian sands that occurred in the sand dunes located in the Cape Flats region. This is the area situated along the areas on the northern reaches of the False Bay coastline, extending from Muizenberg through to Macassar. These sands are characteristically poorly cemented, inert, and quartz rich, in composition. In addition, as a resource they are easily extracted and processed and lie within close proximity to their end use, thus making them an ideal, cost effective source.

In the late 20th Century, there was rapid population growth occurring in the Cape Town area, which resulted in a boom in the construction industry. This boom caused increased demand for construction materials, which led to the exploitation of the hillwash and colluvial sands located in the Malmesbury-Klipheuwel region. These sands are known to be of slightly superior quality in the aggregate market, due to their better particle distribution compared with that of the dune sands. However, these deposits do require a greater degree of processing in order to remove the organic and clay constituents. An additional problem is that the sands may be contaminated by organic fertilisers introduced by farming operations, thus necessitating additional processing. These resources continue to be used today, however they have become extensively depleted. Sands from the Malmesbury-Klipheuwel region have become increasingly difficult to acquire, due to the alternative land use caused by the urban densification of the Cape Town district. As a result there has been an increasing need to locate accessible alternative resources to supplement the ever-growing demand placed upon the fine aggregate industry. Part of this demand had been met by the gradual move towards the use of crushed aggregates over the past decade, which is increasingly seen to be the solution to the future supply concerns by some.

The rocks used for crushed resources primarily consist of greywacke (also known as Malmesbury shale) and hornfels (hornstone) of the Malmesbury Group, granite of the Cape Granite Suite, and sandstone of the Table Mountain Group. The problems associated with these sources are their lower quality relating to a poor particle shape and high water demand, and the higher costs incurred to process the material, as compared with the natural resources. However, there has been continual improvement in the processing techniques, subsequently improving the aggregate quality and project economics. This is making them more comparable with the cost of natural resources, whose costs are gradually increasing due to the depletion problem. Currently, in 2013, crushed aggregates are approximately twice the price of the natural sources. (Cole & Viljoen, 2001)

Although these problems are recognised in the Greater Cape Town area, they are also found globally. This reflects mankind's historical approach to development, which did not necessarily factor in its impact upon the environment and the finite nature of the world's resources.

In this analysis, the potential sources to meet future demand in the Greater Cape Town area are identified, analysed and discussed in the sections that follow. This is conducted according to the three main fine aggregate categories, which are as follows:

- Natural fine aggregates comprising of natural onshore and offshore deposits, as well as the use of site derived aggregates which involves the local use of extracted earth material from the building site,
- Crushed fine aggregates, and
- Recycled fine aggregates (RFA).

6.1 Natural Aggregate Resources

Natural fine aggregate resources are naturally occurring sands that are used in the construction industry in applications such as concrete, mortar and plaster. They typically consist of onshore deposits obtained from aeolian sand dunes, fluvial terraces and hillwash/colluvial pits. However, there are other sources of natural fine aggregates that have not been fully exploited in South Africa. This comprises offshore marine sands, and site-derived resources, which utilise waste material derived from the extraction of on-site soils. With continued research and development, these natural deposits may become economically viable as fine aggregate resources in the Greater Cape Town area, in the future.

6.1.1 Natural Onshore Sand Resources

The Greater Cape Town area has historically had an abundance of natural sands that have constituted the bulk of fine aggregate resources in the region. These resources are dominated by aeolian and hillwash sand deposits, found in the region. The fluvial sands by comparison tend to occur in deposits where the sands are sparsely distributed making them more uneconomical to extract. In research conducted by Cole and Viljoen in 2001, on the building potential of sand resources in the Greater Cape Town area, information was obtained involving all of the sand deposits present in the region. This information has been extracted and displayed in Table 6.1 and Figure 6.1, defining their properties. The information in Table 6.1 includes the following:

- The location of the resource: The area in which the sand deposit is located,
- The type of sand present: Hillwash or Colluvial, Fluvial and Aeolian,
- The competing land uses: Urban, agricultural or natural protected land
- The properties of the resource: Particle size and distribution, mineralogy and texture of the sand deposit, and lastly
- Its estimated quality for use: This is based primarily upon its grading, and does not factor in blending with other resources to achieve more desirable properties. The following criteria were used: High quality = concrete grading envelope, medium quality = building sand grading envelope, and low quality = sands not achieving gradings of the first two grading envelopes (such as foundry sands and industrial sands used for cement manufacture).

This section will discuss these sand deposits, reviewing past and current producing areas, and the potential future development options that can be used for future supply of fine aggregates.

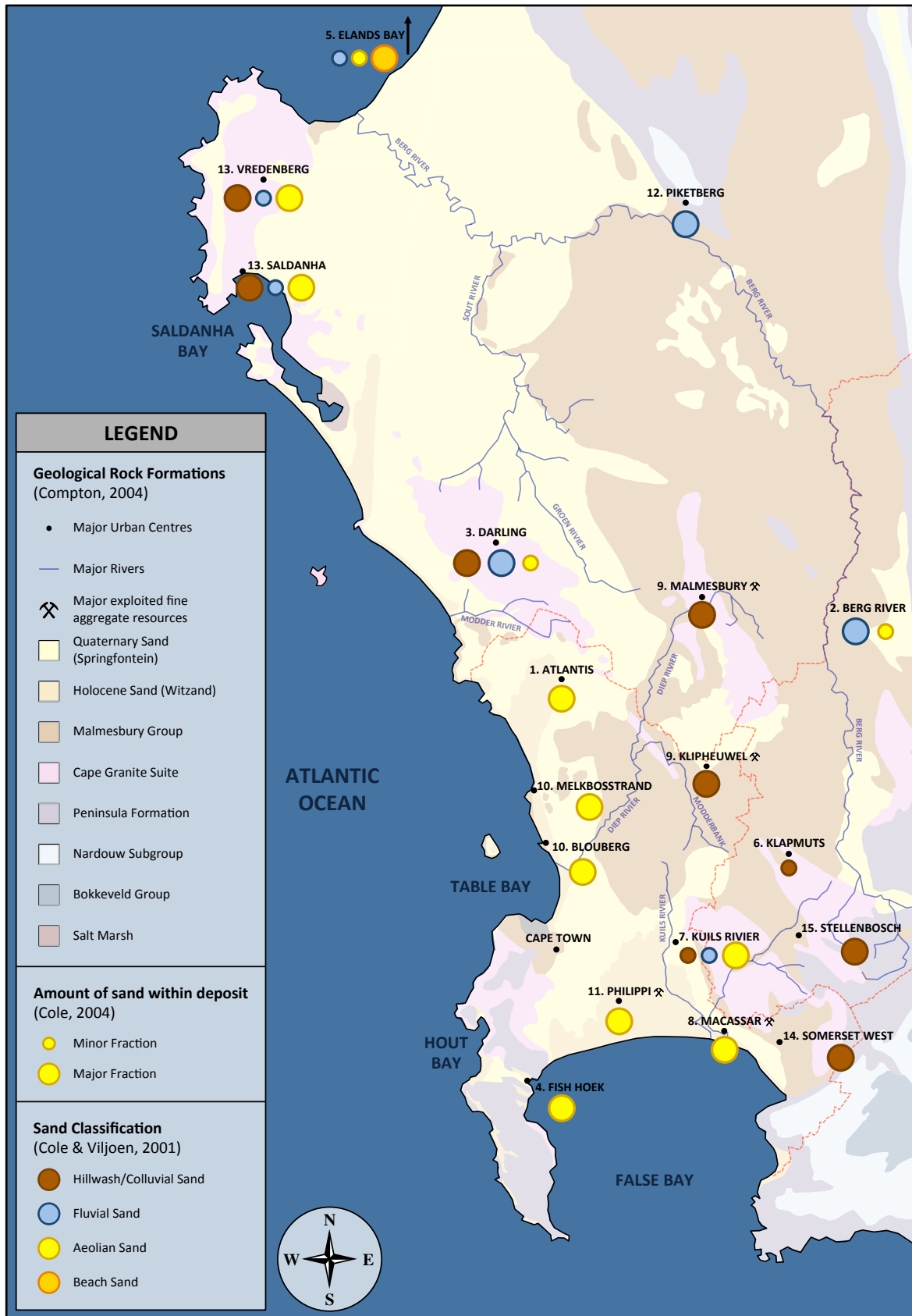


Figure 6.1 – Distribution of sand classifications in the Greater Cape Town area

Natural Fine Aggregate Resources

Table 6.1 – Description of natural fine aggregate resources (onshore deposits) (Cole & Viljoen, 2001)

Aggregate Resource (Location)	Type of Aggregate	Competing Land Use	Properties of Fine Aggregate Resource				Quality and Potential End Use
			Particle Size and Distribution	FM	Mineralogical Composition	Texture	
1. Atlantis	Aeolian: Springfontein Formation (SF)	n/a (Access restricted by underlying geological aquifer)	Very fine to coarse grained	1,24	<ul style="list-style-type: none"> Quartz rich Predominant saltation 	Rounded to sub-rounded	Medium Quality: <ul style="list-style-type: none"> Building Sands Industry Sands
	Aeolian: Witrand Formation (WF)		Very fine to coarse-grained (coarser than SF)	1,12	<ul style="list-style-type: none"> Quartz rich Comminuted shell fragments ($\pm 24,2\%$) 	Rounded to sub-rounded	Poor to Medium Quality: <ul style="list-style-type: none"> Building Sands Foundry Sands
2. Berg River	Fluvial Sands (Major)	Agricultural land	Fine to very coarse-grained	2,83	<ul style="list-style-type: none"> Predominance of quartz Gritty, pebbly composition 	Rounded to sub-angular	Medium to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands
	Aeolian: (Common) Springfontein Formation (SF)		Very fine to coarse-grained	1,23	<ul style="list-style-type: none"> Quartz rich Sparse fraction of mafic minerals 	Rounded to sub-angular	Poor to Medium Quality: <ul style="list-style-type: none"> Building Sands Industrial Sands (Cement Manufacture)
3. Darling	Alluvial, Hillwash & Colluvial Sands (Common)	Agricultural land	Very fine to medium grained	1,95	<ul style="list-style-type: none"> Minor fractions of rock fragments and mafic minerals Gritty composition 	Sub-rounded to angular	Medium to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands (Minor)
	Fluvial Sands (Common)		Very-fine to medium grained	2,25	<ul style="list-style-type: none"> Predominance of quartz Gritty, pebbly composition Sparse fraction of mafic minerals 	Rounded to angular	Medium to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands (Major)

Table 6.1 (Continued)

Aggregate Resource (Location)	Type of Aggregate	Competing Land Use	Properties of Fine Aggregate Resource				Quality and Potential End Use
			Particle Size and Distribution	FM	Mineralogical Composition	Texture	
3. Darling	Aeolian: Springfontein Formation (SF)	Agricultural land	Very fine to medium grained	1,16	<ul style="list-style-type: none"> Deflation from fluvial sands Quartz rich Predominant saltation 	Rounded to sub-rounded	Poor to Medium Quality: <ul style="list-style-type: none"> Building Sands Filler Sands (Major)
	Aeolian: Witzand Formation (WF)		Very fine grained	1,22	<ul style="list-style-type: none"> Quartz rich Steep saltation segments Comminuted shell fragments ($\pm 27,8\%$) 	Rounded to sub-rounded	Poor to Medium Quality: <ul style="list-style-type: none"> Building Sands Filler Sands (Major) Foundry Sands
4. Fish Hoek	Aeolian: (Major) Springfontein Formation (SF)	Urban land	Very fine to coarse grained	1,48	<ul style="list-style-type: none"> Quartz rich 	Rounded to sub-rounded	Medium Quality: <ul style="list-style-type: none"> Building Sands
	Aeolian: (Major) Witzand Formation (WF)		Very fine to medium grained	1,25	<ul style="list-style-type: none"> Quartz rich Comminuted shell fragments ($\pm 2,9\%$) 	Rounded to sub-rounded	Medium Quality: <ul style="list-style-type: none"> Building Sands
5. Elands Bay*	Beach (Major)	Agricultural land/ Protected natural land	Fine to coarse grained	-	<ul style="list-style-type: none"> Quartz rich Pebbly composition Abundant shells and comminuted shell fragments 	Rounded to angular	Medium Quality: <ul style="list-style-type: none"> Building Sands
	Aeolian: (Common) Springfontein Formation (SF)		Very fine to fine grained	-	<ul style="list-style-type: none"> Quartz rich 	Rounded to sub-rounded	Medium Quality: <ul style="list-style-type: none"> Building Sands
	Aeolian: (Common) Witzand Formation (WF)		Fine grained	-	<ul style="list-style-type: none"> Quartz rich Silty composition Comminuted shell fragments 	Rounded to sub-rounded	Medium Quality: <ul style="list-style-type: none"> Building Sands
	Fluvial (Common)		Fine to coarse grained	-	<ul style="list-style-type: none"> Quartz rich Gritty composition 	Rounded to sub-angular	Medium Quality: <ul style="list-style-type: none"> Building Sands

Table 6.1 (Continued)

Aggregate Resource (Location)	Type of Aggregate	Competing Land Use	Properties of Fine Aggregate Resource				Quality and Potential End Use
			Particle Size and Distribution	FM	Mineralogical Composition	Texture	
6. Klapmuts - Windmeul	Hillwash & Colluvial (Major)	Agricultural land	Veryfine to medium grained	2,56	<ul style="list-style-type: none"> Quartz rich Minor rock fragments Gritty, pebbly composition 	Sub-rounded to angular	Medium to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands (Major)
7. Kuitils Rivier	Hillwash & Colluvial (Minor)	Urban land	Veryfine to coarse grained	1,21	<ul style="list-style-type: none"> Quartz Sparse fraction of mafic minerals Slightly, gritty composition Minor mud content 	Sub-rounded to angular	Medium Quality: <ul style="list-style-type: none"> Building Sand (Major) Filler Sand Industry Sand
	Fluvial (Minor)		Veryfine to medium grained	2,25	<ul style="list-style-type: none"> Predominance of quartz Sparse fraction of mafic minerals Gritty, pebbly composition 	Rounded to angular	Medium Quality: <ul style="list-style-type: none"> Building Sand (Major)
	Aeolian: (Common) Springfontein Formation (SF)		Veryfine to medium grained (Coarse grained in sections)	1,10	<ul style="list-style-type: none"> Quartz rich Sparse fraction of mafic minerals 	Rounded to sub-rounded	Poor to Medium Quality: <ul style="list-style-type: none"> Building Sand Filler Sand (Major) Foundry Sand Industry Sand
	Aeolian: (Common) Witzand Formation (WF)		Veryfine to medium grained	0,97	<ul style="list-style-type: none"> Quartz rich Sparse fraction of mafic minerals Comminuted shell fragments ($\pm 25, 1\%$) 		Poor to Medium Quality: <ul style="list-style-type: none"> Building Sand Foundry Sand
8. Macassar (Major Fine Aggregate Resource)	Aeolian: (Exclusive) Witzand Formation (WF)	Urban land/ Conservation area	Veryfine to coarse grained (well graded)	1,13	<ul style="list-style-type: none"> Quartz rich Steep saltation segments Comminuted shell fragments ($\pm 60, 3\%$) 	Rounded to sub-rounded	Poor to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands Filler Sands

Table 6.1 (Continued)

Aggregate Resource (Location)	Type of Aggregate	Competing Land Use	Properties of Fine Aggregate Resource				Quality and Potential End Use
			Particle Size and Distribution	FM	Mineralogical Composition	Texture	
9. Malmesbury – Klipheuwel (Major Fine Aggregate Resource)	Hillwash & Colluvial (Major)	Agricultural land	Fine to coarse grained	1,89	<ul style="list-style-type: none"> Quartz rich Minor fractions of mafic minerals and rock fragments Contains a silt and clay content 	Sub-rounded to angular	Medium to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands
10. Melkbosstrand – Bloubergstrand	Aeolian: (Major) Witzand Formation (WF)	Urban land	Veryfine to medium grained	1,39	<ul style="list-style-type: none"> Quartz rich Steep saltation segments Comminuted shell fragments ($\pm 20,9\%$) 	Rounded to sub-rounded	Medium Quality: <ul style="list-style-type: none"> Building Sands
11. Philippi (Major Fine Aggregate Resource)	Aeolian: (Exclusive) Witzand Formation (WF)	Urban land	Veryfine to medium grained	1,56	<ul style="list-style-type: none"> Quartz rich Steep saltation segments Comminuted shell fragments ($\pm 21,8\%$) 	Rounded to sub-rounded	Poor to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands Filler Sands
12. Piketberg*	Fluvial (Major)	Agricultural land	Very fine to very coarse grained	-	<ul style="list-style-type: none"> Quartz rich Silty to gritty composition 	Rounded to angular	Medium to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands
13. Saldanha – Vredenburg*	Hillwash (Common) Aeolian: (Common) Springfontein Formation (SF) Aeolian: (Common) Witzand Formation (WF)	Urban land	Veryfine to coarse grained Veryfine to medium grained Veryfine to medium grained	2,23 - -	<ul style="list-style-type: none"> Quartz rich Silty to gritty composition Quartz rich Steep saltation segments Comminuted shell fragments ($\pm 30\%$) 	Sub-rounded to Angular Rounded to sub-rounded Rounded to sub-rounded	High Quality: <ul style="list-style-type: none"> Concrete Sands Medium to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands Medium to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands

Table 6.1 (Continued)

Aggregate Resource (Location)	Type of Aggregate	Current Land Use	Properties of Fine Aggregate Resource				Quality and Potential End Use
			Particle Size and Distribution	FM	Mineralogical Composition	Texture	
13. Saldanha - Vredenburg*	Fluvial (Minor)	Urban land	Very fine to very coarse grained	2,9	<ul style="list-style-type: none"> Quartz rich Slightly to gritty composition 	Sub-rounded to sub-angular	Poor Quality: <ul style="list-style-type: none"> Filler Sands
14. Somerset West	Hillwash (Common)	Urban land/ Agricultural land	Fine to coarse grained	2,82	<ul style="list-style-type: none"> Quartz rich Minor fraction of mafic minerals Scarce mica content Contains a silt and clay content 	Sub-rounded to angular	High Quality: <ul style="list-style-type: none"> Concrete Sands
15. Stellenbosch	Hillwash & Alluvial (Major)	Urban land/ Agricultural land	Fine to coarse grained	2,34	<ul style="list-style-type: none"> Quartz rich Sparse fraction of mafic minerals Slightly gritty composition 	Sub-rounded to angular	Medium to High Quality: <ul style="list-style-type: none"> Building Sands Concrete Sands
16. Worcester	Hillwash (Common)	Urban land/ Agricultural land	Fine to coarse grained	2,24	<ul style="list-style-type: none"> Quartz rich Sparse fraction of mafic minerals 	Sub-rounded to angular	Medium Quality: <ul style="list-style-type: none"> Building Sands
17. Kleinmond	Fluvial (Common)	Agricultural land	Fine to coarse grained	1,31	<ul style="list-style-type: none"> Quartz rich Gritty, pebbly composition 	Rounded to sub- angular	Poor to Medium Quality: <ul style="list-style-type: none"> Building Sands Foundry Sands

* Sand resources located outside of study region, however could potentially be used to supplement production in the future.

Information adapted from Cole & Viljoen, 2001, Cole, 2008, and Cole, 2010

6.1.1.1 Current and Previously Exploited Resources

The Greater Cape Town area has an abundance of natural sands resulting in many natural sand deposits being exploited for fine aggregate use. There are three primary sources that have constantly provided the bulk of these resources used for production, comprising of: the Cape Flats, West Coast, and Malmesbury-Klipheuwel sand resources. These resources were exploited due to the vast size of their deposits as well as their superior quality, which is acceptable for use in concrete and other applications in the construction industry.

a) Cape Flat Sands

Traditionally the bulk of the fine aggregates used in the Greater Cape Town area were derived from the Cape Flats. This is located along the southern coastline bordering False Bay. These sands are mainly exploited from sand mines located in Philippi and west of Macassar. They comprise of aeolian dune sands of the Witzand Formation, which are generally composed of a single-sized particle grading. These range from very fine to medium-grained in size, with well over 90% of these sands passing through a 1,180mm sieve and retained by a 0,150mm sieve. (Grieve, 2009)

In addition, there are two variants of Witzand Formation sands, divided into two categories: shell-bearing and shell-free sands. The shell-free sands, also commonly known as silica sands, are of superior quality to the shell-bearing sands. Although the shell-bearing sands are poorer in quality, the majority of these sands can be used in concrete, providing they do not contain a shell content exceeding that of 30% of the sand's mass. (Cole & Viljoen, 2001) (Grieve, 2009)

Initially the silica sands were exploited from Philippi by both the construction and glass manufacturing industries. As these resources became extensively exploited, extraction moved eastwards towards the Macassar region. These sands are similar in composition, but are generally finer grained. This is evident with the fineness modulus (FM) of these sands being reported as 1,56 in Philippi and 1,13 in Macassar. (Cole & Viljoen, 2001)

Currently, both these resources continue to be exploited; however the majority of the remaining material is very fine-grained. As a consequence the FM of these sands falls into the lower end of the FM spectrum acceptable for use in concrete. ($1,2 < FM < 3,5$). In addition, there are limited fractions of sand between the 0,150mm and 0,075mm particles sizes, resulting in a lack of cohesiveness and excessive bleeding in the concretes fresh state. These sands also have a typical water requirement ranging between 180 l/m³ to above 200 l/m³, with the latter occurring in concrete using very fine-grained material. These undesirable properties are often resolved through blending these sands with the commercially produced crusher sands. (Grieve, 2009) (Afrisam Staff, 2013)

In 2011, Cole from the Council for Geoscience estimated that the remaining resources located in this region are confined to south of Philippi and in the Macassar area, with an inferred resource of 10Mt and 30Mt respectively. Furthermore, the majority of the sands located in the Philippi region lie below the groundwater level, therefore to extract these sands, dredging operations are required. (Cole, 2011)

b) West Coast Sands

Another source of aeolian dune sands occurs along the western coastline spanning from Blouberg to north of Melkbosstrand and inland towards Atlantis. These sands are of similar composition to those occurring in the Cape Flats. They are characterised by being very fine to medium-grained, rounded to

sub-rounded and quartz rich, with certain of these sands containing shell fragments. A few of these deposits have been exploited for fine aggregate use. However, due to substantial development occurring in these areas, a lot of the sand quarries in these regions have been abandoned. There are only a few currently still operational, located north of Melkbosstrand, such as De Anker Sand Mine owned by Afrimat.

The remaining extent of these resources is approximately in the order of 5Mt, as estimated by Cole in 2011. However, this excludes the resources deemed to be inaccessible, such as the vast sand deposit located in the Atlantis area. This is due to the deposit overlying a geohydrological aquifer, which supplies water to the town. (Refer to section 6.1.1.2 b, on problems relating to accessibility of sand deposits)

c) Malmesbury-Klipheuwel Sands

The last major sand resource that has been exploited is located in the Malmesbury-Klipheuwel region. The sand deposits from this region comprise hillwash and colluvial sands, commonly referred to as siliceous pit sands by the Engineering community. These sands are characteristically of high quality due to their inherent rounded particle shape and continuous grading. As a result, these sands provide a good source of concrete fine aggregate. This is despite the high fines content (up to 20% minus 0,150mm and 15% minus 0,075mm), which in fact contributes to a superior quality, with low water requirements of approximately 170 l/m³. In addition the resulting concrete does not have excessive shrinkage normally associated with a high fines content. (Cole & Viljoen, 2001) (Grieve, 2009)

This resource was initially extracted from deposits located north of Klipheuwel. They were the preferential source of concrete fine aggregate, due to superior properties compared with those of the dune sands extracted from the Cape Flats. However, this sand has two issues reported to be of concern in concrete mixes. The first concerns its use in dry mix applications, which led to stickiness and reduced workability of the concrete mix. This can be resolved through blending with dune sands. Secondly it is noted that in places it has a high organic content. This has led to some reports of mixes experiencing retardation of the cementing reactions, thus influencing the hardening of the concrete. This can be addressed through appropriate processing which involves removing the organic material in the sands, or through blending with the dune sands. (Cole & Viljoen, 2001) (Grieve, 2009)

These resources have been heavily utilised, and have been almost completely depleted. Today undeveloped deposits of the Klipheuwel sands are rare and difficult to acquire. It has been estimated, in 2011, that the remaining extent of these resource is in the order of 20Mt. However, much of these sands are more sparsely distributed, with a typical deposit thickness of only about 0,85m. (Cole, 2011)

Additional resources with similar properties have been identified and are currently being exploited. These resources are located further north, up the West Coast towards Saldanha and inland towards Malmesbury, however the use of these sands involves substantially greater haulage distances and therefore higher transportation costs. (Grieve, 2009)

6.1.1.2 Impact of Urban Development on Sand Resources

There is a developing trend involving the densification of the City of Cape Town. This is encouraged through a densification strategy implemented by the City of Cape Town to prevent growth occurring further away from the city centre, giving rise to urban sprawl. This is represented in Figure 6.2, which shows the population growth in the City of Cape Town, over the past 100 years. The figure shows that

as the population has increased, the population density has continually decreased. (City of Cape Town, 2008)

This has resulted in the creation of a proposed conceptual map representing future growth patterns that aim to assist this strategy. This is portrayed in the spatial development plans (SDP) of the City of Cape Town, and a simplified version of this diagram highlighting the major land uses is represented in Figure 6.3. (City of Cape Town, 2012)

The consequence of this strategy has contributed to two effects: (1) The densification of the city has caused land currently occupied by natural sand deposits within the city, to be allocated to urban land uses, and (2) The agricultural land has been pushed further away from the city, which also occupies a few of the other natural sand deposits. As a result the access to many of the natural resources has become more limited. There have however been provisions made in the SDP, allowing access to these resources before development commences, but this does not assist those resources located in currently developed regions. (Section 5.1.4 of the CTSDF Statutory Report, 2012)

In addition should access be granted to a resource, the environmental impacts created through mining and processing of the resource need to be considered. These concerns relate to the impact upon the surrounding areas, such as dust, noise and contamination of the groundwater, as discussed in section 4.3.4. These effects are of greatest concern in areas located within close proximity to urban land uses. (Smith & Collis, 2001)

a) Deposits located in Urban Land Use Areas

This relates to sand deposits located in urban land areas, occupied by residential, commercial and industrial sectors. Two major sand deposits that have been heavily utilised for fine aggregate production, are located in areas allocated to residential land uses. This consists of the West Coast and Cape Flat sands, which have already been discussed. In these regions, much of the unexploited land has been allocated to residential use.

The Cape Flats sand areas are occupied primarily by the lower-income working sector. (Refer to Figure 6.3) This is problematic due to the vast extent of the deposits located in this region, combined with this resource being responsible for contributing a large amount towards fine aggregate production. This region is associated with one of the recent lawsuits by the City of Cape Town against Maccsand. This legal action related to Maccsand mining a sand deposit located on a plot of land in Mitchells Plain, which had been allocated for public open space by the city of Cape Town. (Jafta, 2012)

The West Coast sands by comparison are almost entirely tied up through urban land use, with very few quarries currently operating in the area. These currently active mines are still active as they are located on the fringe of the developing regions, at a distance from settlements as to ensure that they have no drastic impact upon the settlements in this region. However, there are pressures being placed upon their continual operation. (Motsoenyane & Lourens, 2011)

b) Deposits located in Agricultural Land Use Areas

This refers to natural sand deposits located in areas where the land is used for agricultural purposes. They are primarily located outside of the city region, as they require a vast amount of space. The resources located in these regions consist of: fluvial sands from the Berg River, and hillwash and colluvial sands located in the area surrounding Stellenbosch, Somerset West, Klapmuts and Windmeul.

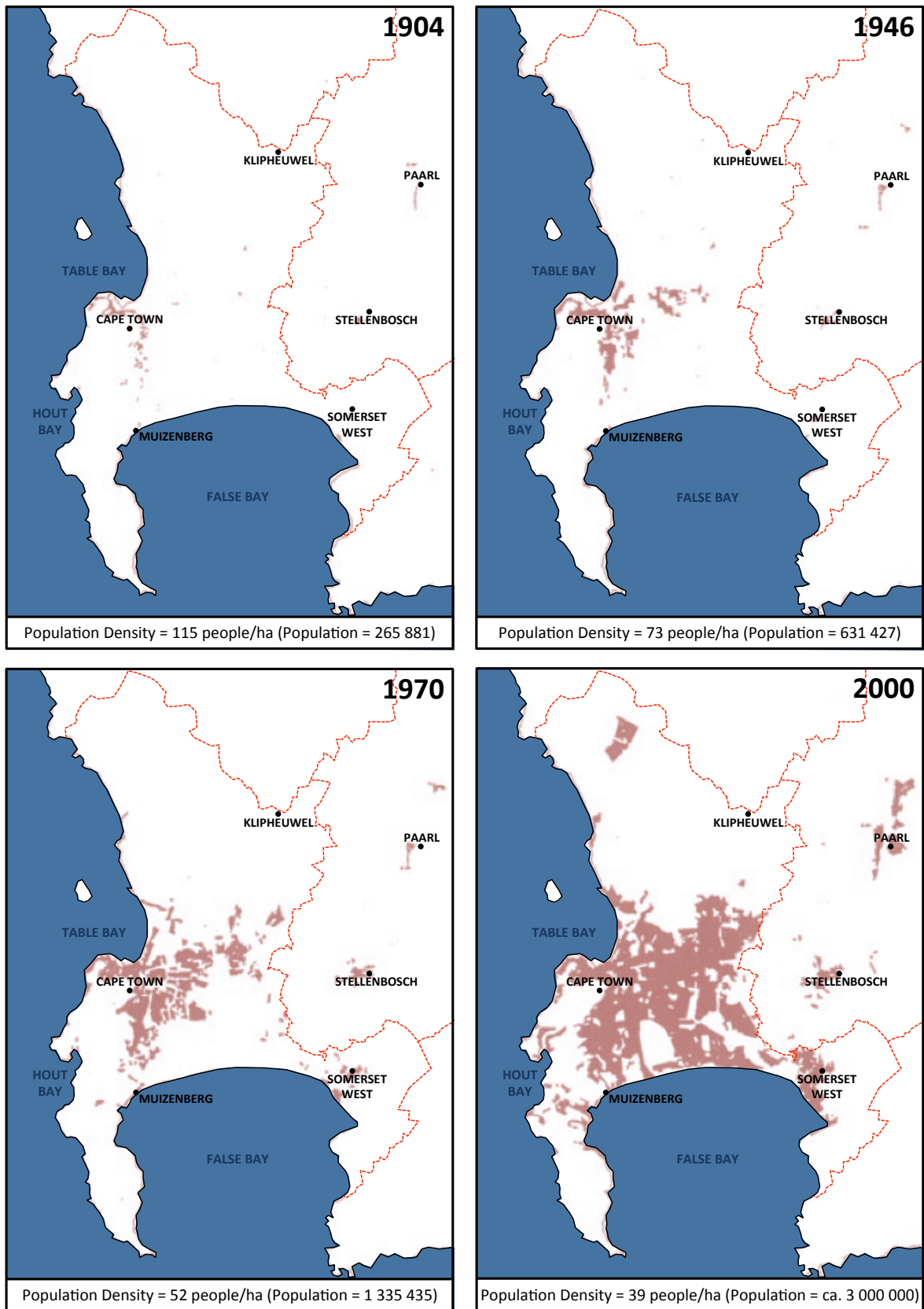


Figure 6.2 – Population growth in the Greater Cape Town area, resulting in an urban sprawl (City of Cape Town, 2008)

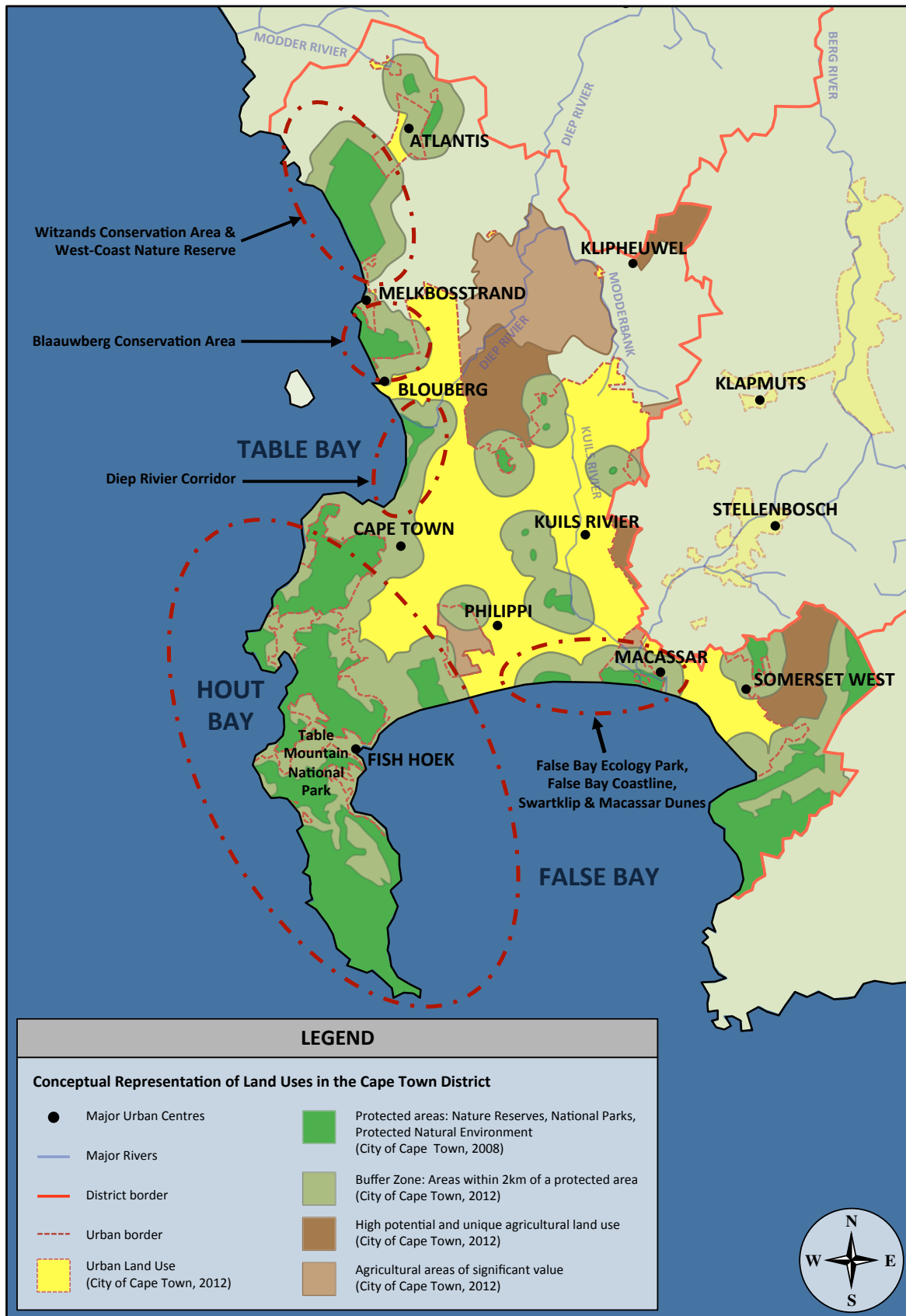


Figure 6.3 – Simplified conceptual representation of the zoning of land uses in the Greater Cape Town area

These regions form part of the Cape Winelands in the Boland District, and as a result, for the most part, this land has a high agricultural value. Consequently this will make these deposits potentially difficult to access.

The fluvial sands are located on the banks of the Berg River extending from Kylemore to Saron. These deposits typically occur on farmland, which are located with a portion of their plot of land bordering the Berg River. These sands are characteristically fine to coarse-grained, rounded to sub angular and quartz rich with a gritty, pebbly composition. The deposits are however, commonly small in extent, with the sands generally occurring in sand bars. These are thin strands of sand deposits that occur along the banks of the river. These deposits, due to the limited nature of the deposit, combined with the agricultural value of the land, are difficult to access and are suggested to be economically unfeasible to mine. (Cole & Viljoen, 2001)

The other hillwash and colluvial deposits located in the Winelands areas are characteristically fine to coarse-grained, sub rounded to angular and quartz rich with a slightly gritty composition. Therefore these sands are generally high quality most probably fit for use as a concrete sand. However, they are located on high value agricultural land, occupied by wine farms. As a result access to these deposits will prove to be very difficult. One factor contributing to this difficulty is the impact that the dust content released in the mining processes of a sand resource has upon the crops. (Durbanville Hills Winery, 2013) Furthermore, even if access were granted, due to the relatively small extent of the deposits this land would be too expensive to mine.

c) Deposits located in Conservation-Protected Areas

This land use refers to the deposits located in an area protected by the City of Cape Town as they form part of nature reserves, national parks or protected natural environment. There are typically four deposits of sand resources located in these regions, comprising of aeolian dune sands located along the western and southern coastlines, in Fish Hoek, on the slopes of Table Mountain, and in Atlantis. (Refer to Figure 6.3 and Table 6.2)

Table 6.2 – Sand deposits located in conservation-protected areas

Sand Deposit	Type of Sand Deposit	Conservation/Natural Protected Area
Atlantis	Aeolian dune sands (Witzand Formation) Aeolian sands (Springfontein Formation)	Underlying aquifer, Witzand Conservation Area, and West-Coast Nature Reserve
Fish Hoek Sands	Aeolian dune sands (Witzand Formation) Aeolian sands (Springfontein Formation)	Table Mountain National Park
Cape Flat Sands	Aeolian dune sands (Witzand Formation)	False Bay Ecological Park, False Bay Coastline, and Swartklip and Macassar Dunes

Table 6.2 (Continued)

Sand Deposit	Type of Sand Deposit	Conservation/Natural Protected Area
West Coast Sands	Aeolian dune sands (Witzand Formation)	Diep River Corridor,
	Aeolian sands (Springfontein Formation)	Blouberg Conservation Area, Witzand Conservation Area, and West-Coast Nature Reserve

(Information obtained from the SDP of the City of Cape Town, 2012)

The Atlantis sands comprise of aeolian sands, of the Witzand and Springfontein Formation. The sands are characteristically very fine to coarse grained, rounded to sub-rounded and quartz rich in composition with fractions of comminuted shell fragments present in some of the Witzand sands. These sands are however, typically finer-grained than those of the Cape Flat sands, which can be attributed to the deflation process. The extent of the resource is vast, with an inferred resource of approximately 437,5Mt. It is however, located on top of an aquifer supplying water to the town of Atlantis, therefore it is a heavily protected resource that has been exploited minimally. Due to the environmental impact that mining of this resource could have upon the aquifer, potentially contaminating the water, further exploitation of this resource is unlikely. (Cole & Viljoen, 2001)

6.1.1.3 Potential Undeveloped Resources in the Greater Cape Town Area

As previously mentioned, a large amount of the natural fine aggregate resources have been exploited, with many studies indicating their increasing depletion. In the Cole & Viljoen report conducted in 2001, it was suggested that the lifespan of the inferred concrete sand resources in the Greater Cape Town area, was approximately 35 years. This figure was based upon the economic growth rate at the time. Since then twelve years have elapsed, thus suggesting that these resources have a lifespan of approximately 23 years left. These shortages are certainly apparent with one of the major natural sand resources, located in Klipheuwel, becoming almost completely exhausted for concrete use. (Cole & Viljoen, 2001)

The other major remaining resource consists of the dune sands exploited from the Cape Flats region, however the amount of sand available is diminishing. In addition, the sand extracted from this region is more varied due to the remaining extent of the resources. This can be attributed to the geological formation of the deposits. The sands typically occur in depositional layers, in which each layer's properties relate to the geological process that deposited the sediment. As a result the deposits have vertically variable properties. This results in a degree of uncertainty in terms of quality of the remaining sands. (Daries, 2012) Furthermore, the sands left unexploited are mainly composed of very fine-grained sands, which require blending with other sources to achieve the appropriate grading for concrete applications. (Cole & Viljoen, 2001)

As discussed previously, the remaining resource availability of other naturally occurring sand deposits is limited in the Greater Cape Town area. As a result it can be concluded that there is a limited future for natural fine aggregate resources. In search for further natural aggregates, the study region was opened up to natural deposits occurring outside of Cape Town.

6.1.1.4 Potential Undeveloped Resources Outside the Greater Cape Town Area

Additional natural resources of hillwash and aeolian sands are located north of the Cape Town District. These are found in the areas of Saldanha, Piketberg, and Vredenburg, and as far north as Clanwilliam and Calvinia. The hillwash sands are generally of higher quality, and the data suggests that many of these deposits are of sufficient quality for concrete use. (Cole, 2008) (Cole, 2010)

This suggests that the greatest potential in terms of natural fine aggregate resources exists outside of the Greater Cape Town area, at greater distances from the market. Consequently this will result in the incurring of higher road transportation costs. This is of concern as fine aggregates are a high bulk, low unit cost commodity, where the transportational costs contribute to a large percentage of the overall production cost. It was estimated in 2001, that aggregates lying outside of a 80km radius from the market, are not economically viable. Since rail transportation is at a lower cost the problem can potentially be addressed through the extension of the existing rail network into these regions. (Cole & Viljoen, 2001)

There are also other resources extending out to the east of the Greater Cape Town area. These are located in the regions of Paarl, Robertson and Worcester. The sands are hillwash and colluvial in origin being derived from the sandstones of the Table Mountain Group. In this region, the sands are characteristically fine to coarse-grained, sub-rounded to angular and quartz rich. They are suitable for use in applications such as concrete, mortar and plaster, after they have undergone a degree of processing. However, these deposits are currently being actively worked and provide sand to the surrounding areas and thus only the surplus production is available for use by other regions in the Greater Cape Town area. (Cole, 2011)

Lastly, although a large amount of the resources identified are tied up through a result of alternative land uses, their location should be recorded for potential use. This is because if there is a construction project located in these areas, the excavated material could potentially be used as a supplementary aggregate resource. This is particularly prevalent in the regions surrounding the aeolian dune sands, present along both the southern and western coastlines. This is discussed in greater depth in section 6.3 on site-derived aggregates.

6.1.2 Natural Offshore Sand Deposits (Marine Sands)

Currently there are no marine sand deposits that are being exploited. However, as highlighted in section 5.2, these are natural sand resources that could be accessed in the offshore marine environment. This has been indicated through analysis of the paleo-river systems combined with the sea level fluctuations, which would have resulted in the deposition of sediment offshore along the coastline. (Compton, 2004) (Refer to Figure 6.4) The characteristics of these sand deposits are believed to be similar to the sand deposits that exist onshore in that region, only differing by the degree of weathering it would have undergone. Consequently the sands should be well rounded, fine to medium-grained, and quartz rich. (Cole & Viljoen, 2001)

Marine resources have provided a great source of fine aggregates for many countries around the world, especially for those with limited land resources available. An example of this is the United Kingdom and Northern Europe, which have been exploiting these resources since the 1960's. (Smith & Collis, 2001) There are however, problems to be solved in order for them to be used as a fine aggregate resource. In

particular, extraction will need to meet stringent environmental protection regulations and the sands will need to be extensively processed in order for them to be used.

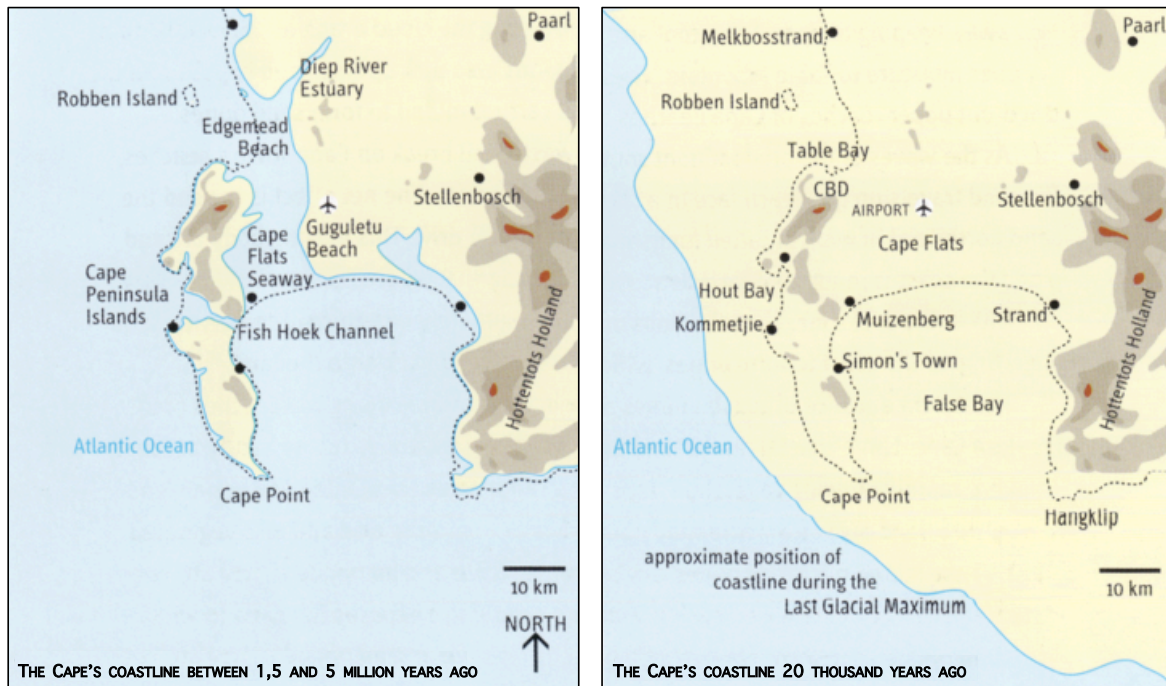


Figure 6.4 – Diagrams representing the change in the Cape’s coastline, thus suggesting a presence of offshore sand deposits (Compton, 2004)

Marine environments are heavily protected and certain portions of the coastline are protected to ensure that the local ecosystems are not affected. In marine protected regions dredging is not possible but in many other areas, activities are strongly regulated to reduce the environmental impact of the dredging process. The mining must be conducted in a manner as to ensure the local ecology in the ocean is not compromised. (Smith & Collis, 2001)

Secondly, aside from the commonly discussed properties, the marine sands have high chloride and shell contents. The chlorides, which are present in the sand through the salt content, are of greater concern as they can potentially affect the hydration reactions and cause corrosion of reinforcement if used in concrete. The shell content by comparison impacts upon the water requirement of the concrete. This is due to its angularity, which contributes to a reduced workability and handling difficulty of the fresh concrete. This is greater the higher the fraction in the sand and is stipulated to be of concern if this fraction exceeds 30% of the sand’s mass. These properties thus require additional processing measures. (Alexander & Mindess, 2005)

6.1.2.1 Potential Undeveloped Resources

As mentioned, a geological analysis of the Cape’s coastline suggested there are potential offshore marine sand deposits that could be used for fine aggregates. This analysis is based on studies and geological surveys of the Western Cape’s coastline. In 2013, Van Zyl from the Council for Geoscience compiled this information into a map, which is shown in Figure 6.5. This map demonstrates that there are vast

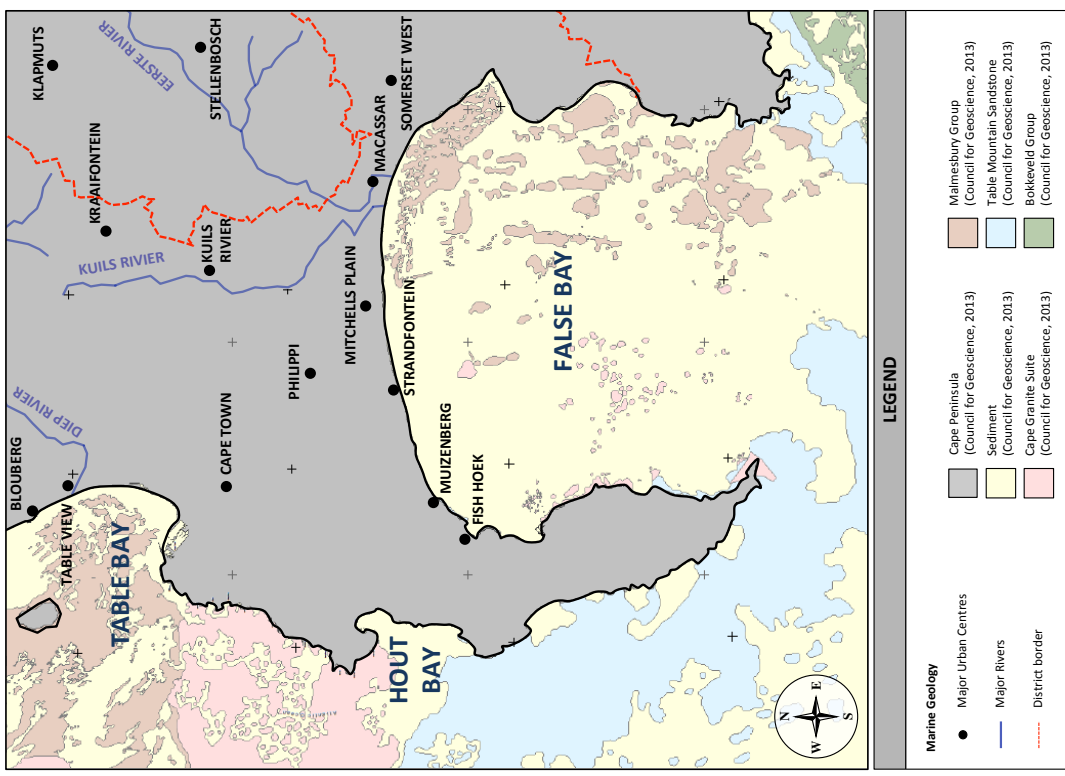
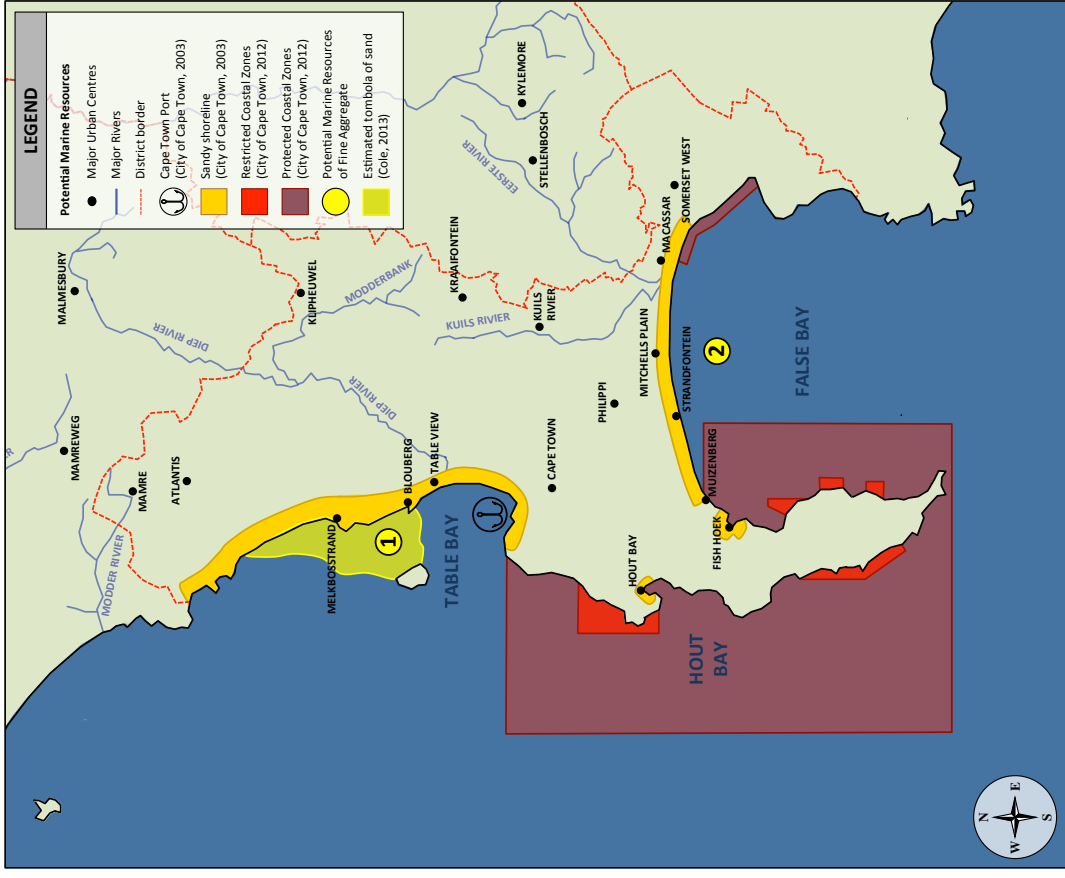


Figure 6.5 – Map delineating the offshore rock geology of the Greater Cape Town area (adapted from Van Zyl, 2013) (Left); and Map delineating the sandy shores and protected coastal zones of the Cape Town District (Right)

deposits of marine sands located in the False Bay region and along the West Coast coastline, extending from Blouberg to the north. The second deposit coincides with a large tombola of sand that is believed to extend from the Cape coastline in the Table Bay area, through to Robben Island. (Van Zyl, 2013)

Although these deposits could potentially be used for fine aggregate use, there are important environmental considerations regarding their extraction. Since much of the resource lies in marine protected areas, access will be restricted thus preventing their extraction. The protected areas were defined in the SDP of Cape Town, with much of the coastline surrounding Table Mountain protected, as well as the coastline extending from Macassar to the east. (This is represented on a map generated in Figure 6.5) (City of Cape Town, 2012) This investigation highlighted two regions that have potential for fine aggregate use, which lie outside marine protection zones. One area is located in Table Bay, which is situated on the West coast of the Greater Cape Town area, extending north towards Atlantis. (Marked 1, in Figure 6.5) The second region exists offshore, along the south coastline, from Muizenberg to Macassar. (Marked 2, in Figure 6.5). Due to proximity to the Port of Cape Town for offloading of dredged sands, the deposit located off the West Coast is probably preferable for extraction.

These findings are preliminary, and with no publication of detailed analysis and research having been conducted. Reasons for this could be due to: (1) A lack of knowledge in the industry of this potential resource, and (2) an often stated belief from members of the construction industry, that there are other fine aggregate resources available with greater ease of access and therefore more economical to use.

6.2 Crushed Aggregate Resources

Another major resource present within the Greater Cape Town area is crushed aggregates. This is the manufacture of crusher sand, through crushing material obtained from sources of hard bedrock. Crushed aggregate resources are a good solution for resolving the shortage of concrete aggregates, particularly in places where the supply of natural sands is limited. This is a significant resource in the region, whereby crusher sands have become increasingly used over the past decade due to the depletion of natural sand supplies.

6.2.1 Current and Previously Exploited Resources

In the Greater Cape Town area, there are three primary rock sources used to manufacture crushed aggregate. These sources are the granite from the Cape Granite Suite, greywacke from the Malmesbury Group and quartzitic sandstones from the Table Mountain Group. These sources are discussed in the sub-sections that follow. (Refer to Figure 6.6 for a geographic representation of the major crushed aggregate sources and Table 6.3, which provides a breakdown of these major crushed aggregate resources)

6.2.1.1 Greywacke Crusher Sands (Malmesbury Shale)

The beds of the Malmesbury Shale form the major source of crushed aggregate within the Greater Cape Town area. Originally mudstones and sandstones, these rocks have been altered or metamorphosed by heat and pressure during the Cape Orogeny to form greywackes, shales and slates. The rocks have also been thermally metamorphosed and changed by the intrusion of granite to form Hornfels. As a result, in this mild metamorphic setting, differentiation between rock types can be difficult as they lie within a continuous spectrum running from mud to shale to slate, and from sandstone to greywacke, depending on their degree of alteration. Consequently all of the rocks extracted from this region for aggregate use are commonly referred to as Malmesbury Shales or Greywacke. (Compton, 2004)

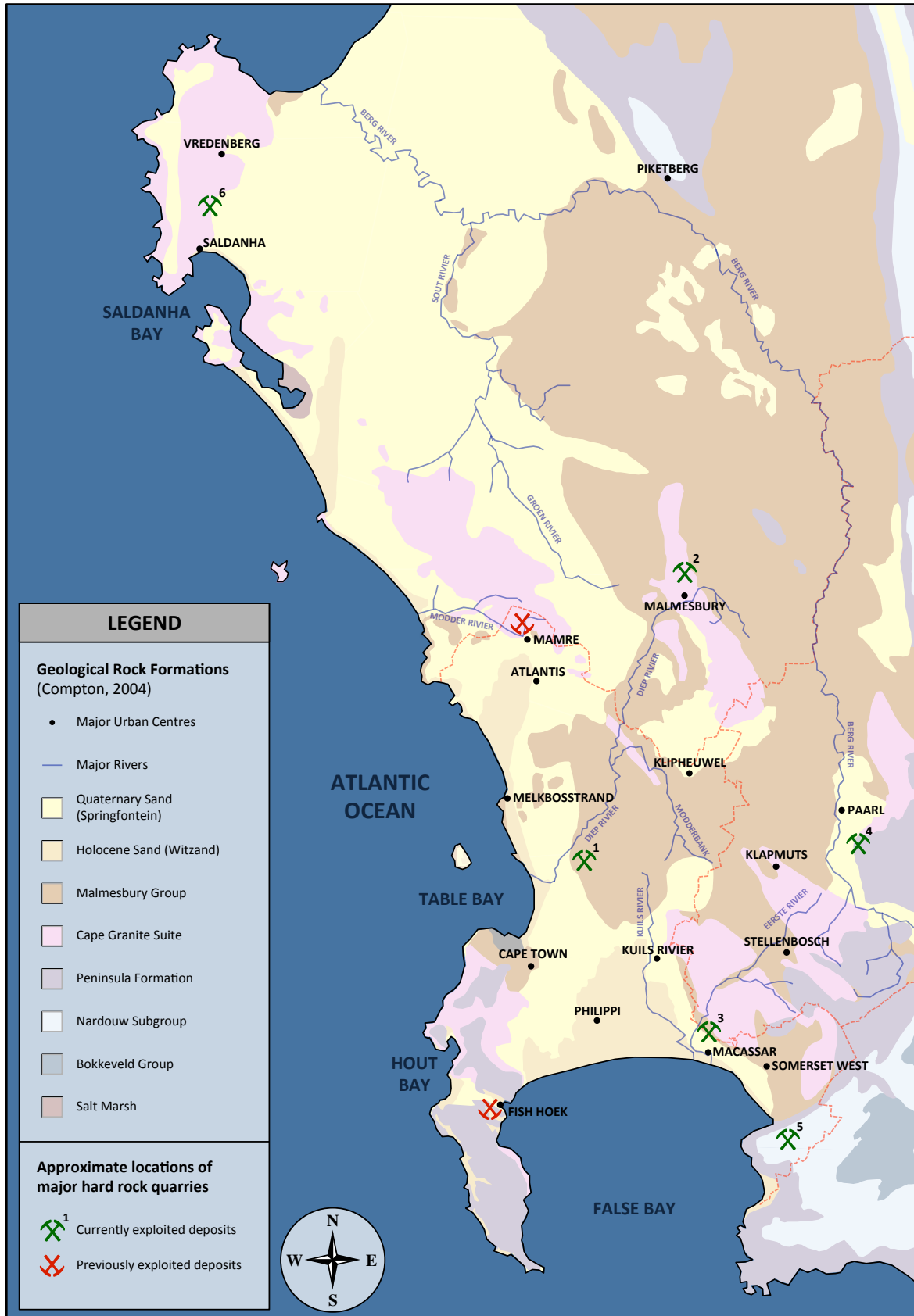


Figure 6.6 – Regions exploited for crushed aggregate (Information obtained from Motsoenyane & Lourens, 2011 and Cole, 2011)

Table 6.3 – Regions exploited for crushed aggregate (Refer to Figure 6.6)

Crushed Resource (Location)	Type of Rock Exploited	Rock Formation Group	Notable Quarry
1. Tygerberg Hills, Durbanville	Greywacke (Malmesbury Shale)	Malmesbury Group (MG)	Peninsula Quarry (Afrisam) Tygerberg Quarry (Lafarge) Ceoli Brothers Quarry
2. Malmesbury	Granite	Cape Granite Suite (CGS)	Rheebok Quarry (Afrisam)
3. Eerste Rivier	Hornfels	Malmesbury Group (MG)	Peak Quarry (Lafarge)
4. Paarl	Quartzitic Sandstone	Table Mountain Group (TMG)	Dennegeur Quarry (Afrimat)
5. Grabouw	Quartzitic Sandstone	Table Mountain Group (TMG)	Palmiet Quarry (Afrimat)
6. Vredenburg	Granite	Cape Granite Suite (CGS)	De Kop Quarry

(Information obtained from Motsoenyane & Lourens, 2011 and Cole, 2011)

The Greywacke deposits are the most utilised as an aggregate resource, the largest of which is located in the Tygerberg Hills and is currently exploited by four aggregate quarries. Smaller deposits have also been exploited, located in the areas of Blouberg and south-west of Philadelphia. By comparison the hornfels rock is primarily located along the Eerste Rivier. This is currently exploited by only one mine called Peak Quarry (a quarry of the same name was originally located on the slopes of Devil's Peak, Table Mountain) owned by Lafarge. The inferred resource of these deposits is enormous with an estimated size to several billion tons, according to Cole in 2011. Consequently, these deposits are suggested to have a lifespan exceeding 100 years. (Cole, 2011)

Both sources of crushed rocks are used to produce concrete aggregates, as well as the coarser base and sub-base material used in road construction. The fine concrete aggregate commonly referred to, as crusher sand, is characteristically angular and flaky in composition, with partial gap graded composition. These properties are a result of the crushing processes and appropriate crushing techniques are required to ensure more desirable properties are obtained for concrete use. The rocks extracted from these deposits are strong and durable, with a standard water requirement of approximately 180 to 185 litres per cubic metre. (Afrisam Staff, 2013)

6.2.1.2 Granite Crusher Sands

Granite is a coarse grained, intrusive igneous rock consisting essentially of quartz and feldspar minerals, together with varying amounts of mica, amphibole and iron oxides. Granites are widespread throughout the Cape and are known as the Cape Granite Suite rock formation. The granite and greywacke rocks are the preferred choice of material used for crushed aggregate resources in the Greater Cape Town area. This granitic material is ideal due to its characteristic high strength and durability. (Cole, 2011) (Grieve, 2009)

The greatest concern associated with the use of granites as a source of crusher sands, is the degree of weathering it has undergone, causing a breakdown of the feldspar constituents to form clay minerals, in the form of kaolin and/or illite. The weathering of the feldspars reduces the granite's strength and the presence of the clay minerals with the micaceous minerals in the weathered granite has detrimental effects on the concrete. Consequently certain granites are not used when determining the potential use as an aggregate resource. (Grieve, 2009)

There are two primary granite deposits that lend themselves for use as a concrete aggregate. These comprise the coarse-grained, porphyritic granite found in the Mamre region, and the fine-grained equi-

granular granite located in the Malmesbury region. The granite in the Mamre region, which forms part of the Darling Batholith, was previously exploited, however these quarries have subsequently been closed down in the past few years. (Afrisam Staff, 2013) Currently the major source of granite is obtained from deposits located in the Malmesbury area. Afrisam exploits these granites at Rheebock Quarry, which is located about 10km north of Malmesbury. The extent of these resources is vast, and like the greywacke deposits, they are expected to have a lifespan exceeding that of 100 years, subject to accessibility reasons. (Cole, 2011)

There are other granite formations present in the Greater Cape Town area that cannot be used for compositional reasons. The other granites of the Darling batholith complex contain large feldspar phenocrysts, which are prone to disintegration and/or too rich in muscovite. The granites present in the Klipheuwel, Somerset West and Kuils Rivier regions have similar problems but are also sheared making them deleterious to the concrete. Outside of the Cape Town district, granites exist that could be used as crushed aggregate resources. These are located in the Vredenburg and Saldanha region, and are exploited by companies such as Afrimat at De Kop Quarry and Lafarge at Saldanha Quarry. (Cole, 2011)

Like the greywacke, the crushed granite is used to produce both concrete aggregate, and the base and sub-base material used in road construction. The crusher sands, are more cubical by comparison to the greywacke, but exhibit a similar grading profile and are potentially a better resource with similar strength and durability, and a slightly lower standard water requirement of approximately 175 to 180 litres per cubic metre. (Afrisam Staff, 2013)

6.2.1.3 Table Mountain Sandstone Crusher Sands

The quartzitic sandstone of the Table Mountain Group is another aggregate source, used in the Greater Cape Town area. This is a sedimentary rock comprising primarily quartz minerals, with varying proportions of feldspars, clays and other rock fragments. It was formed through the progressive lithification of the sedimentary material (sand, clay and silt), which has resulted in the creation of a tightly cemented rock, which is strong and hard. (Grieve, 2009)

As a resource the Table Mountain sandstone forms a good concrete aggregate, however due to its slightly softer composition and location, it is not exploited to the same extent as the granite and greywacke in the Greater Cape Town area. The sandstones were formerly exploited for concrete aggregate, rail ballast and road base and sub-base material at Glencairn Quarry, which is located at the foot of Elsie's Peak, in Fish Hoek. However, this area has been rezoned and protected to form part of the Cape Peninsula National Park, and therefore quarrying has been discontinued. There are a few sources of Table Mountain sandstone present in the Greater Cape Town area, with the main exploitable resource existing in the Somerset West region. This deposit is extremely large, extending south towards Strand and Grabouw and then out towards the east, for another 20km towards the Bot River. This deposit is currently being exploited in one location, at Palmiet Quarry, which is located between the N2 and Peninsula Dam, in Grabouw. (Cole, 2011)

The size of this resource is large; with the only factor precluding its development is the distance to market and environmental constraints. The size of these resources are able to meet the demand for aggregate to the Greater Cape Town area for the foreseeable future. (Cole, 2011)

6.2.2 Potential Undeveloped Resources

This analysis has confirmed that with the technological improvements, crushed fine aggregate resources can meet the core future supply of fine aggregate in the Greater Cape Town area. Based on current reserves this supply has a reserve life in excess of 100 years. This is since the inferred hard rock resources are believed to exceed several billion tons. The technological improvements have helped to produce crusher sands of similar quality to that of the natural sands. In many cases this quality is better than that of the remaining natural sands present within the Greater Cape Town area.

Greywacke extracted from the Tygerberg Hills will continue to be the preferred resource used in Cape Town. This is primarily due to the vast extent of this resource and its close proximity to the market. It will be supplemented by the other sources such as granite and sandstone. The granite resources offer slightly high quality crusher sand, however these resources are located further from the end use.

The most effective use of crushed aggregate resources in concrete fine aggregate is achieved through its blending with the Cape Flat dune sands. This improves the grading, since the crusher material contains the coarser fine material, between 1,18 mm to 4,75 mm and the very fine-grained material, less than 0,075mm but lacks the middle sized particle that are abundant in the dune sands. The blending results in reduced bleeding in fresh concrete and increased durability and an improved concrete finished in hardened concrete. The blending ratio varies from approximately 70:30 to 50:50, crusher sand to dune sand depending upon the application of the concrete mix. In addition, the blending of these aggregate resources will further extend the lifespan of the natural resources. (Afrisam Staff, 2013) (Grieve, 2009)

In terms of quarry development, it is difficult to predict the future development of hard rock quarries. However, based on information obtained from interviews conducted with a few of the major aggregate companies in the Greater Cape Town area, it is suggested that currently there are no immediate demand pressures necessitating new development. This is providing the current quarries continue to meet the demand placed upon them. (Afrisam Staff, 2013), (Wheater, 2012)

However, should further resources be required, an extension of the existing operations to boost production rather than a greenfield, new quarry development, is logical. This is in view of the significant investment required for processing facilities in a new build. In addition, the greatest drivers regarding the location of any quarry are its proximity to the market. Other factors will include: the accessibility of the land, which could be restricted by competing land uses (discussed in section 6.1.1 on natural fine aggregate resources), and the feasibility of extracting and processing the resource. (Grieve, 2009) Consequently this development is suggested to occur in the east of the Cape Town district, towards the Cape Fold Mountains, utilizing the Table Mountain sandstone rocks and the Malmesbury Group greywacke rocks. This can be deduced from mining records, indicating that the more recently developed quarries are located in these regions. (Motsoenyane & Lourens, 2011)

6.3 Site Derived Aggregate Resources

The term “site-derived aggregate” refers to the use of material obtained from a construction or building site, as a source of aggregate. This material is derived from the excavated material, removed from the construction area, for site levelling and foundation purposes. The use of the material is determined by its physical properties, and thus is dictated by the underlying geology and surface deposits, in the region. Material extracted and used for fine aggregate in concrete will require a much higher quality than required for other site purposes. As a result, it is often practically not possible. This corresponds with the findings presented in a dissertation conducted by O’Neill-Williams from the University of Cape Town, 2012. His research focused on the Greater Cape Town area, with the majority of the specimens being obtained from the suburbs of the urban areas surrounding Table Mountain. Two of the main factors limiting the use of the site-derived material for use in concrete are the clay and fines content. This fraction of material can lead to deleterious effects in the concrete produced. (For more information regarding the impact of these properties on concrete refer to Chapter 2) (O’Neill-Williams, 2012)

6.3.1 Potential Undeveloped Resources

Currently on-site material does get used for on-site applications, such as in fill material applications. This is encouraged due to the diminishing capacity of landfill sites in the Greater Cape Town area. Furthermore, the diminished capacity has resulted in increased dumping levies, which further acts as a deterrent to prevent the dumping of waste material. However, through analysis of literature, it does not appear that the soils in the Greater Cape Town region are universally of suitable quality for concrete use. This corresponds with findings, reported by O’Neill-Williams. Yet, subsequent research for this thesis suggests that there are two regions, where the underlying ‘soft rock’ sands could be used for concrete fine aggregate. These regions are located along the western³ and southern⁴ coastlines. This finding is supported by two factors: (1) the soil and rock geology present in these locations, and (2) the location of onshore natural sand deposits that confirm this trend.

The soil and rock geology shows these coastal regions comprise of sand rich soils. This can be attributed to the aeolian sands that have been blown across these regions, overlying the local geology. These sands were previously marine sands that occurred along the coastline, which have been wind-blown by the Cape south-easterly wind inland, in a north-westerly direction. (This is represented in Figure 5.7) These soils are thus described greyish, imperfectly drained, sandy soils, which are quartz rich in composition. (Refer to Figure 5.3) This description is representative of the type of material that would lend itself towards fine aggregate properties.

Furthermore, with reference to the previous subsection on Natural Onshore Sand Deposits, these regions were previously exploited for fine aggregate resources. There are still a few quarries that continue to operate, situated outside of the settlement areas. As a result these resources have not been completely utilised, thus could be potentially used as fine aggregate in construction. This could include fine aggregate used in concrete. However, if it is of substandard quality, it should also be considered for lower quality uses such as building sand or fill material.

³ The western coastline is the region extending from Table Bay extending north towards Atlantis and Saldanha

⁴ The southern coastline is the region located mainly in the Cape Flats area. This is the region extending between Muizenberg and Macassar and as far north as Kraaifontein.

There is potentially an additional benefit for the use of this resource. The low-income work sector currently occupies the land, forming part of the allocated residential land use. In order to help these communities, the government funds a large proportion of the new construction in these areas as part of an initiative to provide shelter for the underprivileged. (City of Cape Town, 2012)

The sands could be a potential resource for the RDP housing, being built in the region. These are small construction projects and thus do not require the same quality of aggregate required by a high strength concrete in larger constructions. The use of this material, obtained through the excavation of the land for foundations etc., would potentially reduce the cost of construction, allowing more housing to be built. Additionally these resources could help with community outreach, since local members of the community could be employed to help with the processing of this material. This will in turn reduce the unemployment of the region through job creation.

There are a few issues that would need to be resolved should this resource be considered. The first is regarding the locality of the Cape Flats, which due to a lack of gradient lies in a flood prone region. (City of Cape Town, 2012) Consequently, all proposals should consider their effect upon potential flooding in the region. This subsequently could result in very little material being excavated during land clearing and foundation digging processes. As a result, the benefits may not prove to be as large and beneficial as previously discussed. In addition, due to the variability of the underlying soils and soft rock, each construction project would require pre-testing, to ensure that the soils are of sufficient quality.

6.4 Recycled Aggregate Resources

The last of the potential sources that can be used for producing fine aggregate in the Greater Cape Town area is the use of construction and demolition (C&D) waste products. This is a concept that has developed over the past few decades with a large amount of research being conducted on the re-use and recycling of this material. This is very important as it aims to reduce the amount of waste products that are required to be landfilled as well as provide an alternative resource to supplement the heavily diminishing stocks of natural aggregates, which are becoming increasingly depleted. (Kutegeza, 2004)

6.4.1 Current and Previously Exploited Resources

In the Greater Cape Town area, the use of C&D waste for recycling purposes has declined. This observation is based on a 2011 report by the City of Cape Town. The statistics reported show that the recycling rate in 2002/03 of C&D waste was 73%, which then diminished to 61% in 2008/09. This report adds with the continually diminishing capacity of landfill sites and newly allocated land occurring further away from the urban areas, it is becoming increasingly important that this waste stream becomes more heavily utilised. (City of Cape Town, 2011)

The utilised C&D waste products can be recycled and used in construction aggregate and brick manufacture. There are companies in Cape Town that are currently conducting this namely, Malans Quarries, Bradis Demolition and Ross Demolition in terms of recycled aggregate products and Cape Brick, Steco Concrete Works, Inca Bricks and Ceramic Bricks for brick products. (Ayers, 2002)

6.4.2 Potential Undeveloped Resources

Recycling construction and demolition waste can be used as base and sub-base material for road construction, aggregate for composite construction material such as concrete, and for fill material. In terms of recycled fine aggregate (RFA), it does not have favourable results when used in concrete applications. These findings were published in a study conducted by Kutegeza from the University of Cape Town, in 2004. His results showed that concrete produced with RFA has reduced compressive strengths and durability in hardened concrete. In fresh concrete it also leads to issues regarding the workability of the concrete mix. This can be attributed to the RFA material, which is generally of a composition such that it has a high porosity and water absorptive properties, leading to an increased standard water requirement. (Kutegeza, 2004)

These results were confirmed by a study conducted by Di Maio and Zega. However, their findings in the article included the blending of RFA with other commercially produced fine aggregates, which subsequently leads to improved results. These results suggested that by blending 30% of RFA with another commercially produced aggregate, it would result in concrete of acceptable quality. Although these findings suggest the potential use of RFA in concrete, there is no conclusive study suggesting that it will ever contribute to a large sector of fine aggregate resources. (Di Maio & Zega, 2011)

In conclusion the recycling of C&D waste is essential in the Greater Cape Town region to aid with the diminishing capacity of landfill sites and to help with the diminishing source of virgin material in the construction of buildings. In terms of RFA and its use in concrete, it is not suggested to have a great potential use, unless used in concrete for lower grade applications, such as in foundations, floors and non-bearing walls. Blending of the material should be considered to help to reduce its deficiencies. It should however be primarily used for applications such as fill material in back filling and site levelling. (Kutegeza, 2004)

6.5 Environmental Considerations

The identification of potential fine aggregate resources for use in the construction industry has become increasingly complex over the past few decades. This is primarily due to the advent of environmentalist concern for human impact on the environment. This factor has become progressively more important in the construction industry, with a requirement that all future developments aim to safeguard the environment for the benefit of current and future generations. It is therefore important to consider the environmental impact of the fine aggregate resources when considering the remaining extent of these resources available in the Greater Cape Town area.

6.5.1 Evaluating the Environmental Impact of a Resource

The process of evaluating the environmental impact of each resource is difficult due to the lack of standardised measurement metrics. Some aspects of the process have been quantified and are discussed below (Embodied energy and carbon), however many aspects of the environmental impact analysis are subjective, unquantifiable and intangible. In particular, the importance of aspects such as the value of scenery, ecology or recreational value, are difficult to assess. For example, it is difficult to measure the impact associated with the removal of a particular species habitat, and the subsequent effect on the surrounding ecosystem. (Muigai et al., 2011)

Since the process is largely subjective, it is heavily dependent upon the party involved in conducting the assessment. The outcome will thus vary depending upon the opinion and value system of the evaluator. Furthermore, the metrics that have been derived to help evaluation become more objective are themselves partially flawed. This is due to a degree of variance inherent in taking measurements in addition to unknown content of some of the environmental values. (Calkins, 2009)

Subsequently, due to the inherent difficulties associated with evaluating the environmental impact of a fine aggregate resource, an in-depth study is required. This study should consider all aspects from embodied energy metrics to unquantifiable impacts, in order to develop a more accurate representation of the preferable resources to be utilised from an environmental perspective.

There is one common principle mutually discussed throughout literature that is suggested to help decrease the environmental impact of a resource. This refers to the use of a higher quality aggregate in concrete. (Aïtcin & Mindess, 2011) This quality is in terms of an aggregate with a lower water demand. This is achieved through ensuring that an aggregate resource produces aggregate that is:

- Clean and inert in composition,
- Relatively rounded and smooth in particle shape and surface texture, and
- Possesses a grain size distribution that is within gradation limits, has a wide distribution and the particle sizes are evenly distributed.

6.5.2 Fine Aggregate Resources in the Greater Cape Town Area

Through the research reported in this dissertation, it is noticeable that the environmental impact has already begun to shape the use of resources within the region. An example of this is that the resources supplying fine aggregate in the Greater Cape Town area have begun to be exploited further away from settlements and conservation areas. Most notably, the aeolian dune sand mines in the Philippi and Macassar regions have faced greater pressures placed on them by the government, forcing the closure of a few mines and preventing any new mines from opening. Evidence of this is the litigious difficulties experienced by Macsand, a sand mine company located in the Philippi and Macassar regions. (Jafta, 2012)

Although the environmental arguments are beginning to shape the exploitation of fine aggregate resources, the unquantifiable metrics are having the largest impact. This is because at the inception of project, it is required to carry out studies such as EIA's that consider the impact upon the surrounding settlements and local ecosystems. In terms of embodied energy, there is little evidence that these impacts are properly considered or quantified. This conclusion is confirmed in the interviews conducted for this dissertation. Essentially the main considerations factored in are in terms of the cost of exploitation, the return on investment, and the cost of implementing the environmental work needed to get project sanctioned by regulatory authorities. (Wheater, 2012) (Afrisam Staff, 2013)

6.6 Closure: Future Supply of Fine Aggregates in the Greater Cape Town Area

In researching fine aggregates in the Greater Cape Town area, it has proven difficult to assess the full extent of the resources available due to the confidentiality of information held within the industry. As a result, currently the actual extent of these resources cannot be accurately determined. However, estimates were acquired that represent an approximate size of the remaining deposits. This information was ascertained from research conducted by Cole from the Council for Geoscience. (Refer to Table 6.4)

With reference to Table 6.4, it can be seen that the remaining extent of the natural sand resources is small by comparison to the residual crushed fine aggregate resource. Consequently it can be deduced that the industry will begin to rely more heavily upon crushed aggregates, which will constitute the future base load for fine aggregate supplies in the Greater Cape Town area. This is further supported by their locality, which is within close proximity to the target market. Furthermore, with the continual technological advances, the cost and quality of aggregates produced will become more comparable with the natural sand resources, making them increasingly attractive. Other resources will potentially be used to supplement this production to meet the future demand. The use of site-derived aggregates in the construction of low cost housing has a great attraction. This is due to the locality of the low-cost housing communities, which are located upon the vast aeolian sand deposits.

The outcomes from the research conducted have also suggested that blending of aggregate resources is an effective solution that should continue to be used. This is currently carried out in the blending of crushed and natural dune sands. The resulting aggregate has the benefit of reducing natural sand demand, subsequently extending the lifespan of these resources and offsetting the deficient properties of crushed rock.

6.6.1 Remaining Extent of ‘Soft’ and ‘Hard’ Rock Deposits for Fine Aggregate use

Table 6.4 – Major remaining resources of the Greater Cape Town area

Type of Constituent	Approximate Extent of Resource Remaining (Mt)		Standard Water Demand (l/m ³)	Approximate Transportation Distance from Cape Town CBD (km)
	2001	2011		
Malmesbury-Klipheuwel Sand	28	20*	170	70
Philippi Dune Sand	33	10	180	20
Macassar Dune Sand	41	30	200	40
Greywacke Crusher Sand	-	> 1,000	185**	20
Granite Crusher Sand	-	> 1,000	180**	70
TMS Crusher Sand	-	> 1,000	190	70

* It has been suggested that this resource is more depleted than the data indicates

** Values are reported for crushed sands blended 50:50 with dune sands

Information obtained from Cole & Viljoen, 2001 and Cole, 2011

A graphical representation of the remaining extent of fine aggregate resources in the Greater Cape Town region can be viewed in Figures 6.7 and 6.8. These figures have been adapted from data collected by Dr. Cole, from the Council for Geoscience. Figure 6.7 represents the decrease in the availability of building sands as discussed, whereby the map represented on the left is an approximate representation of the extent of the building sands in 2001, compared with that of the map on the right which represents the building sand extent in 2011. The cause for the dramatic change between figures is not solely due to the rapid consumption of these resources available, but also due to the accessibility constraints that are notably more apparent in 2011 as perceived by Dr. Cole. This is most notable in the representation of the fluvial sands that occur along the Berg River. These sands were potentially accessible in 2001, whereas in 2011 they are almost entirely tied up in agricultural land use.

With reference to Figure 6.8, this map is a representation of the extent of the crushed aggregate resources available in the Greater Cape Town region. Although the delineation of these deposits are not vast in terms of number of hectares they cover, the extent of the materials available at each location is vast as these deposits extend to great depths below the surface of the earth, compared with that of the sand deposits, which only cover the surface.

The information represented in Figures 6.7 and 6.9 and Table 6.4, combined with the analysis discussed in this chapter, was compiled to form a conceptual map representing the potential distribution of future fine aggregate resources in the Greater Cape Town area. This representation is shown in Figure 6.9.

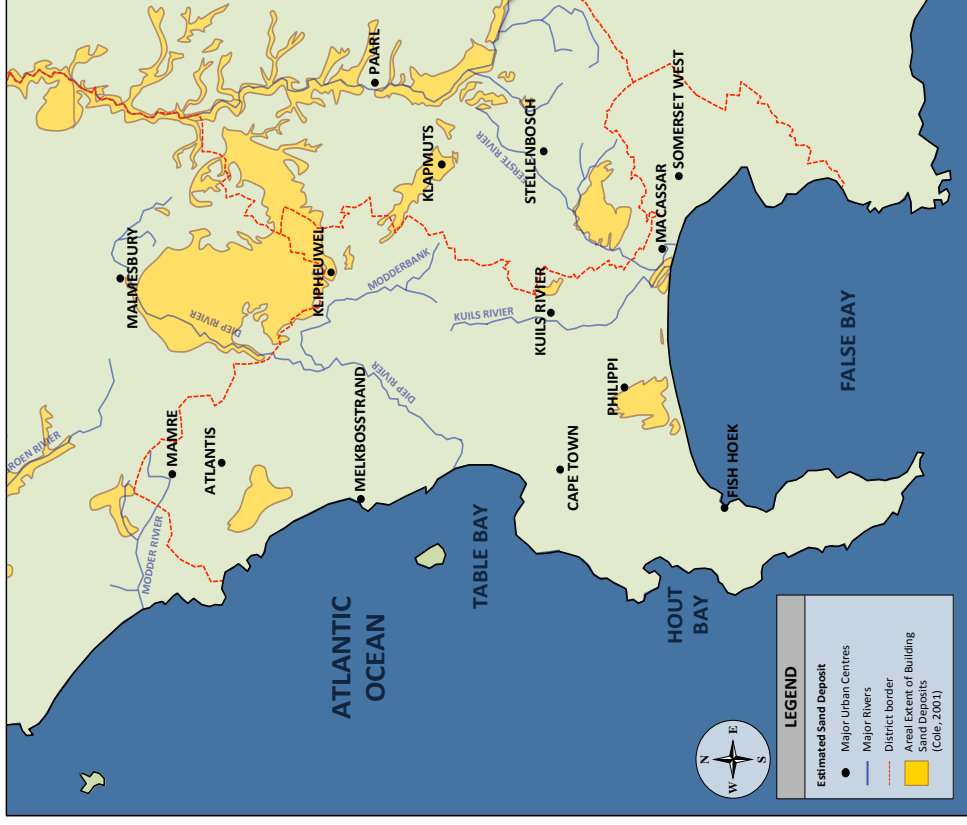
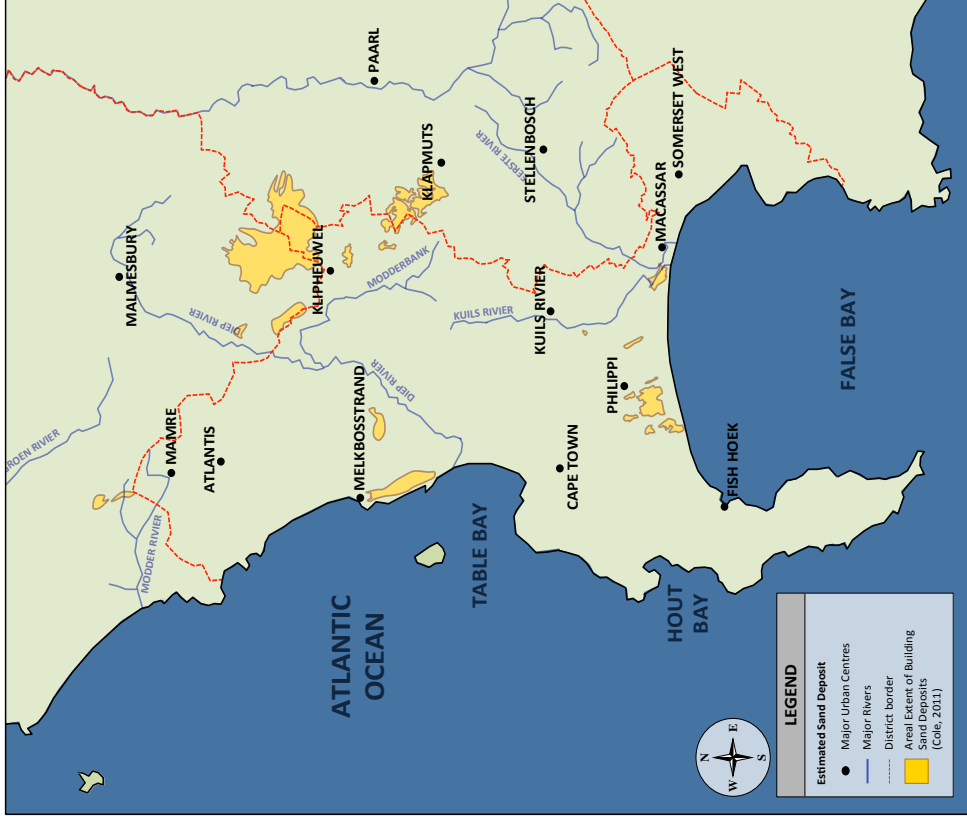


Figure 6.7 – Distribution of building sand deposits, Left: Estimated in 2001, Right: Estimated in 2011 (Information adapted from Cole, 2001 and Cole, 2011)⁵

⁵ Delineation of deposits in 2001 include all sand present, compared with delineation in 2011 which excludes all resources that is unable to be exploited.



Figure 6.8 – Distribution of hard rock deposits, appropriate for crushed aggregate use (Information adapted from Cole, 2011)

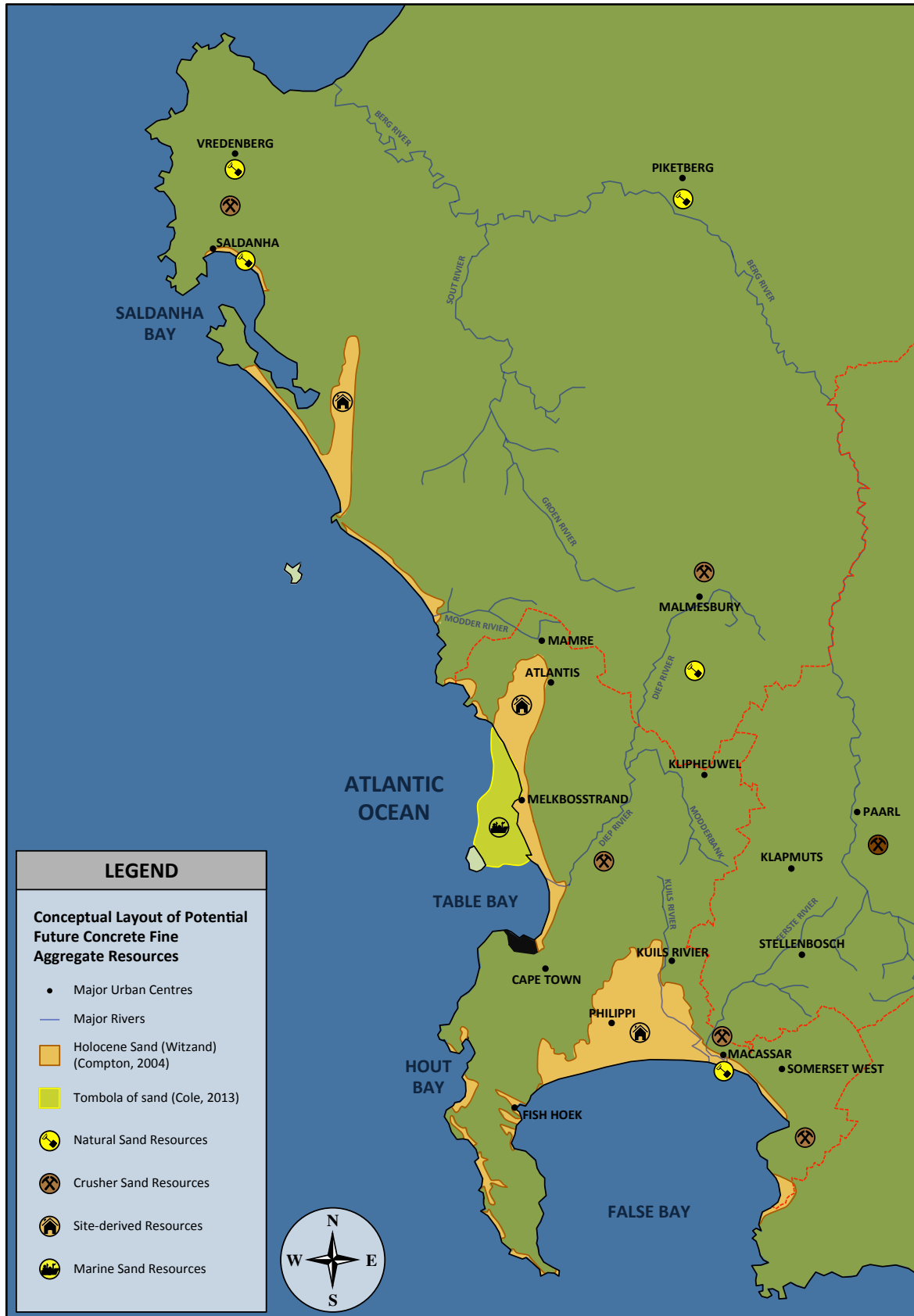


Figure 6.9 – Conceptual map representing the potential future concrete fine aggregate resources in the Greater Cape Town area

Section III
**Closure of Fine Aggregate Resources in
the Greater Cape Town Area**

Chapter 7

Conclusions

The subject of this dissertation addresses the long-term availability of fine aggregate resources in the Greater Cape Town area. This was undertaken to address the growing concern of the diminishing supply of current natural fine aggregate resources in the construction industry. The Greater Cape Town area was historically supplied by natural sands that were relatively cheap and readily available, due to the abundance of sand deposits in the region. However in recent years, these resources are being depleted and as the population has expanded dramatically, settlements have grown and the expansion of extraction facilities has not been possible. Alternative resources have become increasingly difficult to access due to environmental concerns, and zoning of the land for alternative end use.

This thesis set out to assess the validity of this concern, and determine the fine aggregate resources that are available in the Greater Cape Town area, which can be used to meet the future demand placed upon them. This research was undertaken in three phases, consisting of: (1) developing a comprehensive understanding of fine aggregates and their resources, (2) assessing the geological composition of the Greater Cape Town area and the available resources, and lastly (3) assessing the available resources through determining which can be used to meet future demands placed upon the industry.

Fundamentals of Fine Aggregate

Fine aggregates are rock fragments that have a dimension such that 90% of the particles are 0,075mm to 4,75mm in size. Typically their function is to provide the fill material in concrete, occupying the void spaces between the larger rock fragments, which form the aggregate matrix. In order for the rock material to be used for fine aggregate, it must fulfil this function in a manner that does not compromise the overall structural integrity of the concrete product. As a result, there are three fundamental properties that material requires:

- Particle size and distribution – the material should consist of a wide range of particle sizes between 0,075mm and 4,75mm in dimension. These particles should be well distributed in order to minimise the void space in the aggregate matrix.
- Mineralogical composition – the material should be chemically inert in composition, containing no material that may contribute towards a detrimental impact upon the concrete, and
- Particle shape and surface texture – the material used should preferably have a rounded particle shape and smooth surface texture in order to assist with aggregate packing and minimise the void space in the aggregate matrix.

Production of Fine Aggregate

In order for a resource to be exploited, it must be economically viable whilst ensuring that the least impact upon the environment is incurred. As a result the material properties, the potential profitability and the locality of a resource, are fundamental in the determination of potential exploitation.

Natural Fine Aggregate Resources

In the Greater Cape Town area, the naturally occurring fine aggregates have historically been the preferred resource used. They benefitted from their proximity to end use, easy extraction and relatively minor processing required, resulting in lower production costs, thus making a cost effective option. However, as a consequence they have been extensively worked, with much of these resources being depleted, and many deposits nearing the end of their reserve life.

A search for additional naturally occurring fine aggregates has revealed further undeveloped resources, however in most cases they suffer from accessibility issues. This is for a number of reasons, including: competing land uses, surface environmental prohibitions, or limited reserve size. Furthermore, the remainder are located at a considerable distance from the market, thus making them potentially uneconomic due to high transportation costs.

In addition to the onshore natural sand resources, substantial marine sands are known to exist. They are located within close proximity to the major ports in the region. However, their use as a resource is problematic, as their extraction needs to surmount the significant economic and environmental hurdles associated with the working of these types of deposits. These deficiencies are further exacerbated by the lack of expertise in the country, as currently no marine sands are being exploited for use in concrete, in South Africa.

In conclusion, the outlook of these resources for future development is limited. Therefore, the future demand will require to be met through the use of alternative aggregate resources.

Crushed Aggregates

Crushed fine aggregate resources have increasingly been used in the construction industry over the past few decades. As a resource, they previously suffered from the significantly greater processing required and the poorer quality product produced. This has consequently resulted in a higher cost for a material of lower quality compared with that of the naturally occurring sand resources. However, due to technological advances, which have improved the quality of the product produced at a lower cost, the market is gradually moving towards their use. This has resulted in them beginning to dominate the current aggregate market, with them accounting for approximately half of the aggregate used in the Greater Cape Town area.

The future development of these resources will continue, due to the vast extent of the remaining deposits located within relatively close proximity to the market. Furthermore, with the continual technological advances, the cost and quality of aggregates produced will become more comparable with the natural sand resources.

Site Derived Aggregates

The concept of site-derived and recycled material being use for aggregate is relatively novel, and thus will require more research and development to ensure that they are used more effectively. Its use in concrete, has limited applicability, however it could potentially be used for lower grade, local applications. For example, it could potentially be effective where sites are located on undeveloped sand deposits, such as in the low cost housing regions of the Greater Cape Town area.

The future development of these resources is important in assisting with the protection of the environment for future generations. Its function will most probably lend itself more towards use in fill applications. As a result, it is important that there is an increase in encouragement for the use of these materials.

Environmental Impact

Literature discusses one common principle that is suggested to help decrease the environmental impact of a resource, which refers to the quality of an aggregate. This quality is defined in terms of water demand, whereby an aggregate with a lower water demand is of superior quality, and is suggested to be preferable in reducing the environmental impact. This can be achieved through ensuring that the aggregate used is:

- Clean and inert in composition,
- Relatively rounded and smooth in particle shape and surface texture, and
- Possesses a grain size distribution that is within gradation limits, has a wide distribution and the particle sizes are evenly distributed.

These findings are defined according to embodied energy metric systems, which account for one aspect of the total environmental impact incurred. They do not account for the unquantifiable impacts, such as the effect incurred upon the surrounding settlements and local ecosystem. Consequently, it is extremely difficult to ascertain the full extent of the environmental impact associated with an aggregate resource. As a result, further research is required in order to quantify these impacts, or define monetary implications that will help to shape the decision-making as to which aggregate resources can be exploited.

Fine Aggregate Resources and the Construction Industry

Although the economics have not been the subject of this thesis, there is an apparent lack of price differential on rapidly depleting natural resources that have significant value to the construction industry. This is clearly a pricing anomaly in which the market is not recognising impending depletion. This could be potentially addressed through government policy, implementing taxation on use of virgin material, and dumping of waste products. These solutions additionally encourage the use of more environmentally attractive alternatives.

In addition, it is clear that there is a lack of communication present between the geological industry and the engineers and the civil engineering fraternity. This is clearly seen in the use of terminology, which has a different meaning for each community. Furthermore the lack of understanding by the geologists, of the engineer's range of requirements has meant that the search focus, on occasions, has been unnecessarily narrow. It is apparent that this has caused a misunderstanding in the civil engineering community as to the full extent of the remaining resources, making it difficult to establish a proper understanding of the problem.

Chapter 8

Recommendations for Future Research

The difficulty of the research conducted is that it dealt with so many different aspects of the fine aggregate resources in the Greater Cape Town area. Subsequently there was a limitation as to what could be discussed and to the degree with which it was investigated. As a result the findings have led to suggestions for future research topics.

Marine Sand Deposits

It has been identified that there are potentially substantial marine sand resources located off of the Cape coastline. This could potentially provide an alternative source for future use within the local construction industry. There are however, potential pitfalls that have also been identified. These include difficulties surrounding the extraction and processing of the sand deposits, the implications associated with greater CO₂ emissions and high costs caused by these procedures. In order for these resources to be exploited these concerns require appropriate solutions.

Site-derived Resources

In addition to the marine sands, another potential resource has been identified in the form of the existing sand deposits located in the Cape Flats. These deposits have been tied up through the urban land use, where the low-income settlements are located. In order to provide accommodation and facilities for these communities, there is a vast amount of low-cost housing built in the region. As a result of the founding conditions, potentially these resources that have been tied up can be used with respect to site-derived resources. This refers to the use of the excavated material derived on-site in the construction of the new building on the site. Providing there the excavated material is obtained from a sufficient depth, the inferred properties of the region are suggested to be suitable for use.

This resource should be investigated further in order to fully understand the true potential of this material as a resource. The investigation should not only determine whether the material that can be excavated on-site is suitable for use, but it should also consider the implication of the impact that it may have. This refers to problems such as flooding that may occur to the region being flat and potentially in a flood prone region.

Construction and Demolition Waste

Construction and Demolition Waste (C&DW) has suggested to be good source of aggregate material for future use within the industry. Initial research has concluded that its use as a fine aggregate resource in concrete is impractical, however there is potential for its use in other applications such as in fill material. Additionally, subsequent research suggests that it could be used in concrete provided that it is blended with another resource, improving the overall material properties. Consequently further research should be conducted into this field of study as to ascertain a more comprehensive understanding of its potential use and its subsequent limitations. This research is increasingly attractive due to the environmental benefits that this resource could potentially have.

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EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer (Zulpha.Geyer@uct.ac.za; Chem Eng Building, Ph 021 650 4791). Students must include a copy of the completed form with the thesis when it is submitted for examination.

Name of Principal Researcher/Student: *Benjamin Walker* Department: *Civil Engineering*

If a Student: *MSc Student* Degree: *Master of Civil Engineering (MCE) in Structures* Supervisor: *Prof. M.G. Alexander*

If a Research Contract indicate source of funding/sponsorship: *— (CoMSIRU)*

Research Project Title: *Addressing the Long Term Availability of Fine Aggregate Resources in the Cape Peninsula*

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?	YES	<input checked="" type="checkbox"/> NO
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	<input checked="" type="checkbox"/> YES	NO
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	YES	<input checked="" type="checkbox"/> NO
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	YES	<input checked="" type="checkbox"/> NO

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by:

	Full name and signature	Date
Principal Researcher/Student:		<i>22 April 2013</i>

This application is approved by:

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