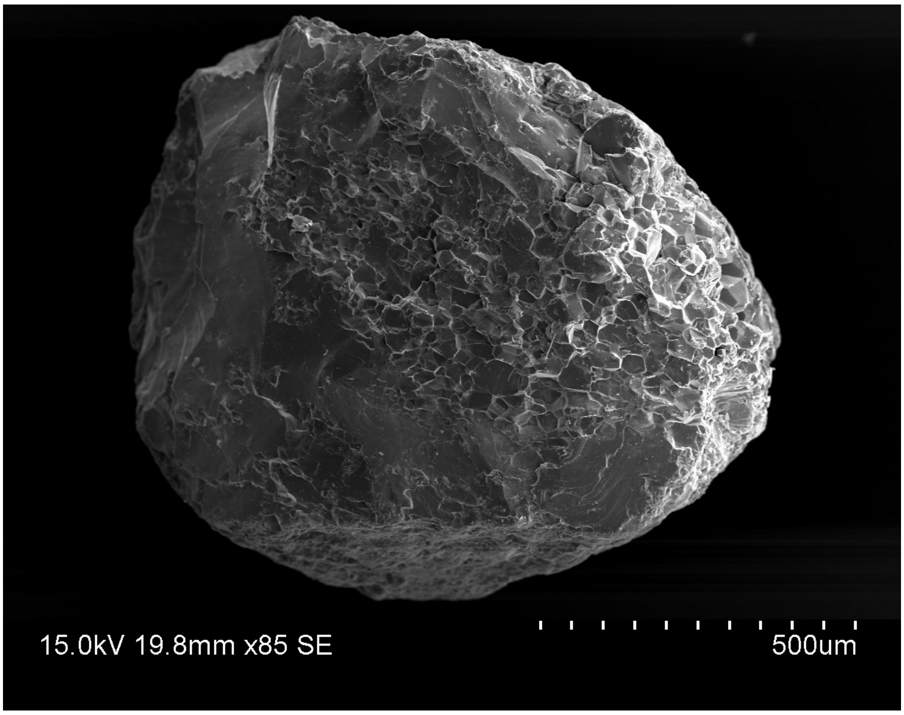
Identification and environmental interpretation of microtextures on quartz grains from aeolian sediments - Brattforsheden and Vittskövle, Sweden

Marijana Stevic

Dissertations in Geology at Lund University,
Bachelor's thesis, no 446
(15 hp/ECTS credits)



Department of Geology
Lund University
2015

Identification and environmental interpretation of microtextures on quartz grains from aeolian sediments - Brattforsheden and Vittskövle, Sweden

Bachelor’s thesis
Marijana Stevic

Department of Geology
Lund University
2015

Contents

Cover Picture: Quartz grain subjected to frost weathering. Photo: Marijana Stevic

Identification and environmental interpretation of microtextures on quartz grains from aeolian sediments - Brattforsheden and Vittskövle, Sweden

MARIJANA STEVIC

Stevic, M., 2015: Identification and environmental interpretation of microtextures on quartz grains from aeolian sediments - Brattforsheden and Vittskövle, Sweden. *Dissertations in Geology at Lund University*, No. 446, 31 pp. 15 hp (15 ECTS credits).

Abstract: Microtextures are micrometer-sized imprints on the surfaces of quartz grains and on grains with other mineralogical compositions. Quartz grains, which occur in most sedimentary environments, contain microtextures which are especially studied due to quartz unique mineralogical properties allowing for preservation of microtextures through different environments. In this study, microtextures are an important source for determining the sedimentary history of quartz grains from two localities in Sweden: Brattforsheden and Vittskövle. The sample from Brattforsheden has been collected from an aeolian inland dune and the sample from Vittskövle was collected from an aeolian coastal dune. To identify the variability and calculate the occurrences of different microtextures the samples have been studied under the scanning electron microscope (SEM). Frequencies produced from the two samples indicate that grains from Brattforsheden were affected by glacial environments in the past and more recently by aeolian settings compared to the sample from Vittskövle. The latter sediment sample was shaped by fluvial and aeolian conditions for a longer time. The environmental history for both samples has been concluded by comparing with previous publications where different microtextures have been proven to belong in specific environments.

Keywords: microtextures, quartz grains, aeolian sediments, occurrence, environmental interpretation, scanning electron microscope.

Supervisor: Edyta Kalińska-Nartiša

Subject: Quaternary Geology

Marijana Stevic, Department of Geology, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden. E-mail: nat12mst@student.lu.se

Identifiering och miljötolkning av mikrotexturer på kvartskorn från aeoliska sediment - Brattforsheden och Vittskövle, Sverige

MARIJANA STEVIC

Stevic, M., 2015: Identifiering och miljötolkning av mikrotexturer på kvartskorn från aeoliska sediment - Brattforsheden och Vittskövle, Sverige. *Examensarbeten i geologi vid Lunds universitet*, Nr. 446, 31 sid. 15 hp.

Sammanfattning: Mikrotexturer är mikrometerstora avtryck på kvartskornens ytor samt på korn med andra mineralogiska egenskaper. Kvartskorn, som förekommer i de flesta sedimentära miljöer, innehåller mikrotexturer som undersöks särskilt på grund av kvartsmineralets unika mineralogiska egenskaper som möjliggör bevarandet av mikrotexturer genom olika miljöer. I denna studien är mikrotexturer en viktig källa för att kunna bestämma den sedimentära depositionen av kvartskorn från två områden i Sverige, Brattforsheden och Vittskövle. Provet taget från Brattforsheden har tagits från en aeolisk land dyn och provet från Vittskövle är taget från en aeolisk strand dyn. För att identifiera variationen och beräkna förekomsten av olika mikrotexturer så har proverna studerats med hjälp av ett svepelektron mikroskop. Förekomsterna uträknade från de två proverna visar på att korn från Brattforsheden var påverkade av glaciala förhållanden förr och på senare tider av aeoliska förhållanden till skillnad från Vittskövle provet. Vittskövle provet påverkades av fluviala och aeoliska förhållanden en längre tid än provet från Brattforsheden. Miljöutvecklingen för båda proverna har konstanterats med hjälp av tidigare publicerad forskning där olika mikrotexturer har visat sig bildas i specifika miljöer.

Nyckelord: mikrotexturer, kvartskorn, aeoliska sediment, förekomst, miljötolkning, svepelektron mikroskop

Handledare: Edyta Kalińska-Nartiša

Ämnesinriktning: Kvartärgeologi

Marijana Stevic, Geologiska institutionen, Lunds universitet, Sölvegatan 12, 223 62 Lund, Sverige. E-post: nat12mst@student.lu.se

1 Introduction

The study of quartz grains from different geological settings has been proven to be an important and useful method for the reconstruction of past environments. The characteristic processes which have been crucial in the shaping and the development of "microtextures" or "surface textures" on quartz grains has been recognized and studied by several authors (e.g. Porter 1962; Krinsley & Funnell 1965; Krinsley & Donahue 1968; Margolis 1968; Whalley & Krinsley 1974; Mahaney & Kalm 2000; Mahaney et al. 2001; Mahaney 2002; Vos et al. 2014).

The introduction of the electron microscope in the early 20th century has improved the studies of grains from different settings. The discovery of micrometer sized imprints on quartz grains has become possible with the electron microscope (Bull 1981). Since the early recognitions of microtextures on the surfaces of quartz grains, many studies have been conducted to describe the origins as well as the shapes of new identified textures (e.g. Krinsley & Funnell 1965; Soutendam 1967; Krinsley & Donahue 1968; Margolis 1968; Margolis & Krinlsley 1971; Whalley & Krinsley 1974).

The later development of the scanning electron microscope in the 1960's which made it possible to study grains in higher resolutions, has only helped improving analysis of microtextures (Bull 1981). Different methods of studying the fine scaled microtextures and the importance of applying the best method when studying grains has been investigated by Soutendam (1967).

This project will focus on the identification of microtextures by using similar methods as has already been used by different authors. The main aim is to identify the quartz grains microtextures by comparing obtained results with other studies. The frequencies of microtextures are calculated on quartz grains from two aeolian localities in Sweden, Brattforsheden and Vittskövle (Fig. 1).

The research steps and aims of this project can be described as follows:

1. Identifying different microtextures on quartz grains from two samples collected separately from aeolian sediments at Brattforsheden and Vittskövle, Sweden.
2. Calculating the frequency of microtextures found on quartz grains from the two different samples.
3. Correlating the types of microtextures identified with the source environments of the two samples and comparing the results with previous publications and studies.
4. And lastly to obtain a better understanding of the common techniques and methods used to study microtextures on quartz grains.

2 Sample locations

The samples investigated come from two different localities in Sweden (Fig. 1). The Brattforsheden sample has been collected from the southwestern part of Sweden and is termed "061320" by Alexanderson & Fabel (2015). The sample belongs to the Källorna 2 aeolian dune. The second aeolian dune sample, was collected from the southern parts of the Kristianstad plain (Skåne) in the Vittskövle area and is termed "V 0.2" (Kalińska-Nartiša, pers. comm.).

The aeolian dune samples can be divided in two sub-environments: inland and costal dune (samples "061320" and "V 0.2", respectively, Alexanderson & Fabel 2015; Kalińska-Nartiša, pers. comm).

The Brattforsheden area is characterized by glacifluvial deposits covered by extensive inland dunes (Alexanderson & Fabel 2015). Dunes found in the area have mostly crescentic and parabolic shapes and the dune sizes are ranged from smaller to larger with the larger ones being confined to the northwestern and southestern parts of Lake Alstern (Alexanderson & Fabel 2015). The coordinates for the "061320" sample collected at Källorna 2 are 59.60720° N and 13.88415° E (Alexanderson & Fabel 2015).

The dune investigated is located on a delta plain. Otherwise the dune was made up of "well-sorted, vaguely laminated fine-medium sand" and sample "061320" was dated to 10.3±0.6 ka (Alexanderson & Fabel 2015). The aeolian deposits in the area after the last glaciation have been affected by different periods of aeolian sedimentation with periods of less "aeolian activity" being caused by vegetation during the Holocene and later increased activity likely being caused by humans in different locations (Alexanderson & Fabel 2015).

The "V 0.2" Vittskövle sample was collected from an aeolian dune with no noticeable laminations and mostly massive sand making up most of the layer. The coordinates for the "V 0.2" sample are 55.865468° N

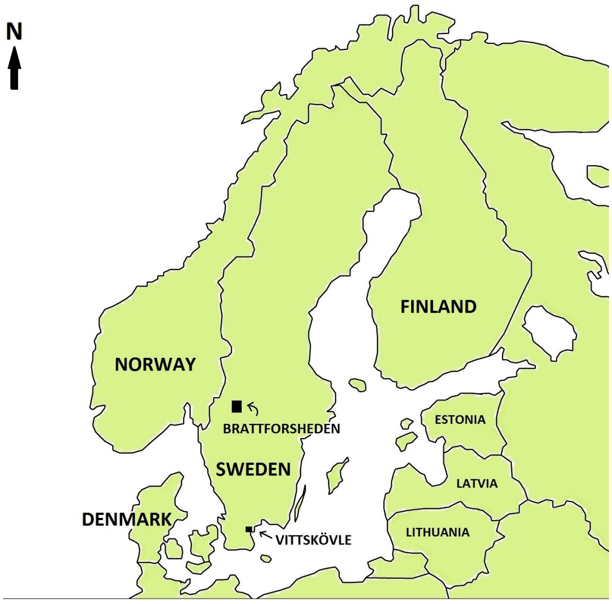


Fig. 1. A map of northern Europe with the locations of Brattforsheden and Vittskövle marked out with squares in Sweden.

and 14.167283° E and the age for this sample has not yet been dated (Kalińska-Nartiša, pers. comm.).

Although the aeolian sediments are of unknown age, the dunes deposited on the Kristianstad plain are regarded as younger deposits resulting from human activity in most areas (Agrell 1981). Dune sands of the Vittskövle site contain coarser grains that can be explained by the short transporting distances (Agrell 1981).

Additionally, the Vittskövle dune is regarded as a coastal aeolian dune, representing a different setting than the Brattforsheden sample. However, Agrell (1981) refers to an inland dune situated in close proximity to coastal deposits in this area. The Vittskövle dune sediments are homogeneous and further symmetrical form support the west-northwest wind direction (Agrell 1981). Lastly, the Vittskövle dune started to form due to human-made obstacles in the area and recently is covered by grass and pine trees (Agrell 1981).

3 Previous studies and microtextures

Numerous studies have been conducted by several authors to correlate certain microtextures to their original environment and the processes involved in their formation. To be able to recognize microtextures in the samples studied in this project, some understanding of different microtextures and how they are defined was needed. The names of the microtextures and the terminology associated with them are primarily adopted from Mahaney (2002) and Vos et al. (2014).

Quartz grains are used for the study of microtextures mainly because quartz is a mineral which occurs in almost all environments and has properties that allow to store and preserve structures through different generations of weathering (Mahaney 2002). This is mainly seen in quartz grains which have been transported through glacial, aeolian and fluvial environments with diagenetic processes and mechanical imprints often leaving microtextures which indicate that they have been created on different occasions (Mahaney 2002). This means that recent textures can overprint older ones when grains are transported into new environments (Krinsley & Funnell 1965; Krinsley & Donahue 1968; Mahaney 2002).

Occasionally, parts of quartz grains with depressions might not be as affected by overprinting as other grains and some grains might indicate lesser amounts of overprinting than others (Krinsley & Funnell 1965). An overview of the microtextures identified in this project and references to the relevant studies having previously described them is found in Table 1.

3.1 Grain outline

The outline of the quartz grains are defined as angular, subangular and rounded (Vos et al. 2014). These terms are used to determine the shapes of the grains, the approximate time and distance a grain has been transported (Costa et al. 2013; Vos et al. 2014).

The connection between the presence of microtextures and the distance-time factor together with the sizes of the grains has been studied by Costa et al. (2013). Grains with edges which have been fractured and underwent very little transportation are regarded as angular grains (Mahaney 2002; Vos et al. 2014).

Environments with deposits which have been affected mainly by glaciation often exhibit grains with a greater angularity, which is indicated by grains from (morainic) tills (Mahaney et al. 1996) and sediments deposited together with dropstones and ice-rafted debris (Helland & Holmes 1997).

Rounded grains are present in aeolian environments where grains are subjected to saltation and eventually causing the grains to form a more rounded shape (Mahaney 2002). The roundness of the grains has also proven to depend on the amount of redeposition (Kleesment 2009). Finally, subangular grains are described as grains with “blunt edges” (Vos et al. 2014) being transported shorter distances and deposited faster (Madhavaraju et al. 2009). Subrounded grains are thought to be formed in fluvial environments (Madhavaraju et al. 2009).

3.2 Mechanical features

Among mechanical microtextures, conchoidal fractures are described by Mahaney (2002) as “a smooth curved fracture, with a ribbed appearance, similar to the curve of a conch or seashell”, but additionally, their different sizes are mentioned by Vos et al. (2014). Krinsley & Funnell (1965) describe “conchoidal breakage-patterns” with different sizes that are a result of grains having different widths and lengths in sediments from glacial environments.

Radial fractures are described as fractures with linear shapes radiating from a focused point which has been created by impact on a small area of the grain and is common on grains from glacial environments (Mahaney 2002). Radial fractures have also been found on grains from supraglacial sediments by Mahaney et al. (1991). “Blocky conchoidal breakage-patterns” are mentioned by Krinsley & Funnell (1965) and Krinsley & Donahue (1968) and described as features with a more constant size and occurring in aeolian and littoral environments with “regular” sides.

Arcuate steps (term used by Vos et al. 2014 and Moral Cardona et al. 1997) are mentioned as “Arc-shaped steps” by Krinsley & Funnell (1965) and Krinsley & Donahue (1968) and thought to be

Table 1. A list of microtextures searched for including some microtextures which were later identified in SEM. The references listed are previous works which describe or mentioned the different microtextures listed. Microtextures that are identified in the samples from Vittskövle and Brattforsheden are marked as “yes” for found at least in one of the samples or “no” if not identified at all.

Microtextures/features	**Identified**	**References**
Shape of grain:		
Angular	yes	(Mahaney et al. 1996; Helland & Holmes 1997; Mahaney 2002; Costa et al. 2013; Vos et al. 2014)
Subangular	yes	(Madhavaraju et al. 2009; Vos et al. 2014)
Rounded	yes	(Mahaney 2002; Kleesment 2009)
Mechanical:		
Conchoidal	yes	(Krinsley & Funnell 1965; Krinsley & Donahue 1968; Mahaney 2002; Vos et al 2014)
Arcuate steps	yes	(Krinsley & Funnell 1965; Krinsley & Donahue 1968; Whalley & Krinsley 1974; Moral Cardona et al. 1997; Mahaney 2002; Vos et al. 2014)
Straight steps	yes	(Mahaney 2002; Vos et al. 2014)
Subparallel linear fractures	yes	(Mahaney et al. 1996; Mahaney 2002)
Parallel striations	yes	(Krinsley & Funnell 1965)
Graded arcs	yes	(Krinsley & Funnell 1965; Krinsley & Donahue 1968)
Meandering ridges	yes	(Krinsley & Funnell 1965; Krinsley & Donahue 1968)
Flat cleavage surfaces	yes	(Whalley & Krinsley 1974; Mahaney et al. 1991; Mahaney 2002; Vos et al. 2014)
Straight/curved grooves	yes	(Krinsley & Funnell 1965; Krinsley & Donahue 1968; Mahaney 2002)
V-shaped cracks	yes	(Krinsley & Funnell 1965; Krinsley & Donahue 1968 Mahaney 2002)
Upturned plates	yes	(Margolis & Krinsley 1971; Whalley & Krinsley 1974; Mahaney et al 1991; Mahaney 2002)
Crescentic marks	yes	(Vos et al. 2014)
Bulbous edges	yes	(Mahaney 2002)
Abraded edges	yes	Mycielska-Dowgiałło 1993; Helland et al. 1997; Immonen 2013)
Chemical:		
Imbricated grinding features	no	(Krinsley & Funnell 1965; Krinsley & Donahue 1968; Madhavaraju et al 2009; Vos et al. 2014)
Oriented etch pits	yes	(Margolis 1968; Manker & Ponder 1978; Vos et al. 2014)
Solution pits	yes	(Madhavaraju et al 2009; Vos et al. 2014)
Solution crevasses	yes	(Madhavaraju et al 2009; Vos et al. 2014)
Crystalline overgrowths	yes	(Krinsley & Funnell 1965; Waugh 1970; Margolis & Krinsley 1971; Mahaney et al. 1991; Woronko & Hoch 2011; Vos et al. 2014)
Precipitation	yes	(Whalley & Krinsley 1974; Mahaney 2002)
Breakage blocks	yes	(Helland et al. 1997; Van Hoesen & Orndorff 2004)
Imbricated blocks	yes	(Helland et al. 1997; Van Hoesen & Orndorff 2004)
Silica globules	no	(Madhavaraju et al. 2009; Vos et al. 2014)
Silica pellicles	no	(Madhavaraju et al. 2009; Vos et al. 2014)
Silica flowers	yes	(Madhavaraju et al. 2009; Vos et al. 2014)
Relief:		
Low relief	yes	(Mahaney 2002; Vos et al. 2014)
Medium relief	yes	(Mahaney 2002; Vos et al. 2014)
High relief	yes	(Krinsley & Funnell 1965; Krinsley & Donahue 1968; Mahaney 2002; Vos et al. 2014)
Others:		
Elongated depressions, depressions	yes	(Mahaney 2002; Vos et al. 2014)
Adhering particles	yes	(Mahaney 2002; Vos et al. 2014)
Dulled surfaces	yes	(Widdowson 1997)
Vug	yes	(Mahaney 2002)
Radial fractures	yes	(Mahaney et al. 1991; Mahaney 2002)

"percussion fractures". These steps are also mentioned by Whalley & Krinsley (1974) as "Arc-steps" and described as a "series of concentric stepped (usually) arcs", being associated with conchoidal fractures and having a mostly "regular" spacing in between.

Mahaney (2002) described these steps as "deep tears or breaks in the mineral fabric caused by impact". Moral Cardona et al. (1997) referred to them as developed together with conchoidal fractures. Subsequently, straight steps (Vos et al. 2014) or linear steps are described by Mahaney (2002) as "deep tears or breaks in the grain surface".

These textures are similar to subparallel linear fractures which are described as fractures which "grade into conchoidal fractures" by Mahaney (2002). Subparallel linear fractures are present on grains from glacial environments and caused by mechanical processes (Mahaney et al. 1996). Straight steps are explained as "semi-parallel steps" by Krinsley & Funnell (1965) and Krinsley & Donahue (1968) and are described to be related to shear stress.

Parallel striations were first described by Krinsley & Funnell (1965), as sharp edges leaving marks as they moved across other grains in glacial environments. Graded arcs defined as "fan-shaped patterns" (Krinsley & Donahue 1968) which are defined as "percussion fractures" and resemble conchoidal fractures but with arcs that "occur in concentric series" (Krinsley & Funnell 1965).

Graded arcs are present in aeolian environments, tropical deserts and coastal dune environments (Krinsley & Donahue 1968). Meandering ridges are described as features formed when a few conchoidal fractures (with the size of ca. 15 µm) are intersecting and occurs mainly in aeolian environments (Krinsley & Funnell 1965; Krinsley & Donahue 1968).

Imbricated grinding features are mentioned in the review by Vos et al. (2014) and termed as "imbricated breakage blocks" by Krinsley and Funnell (1965) and Krinsley & Donahue (1968). These features are defined as "a series of steeply dipping hogback ridges" (Krinsley & Funnell 1965; Krinsley & Donahue 1968). Imbricated grinding features are not illustrated in this project but can be seen in Madhavaraju et al. (2009).

Flat cleavage surfaces (Vos et al. 2014) are described by Mahaney (2002) as clean fractures with mostly no other smaller fractures present on this flat surface which can also be somewhat curved but not rounded (also described by Mahaney et al. 1991). Whalley & Krinsley (1974) described these features as a "facet", a flat area which is most likely caused by breakage along cleavage planes.

Straight and curved grooves with lengths of approximately 2–15 µm are characteristic of high energy littoral environments (Krinsley & Donahue 1968). The causes of these features are due to "grain-to-grain collisions" with a "rocking" or quick motion (Krinsley & Funnell 1965; Krinsley & Donahue 1968). Mahaney (2002) described curved grooves as elongated features resulting from a grain having scoured on the surface of another grain in glacial environments, while straight grooves are described as being caused by greater forces scouring into the surface of a grain with little resistance.

V-shaped cracks result from "grain-to-grain collisions" in subaqueous environments (Krinsley & Funnell 1965). These textures are triangular in shape and mostly found in littoral environments (with higher energies) where they are non-oriented (Krinsley & Donahue 1968). The sizes of the cracks depend on the energy available in the environment (with higher energy causing larger and deeper cracks up to 5 µm) and they might be created on different occasions, causing V-shapes with different orientations (Krinsley & Donahue 1968).

Upturned plates are described by Mahaney (2002) as a surface affected by mechanical processes which have caused the plates on the surface to become slightly "loose". Whalley & Krinsley (1974) describe these features as "small plates protruding from the surface". Margolis & Krinsley (1971) examined grains with dipping planes which are oriented according to the crystal planes of quartz. Upturned plates are also present in costal dune environments and sands deposited in periglacial environments (Margolis & Krinsley 1971; Mahaney et al. 1991).

Crescentic marks (mechanical) are mentioned in the review by Vos et al. (2014). Bulbous edges are described by Mahaney (2002) as "rounded grain edges in the shape of a parabolic curve". Abraded edges are pointed out in illustrations by Immonen (2013) as well as by Mycielska-Dowgiałło (1993) where Swedish samples exhibited worn edges caused by aeolian transportation. These mechanical features are also found in subaqueously transported samples which were studied by Helland et al. (1997).

3.3 Chemical features

Among the textures of chemical origin, oriented etch pits are described as features developed mostly in marine environments where the sea water affects the grains by dissolution (Margolis 1968). These features are thought to be the result of flaws in the crystal lattice of quartz grains and they can also be noticed on grains from rivers and lakes (Margolis 1968). Oriented etch pits are triangular (Manker & Ponder 1978) and as the name says they are oriented and aligned with the crystal planes with their sizes being 1–30 µm (Vos et al. 2014).

Solution pits (Vos et al. 2014) are referred to as chemical features with circular shapes created by diagenetic processes by dissolution. Solution crevasses are similar to solution pits and are described as cracks developed by dissolution (Vos et al 2014). Solution pits and solution crevasses are recognized as dissolutional features on grains from beach sediments by Madhavaraju et al. (2009). Silica globules, silica pellicles and silica flowers are mentioned and illustrated in Vos et al. (2014) and in Madhavaraju et al. (2009).

Crystalline overgrowths are mentioned by Vos et al. (2014) as precipitation of silica forming subhedral or euhedral overgrowths. Krinsley & Funnell (1965) described these as “prismatic patterns” with elongated prisms were caused by recrystallization on grains. Waugh (1970) refers to different shapes of overgrowths on quartz grains found in aeolian dune sediments deposited in arid desert environments.

Overgrowths on quartz have also been recorded on sand grains from cross-bedded dunes by Margolis & Krinsley (1971) and from supraglacial debris by Mahaney et al. (1991).

Precipitation is regarded as coating features with precipitated silica or e.g. carbonates on grains which is the result of diagenesis (Mahaney 2002). Precipitation with silica cemented particles on the surfaces of quartz grains has been noticed on grains from glacial environments by Whalley & Krinsley (1974).

Breakage blocks and imbricated blocks can be seen in Helland et al. (1997) and Van Hoesen & Orndorff (2004) and were used to identify these features in this project. Dulled surfaces are produced on grains in diagenetic environments and caused by solution of a surface with silica which results in the surface having a dulled appearance (Widdowson 1997).

3.4 Relief

The relief of grains can be divided into low, medium and high (Mahaney 2002; Vos et al. 2014). Low relief is recognized as surfaces being smooth with near to no topographic irregularities while medium relief indicates a surface being affected by collisions or weathering processes (diagenetic environments) resulting in a somewhat irregular surface (Mahaney 2002; Vos et al. 2014).

High relief is recognized on a grain with a highly irregular surface which mostly belongs in a glacial environment where glacial grinding and crushing has affected the grains (Krinsley & Funnell 1965; Krinsley & Donahue 1968; Mahaney 2002; Vos et al. 2014).

3.5 Other features

Elongated depressions or depressions are described as features with a diameter of ca. 250 µm and related to grains with bulbous edges (Mahaney 2002). They often occur between two ridges or as concavities and are formed in aeolian environments with high energies where saltating grains collide with each other (Mahaney 2002; Vos et al. 2014).

Adhering particles are described as particles which are “adhering” on the surfaces of grains (Mahaney 2002). Adhering particles found in abundance are typical for glacial and aeolian grains with the particles originating from other grains or from the same grain studied (Mahaney 2002; Vos et al 2014).

Scaling features seen in the illustrations by Vos et al. (2014) were used when searching for these features in both samples studied.

4 Methods

The identification of microtextures required studying of literature before sample preparation and analysis by scanning electron microscopy (SEM). This was done to ensure that samples were prepared so that mostly representative grains of the two sub-environments would be observed and analyzed. Previous publications with identifications and descriptions of different environments were an important asset in understanding and identifying similar microtextures in this project.

The methodology used to prepare and study samples under the scanning electron microscope (SEM) was based mainly on the methods presented in the atlas by Mahaney (2002), the review by Vos et al. (2014) and a study on dunes in Finland by Kotilainen (2004). Sampling of the aeolian dune sample at the Källorna 2 (Brattforsheden) was conducted by Alexanderson in 2006. The Vittskövle sample was sampled from a coastal dune by Kalińska-Nartiša (pers. comm.) in 2014. Further details of the preparation of the samples and SEM work are described as follows.

4.1 Preparation of samples

Samples collected from the field were primarily washed and sieved before individual quartz grains were picked out under the light microscope. The sample from Vittskövle was dry sieved and rinsed with distilled water approximately six times before being dried in room-temperature. No additional treatment was needed to remove organic materials in the sample since they did not exhibit noteworthy amounts of organic matter that could not be removed by simply rinsing the grains (Kalińska-Nartiša, pers. comm.).

Grains with the diameter of 0.5–1.0 mm from the Vittskövle sample was chosen for observations under the light microscope. The largest quartz grains were then carefully picked under the light microscope to assure that the diameter was larger than ca. 0.7 mm and closer to 1 mm. This is so that the sizes of the grains from both samples would be fairly similar though they were not picked out from same ranges in size. 15 quartz grains with similar colors or tones were picked randomly and care was taken to assure that the grains were mainly consisting of quartz and not feldspars.

The grains with diameters ranging from 0.8 to 1.0 mm were picked from the Brattforsheden sample. The first 15 quartz grains were chosen out of the sample though there was no need to pick out the largest grains when the diameter of 0.8 mm was the minimum. 15 grains from each sample is considered to be sufficient for this study considering the time needed for browsing and recognizing microtextures.

In Vos et al. (2014) and Kotilainen (2004) the number of 15 grains were considered good enough for identifying most of the microtextures present and the careful separation of grains with similar diameters was suggested by Mahaney (2002) and by Vos et al.

(2014). Vos et al. (2014) also stated that grains ranging from 100 µm–2 mm would give representative results when evaluating the presence of different microtextures.

The grains collected from of the Vittskövle and Brattforsheden samples were placed carefully on one holder (stub) for each sample. A double sticky tape was used to place the grains picked, making sure the grains would not be lost further on. A tiny piece of paper was placed in the corners of the holders after which the grains were placed in an organized order to facilitate orientation when browsing under the SEM (Mahaney 2002; Kotilainen 2004; Vos et al. 2014).

The two holders were coated with gold approximately for 195 seconds in a gold-sputtering device under vaccumized conditions. This was done to ensure that the electrical charging which appears on the surface would be low while protecting the grains when browsing under the SEM (Vos et al. 2014). The pictures of the grains are considered to be clearer and the microtextures present would not be obscured by the coating (Kotilainen 2004; Vos et al. 2014).

4.2 Identification of microtextures by SEM

The prepared holders with a total of 30 grains were marked with the names of the samples. 15 random quartz grains from each sample were browsed under the SEM. The grains were studied by using the Hitachi S-3400 N Scanning Electron Microscope at the Department of Geology, Lund University.

The holders of the grains were carefully treated using rubber gloves to prevent losing grains or dirtying the samples by leaving fingerprints. Prior to analyzing the grains, different settings optimal for browsing were adjusted according to prewritten manuals used in the SEM lab. The voltage during the operation of the device was set to 15 kV throughout the analysis. The magnification used to observe textures was constantly changed between 20x to approximately 4000x though the image would become blurred if the magnification was increased beyond 4000x.

When analyzing grains, a chart or log with a number of 37 microtextures was used to mark out the presence of certain microtextures when identified on a single grain. To minimize the eventual overlooking of certain textures due to the possibility of textures not fitting into the environments which the grains were sampled from, an objective way of browsing was adopted by expecting each of the textures being present until otherwise was noted. In other words, all of the microtextures listed in the chart were searched for in each of the 30 grains studied.

Before browsing each of the grains, a drawing of the holder and the positioning of the grains was done. Each grain was given a number so that notes for the grains could be connected to the right grain when continuing to study the rest of the sample. Photos were taken subsequently while browsing and primarily photos of the whole grain and textures found were taken. The magnification was kept approximately between 100x and 2000x when taking pictures though the textures on the photos would not be easily recognized with higher magnifications. Images produced were in black and white and the frame time was 20 seconds.

The atlas by Mahaney (2002) and both older and more recent publications were used to identify and describe the different microtextures found on the quartz grains from the two aeolian samples (e.g. Krinsley & Funnell 1965; Krinsley & Donahue 1968; Margolis 1968; Whalley & Krinsley 1974; Manker & Ponder 1978; Helland et al. 1997; Madhavaraju et al. 2009; Immonen 2013; Vos et al. 2014).

The different findings were then discussed by comparing the results with the microtextures already discovered and described in published literature. The frequency of the occurrence of single microtextures was then calculated by counting the number of times a microtexture was identified on the grains in each sample. A table with the frequencies in percentages was then constructed to show which microtextures were the most commonly occurring in the samples. A histogram with the frequencies was further constructed for the samples to facilitate the understanding of the occurrence. The way of presenting the results was primarily based on Mahaney (2002), Immonen (2013), Immonen et al. (2014) and Vos et al. (2014).

5 Results

The results presented are based on the interpretation of SEM photographs and grains studied under the SEM. Microtextures identified from the two aeolian samples are presented and the textures are connected with the relevant figures. The microtextures are listed in Table 2, together with the calculated frequencies for each of the microtextures identified in sample V 0.2 and 061320, respectively. Reference is made to the figures presented below in Table 2 to the relevant microtextures.

5.1 Vittskövle sample (V 0.2)

A frequency diagram of the occurrences of different microtextures in percentages for this sample can be seen in Fig. 15.

The Vittskövle sample consists of primarily 80% of subangular grains (Fig. 2A). 60% of the grains exhibited abraded edges and 73% precipitation features. The chemical features here are mostly represented by precipitation and solution features on the grains. Precipitation has been noticed in depressions (Fig. 2B) but also on the grains surfaces in general (Fig. 2C). Dulled surfaces were seen on 53% of the grains examined (Fig. 2B and D). They appeared mostly on grains with smooth surfaces which seemed to have been influenced by water.

Traces of large breakage blocks were seen on 27% of the grains and 33% had smaller breakage blocks (Fig. 2E) with otherwise abraded edges and groove-

Table 2. Different microtextures studied on quartz grains from sample V 0.2 (Vittskövle) and 061320 (Brattforsheden). The results of the occurrences of each microtexture in both samples are presented as numbers equal to different values in percentages: 1 = 5–<25%, 2 = 25–<50%, 3 = 50–<75%, 4 = >=75% . No number in the box is equal to that microtexture not being present in the sample. "?" indicates that the presence of a microtexture is not certain. The names of the microtextures presented in the table are similar to those presented in Table 1. with references. The frequencies can be seen in detail for sample V 0.2 in Fig. 15 and for sample 061320 in Fig. 16.

	Microtextures	**V 0.2**	**061320**	**Figures**
Mechanical	1. Angular	1	1	Fig. 6F, 13B, 13C
	2. Subangular	4	4	Fig. 2A, 6A, 7F, 9A, 10B
	3. Rounded	1		
	4. Conchoidal (<10 µm)	2	3	
	5. Conchoidal (<100 µm)	4	4	Fig. 3E, 3F, 9E, 14A, 14E
	6. Conchoidal (>100 µm)	3	3	Fig. 3C, 9E, 12D
	7. Arcuate steps	3	4	Fig. 2C, 3C, 3F, 5B, 9E, 9F, 12D, 13A
	8. Straight steps	4	3	Fig. 2C, 5F, 9E
	9. Meandering ridges	2	3	Fig. 3E, 4A
	10. Flat cleavage surfaces		2	Fig. 9A, 9B, 11D
	11. Graded arcs	1		Fig. 3A, 3B
	12. V-shaped cracks	4	1	Fig. 3D, 12E
	13. Straight/curved grooves	4	4	Fig. 2E, 4A, 5F, 6A, 6B, 9C, 9D, 12C, 14D
	14. Upturned plates	?	2	Fig. 10A, 10C, 14B, 14E, 14F
	15. Crescentic marks	3	1	Fig. 4D, 4E, 6D
	16. Bulbous edges	4	1	Fig. 4B, 8D
	17. Abraded edges	3	2	Fig. 3C, 4A, 6B, 7F, 9E, 14C
	18. Parallel striations	3	2	Fig. 10D
	19. Imbricated grinding features	?	?	
Chemical	20. Oriented etch pits	2	1	Fig. 5A, 5B, 5C, 5E, 7C, 7D, 7E, 8C, 13D
	21. Solution pits	3	2	Fig. 4D, 12A, 13F
	22. Solution crevasses	2		Fig. 2F
	23. Crystalline overgrowths	2	1	Fig. 5F, 8A, 8B
	24. Precipitation	3	3	Fig. 4C, 4E, 5A, 5C, 5D, 9A
	25. Breakage blocks small	2	2	Fig. 2E
	26. Breakage blocks large	2	2	
Both	27. Low relief	1	1	Fig. 4B, 6A, 8D
	28. Medium relief	4	3	Fig. 2A, 4A, 7F, 10B, 10E
	29. High relief	1	2	Fig. 6F, 9A, 13B
	30. Elongated depressions	3	2	Fig. 4A
	31. Adhering particles	4	4	Fig. 3B, 3F, 4E, 14E
	32. Depressions	3	2	Fig. 4B, 4C
	33. Dulled surfaces	3		Fig. 2B, 2D, 4A

like features representing the grains. Most of the grains seem to exhibit different generations of textures with mechanical features often having preceded chemical ones. Some grains have fractures or depressions which are being covered by adhering particles and precipitation of silica. On some grains, the precipitated silica obscures the underlying mechanical features by covering them with sheets of silica. Solution crevasses were observed on a 27% of the grains, occurring here as narrow scars less than 50 µm in lenght on the surfaces (Fig. 2F).

Graded arcs were scarcely seen on grains in this sample with 20% occurrence (Fig. 3A). Crescentic marks (60%) were identified occasionally in smaller areas on slightly more reworked grains (Fig. 3B). The majority of the grains (93%) had conchoidal fractures which were smaller than 100 µm and the presence of conchoidal fractures larger than 100 µm (67%) were slightly less common (Fig. 3C). Small V-shaped cracks were found on 87% of the grains (with the fea-

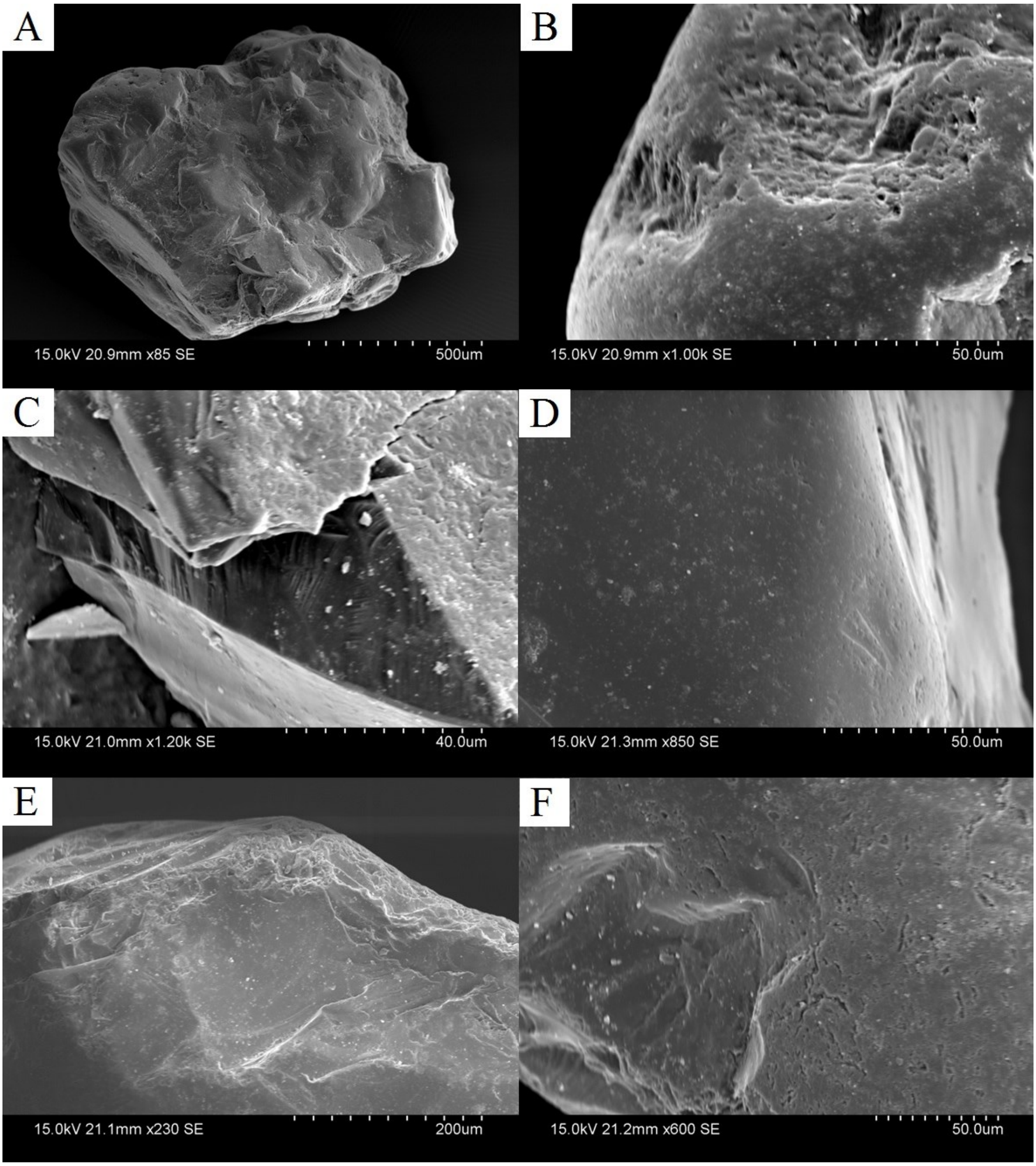


Fig. 2. (Sample V 0.2) A. Subangular grain, sample V 0.2. B. Dulled surface on the grain outside depressions. C. Arcuate steps and straight steps in a fresh fracture (center) and precipitation on the surface (right). A conchoidal fracture is seen below the fresh fracture. D. Dulled surface. E. Small breakage blocks are present on the top edge towards right. Straight grooves can be seen on the upper left part of the grain with a conchoidal fracture in the center of the image. F. Solution crevasses can be seen to the right on the surface above the fracture.

tures often being smaller than 20 µm and covering small areas of the grain's surface which is seen in Fig. 3D. Meandering ridges occurred on 33% of the grains and were occasionally found on grains together with conchoidal fractures (Fig. 3E). Arcuate steps which occur on 73% of the grains have also been seen on grains together with conchoidal fractures (Fig. 3F).

A subrounded grain with dulled surfaces, grooves, meandering ridges and conchoidal fractures can be seen in Fig. 4A. Another abraded grain with subrounded outline can be seen in Fig. 4B with bulbous edges characterizing most of the grains surface. The surfaces seen on Fig. 4C–F and Fig. 5A–D have been affected by precipitation of silica and some dissolution. Fig. 4D shows a surface with precipitation together with crescentic marks, solution pits and small

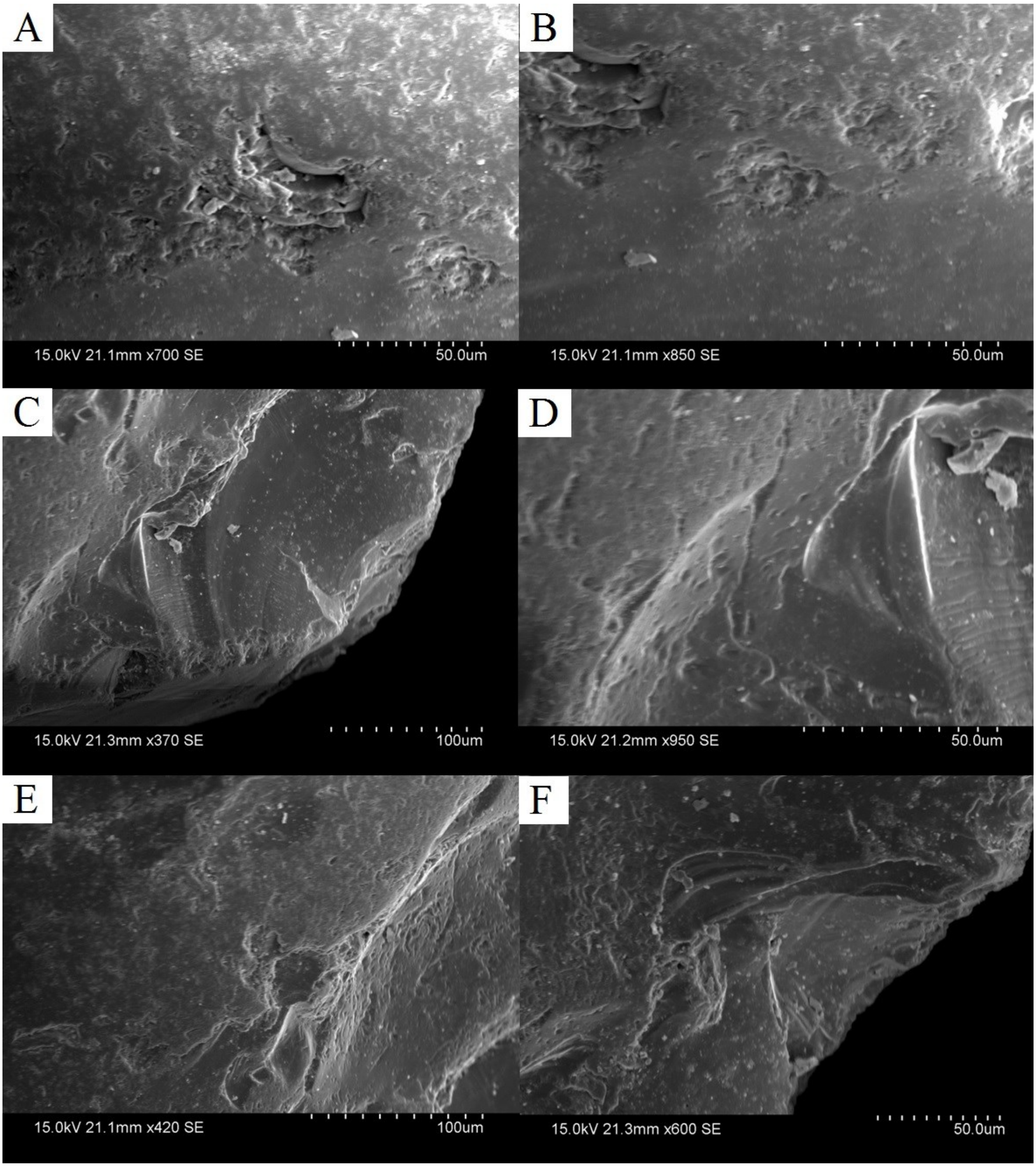


Fig. 3. (Sample V 0.2) A. Graded arc in the center. B. Graded arc in the upper left with crescentic marks in the center of the image. Some adhering particles can be seen on the grain. C. Conchoidal fracture (>100 µm) with arcuate steps and some sub-parallel linear fractures. Abraded edges can be seen on the lowermost edge. D. Vague impressions of V-shaped cracks can be seen one the left wall of the fracture. E. A meandering ridge with a conchoidal fracture (<100 µm) in the center. F. Clear arcuate steps within a conchoidal fracture (<100 µm) (center) and some adhering particles (top).

flakes which seem to be coming from the grain’s surface.

Two of the observed grains in this sample have precipitations which appear as small crystalline structures (less than 10 µm) with shapes reminiscent of flowers growing on the surfaces (Fig 4F and 5A–D). Oriented etch pits have been noticed on 47% of the grains (Fig. 5A–C and E). Curved grooves with straight steps can be seen in Fig. 5F together with what is possibly precipitation appearing as small rectangular overgrowths.

A grain with mainly a subangular appearance but with some extensive reworking and no sharp edges can be seen in Fig. 6A–E together with crescentic marks and some conchoidal fractures. A fairly straight groove can also be seen on the surface of the same

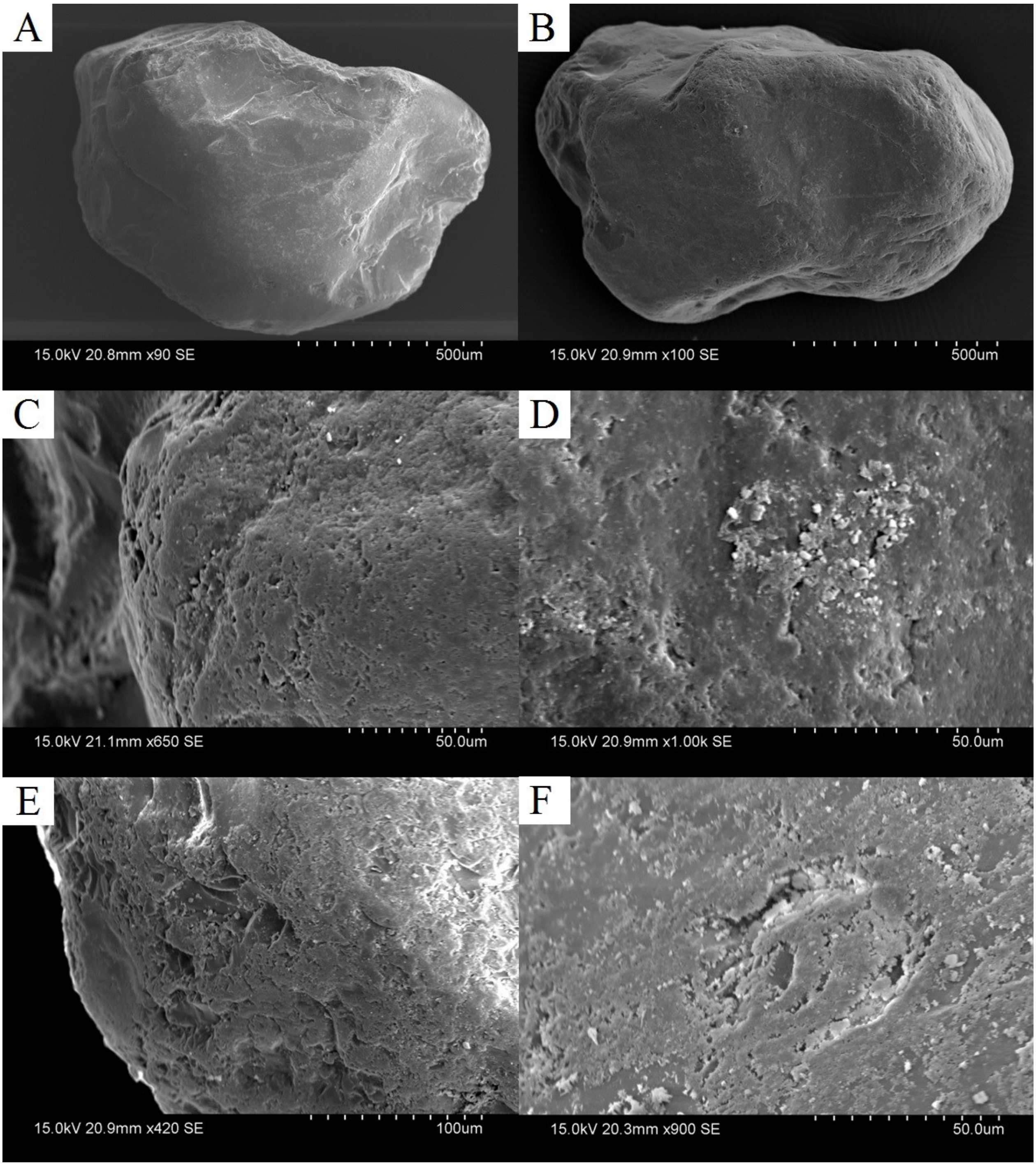


Fig. 4. (Sample V 0.2) A. Subrounded grain with abraded edges and dulled surfaces. Straight grooves can be seen in upper left, conchoidal fractures in the upper center and meandering ridges in the lower right of the grain. Elongated depression left of the grain. B. Subrounded grain with bulbous edges. C. Precipitation on grain outside of depressions. D. Crescentic marks and solution pits are present on a surface affected by dissolution. Some flakes, probably silica originating from the same surface can be seen in the center. E. A grain covered by precipitation. Crescentic marks can be seen on the right side of the grain and fractures together with adhering particles can be seen in the center and towards the left. F. Precipitated silica covering most of the grains surface with the precipitations resembling small flowers (<10 μm).

grain (Fig. 6A) with a highly rounded outline seen in the enlargement of Fig. 6B. Some flakes which could be made of silica can be seen in Fig. 6E, originating possibly from another quartz grain.

Out of 15 grains examined in this sample, only one grain had an angular shape with mainly conchoidal fractures (Fig. 6F). Fig. 7A–E represents the same angular grain as in Fig. 6F. Subparallel linear fractures can be seen in Fig. 7A and some radial fractures can be seen in Fig. 7B within a conchoidal fracture. Oriented etch pits are present in extensive amounts on the same angular grain (Fig. 7C–E).

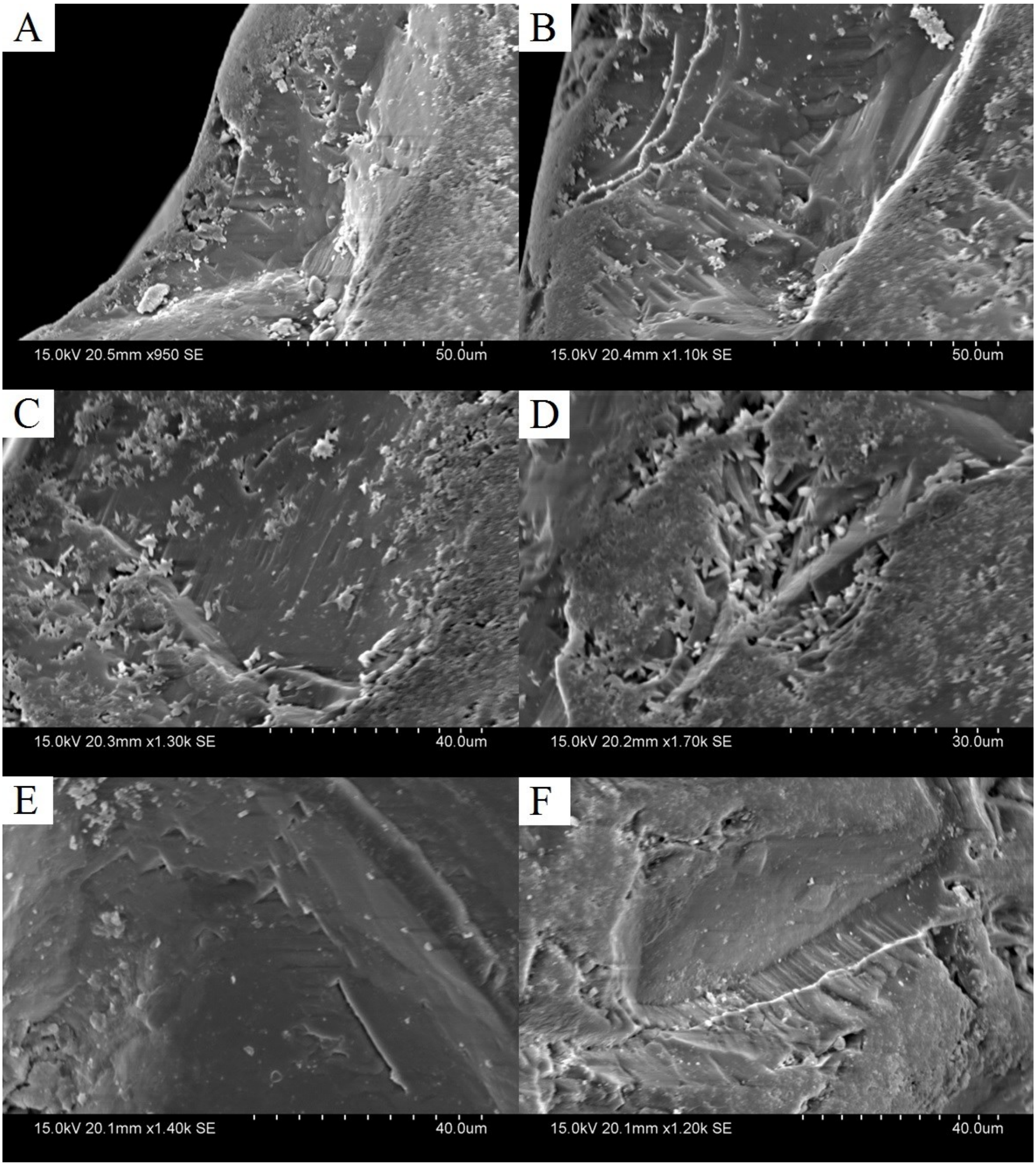


Fig. 5. (Sample V 0.2) A. Oriented etch pits can be seen in the center together with precipitation covering most of the area around the fracture. B. A similar surface as the one sin in A. with numerous oriented etch pits in a conchoidal fracture. Arcuate steps are present to the left of the surface. C. Oriented etch pits can be seen on a plane, developing along the fracture-wall to the left. Precipitation is present as clusters of silica resembling flowers. D. Fine crystals probably formed due to precipitation. The shapes are similar to silica flowers (Madhavaraju et al. 2009) E. Oriented etch pits having developed on a fresh fracture. F. Straight steps can be seen in a curved groove with possible rectangular overgrowths appearing above the steps.

Grains with smooth surfaces are less common in the sample with no exact percentages indicating the occurrence (Fig. 7F). Unlike the rectangular outgrowths seen in Fig. 5F, some silica precipitation occur as round or bulging features on the surfaces of two grains seen in Fig. 8A and B. Oriented etch pits which occur clustered on a surface can be seen in Fig. 8C. A nearly rounded grain with a vug and bulbous edges can be seen in Fig. 8D. Conchoidal fractures less than 10 µm were noticed on 47% of the grains.

No flat cleavage surfaces were identified on grains in this sample and the presence of upturned plates was not certain. Parallel striations occurred only in small areas of the grains examined and imbricated grinding

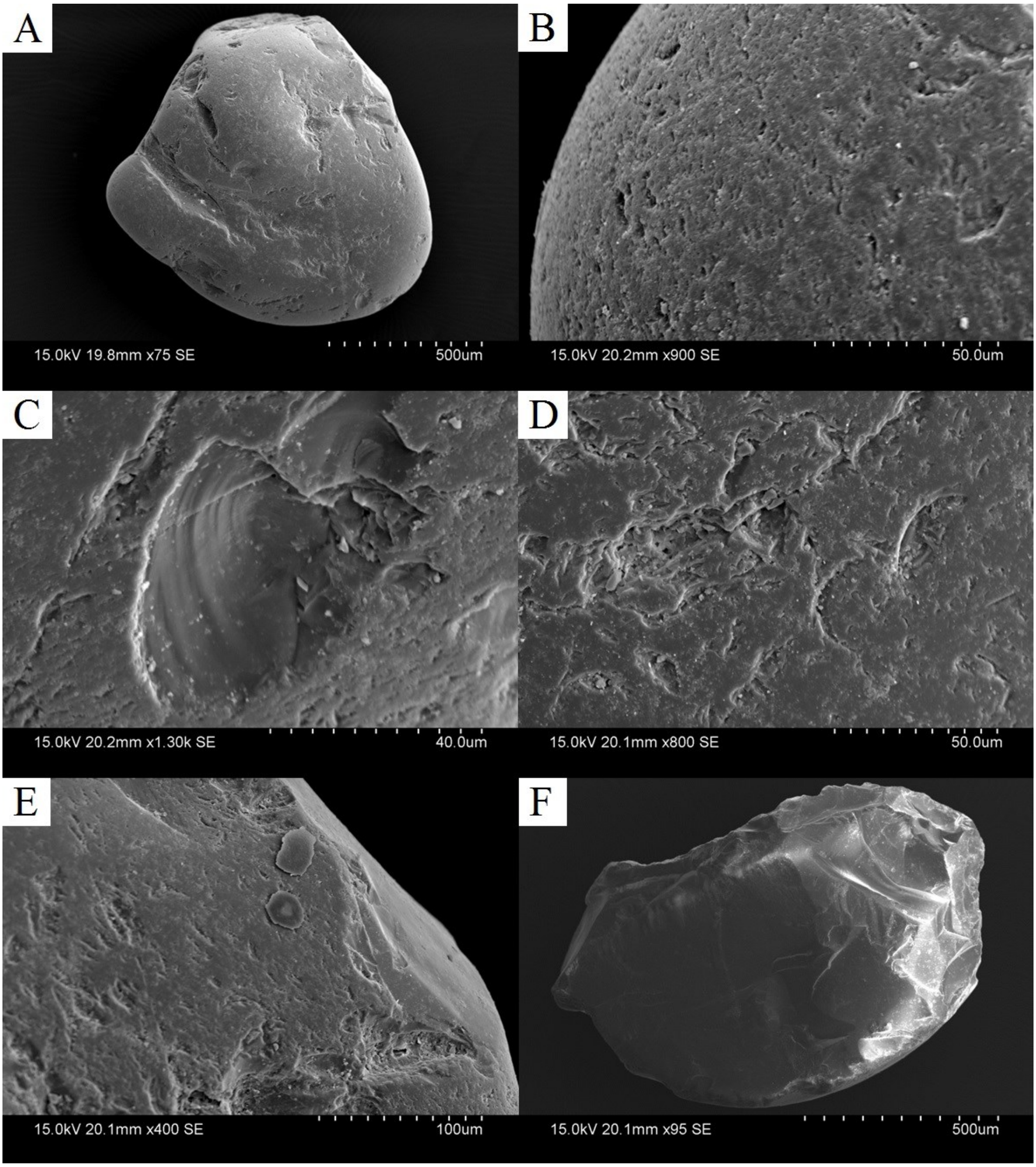


Fig. 6. (Sample V 0.2) A. Subangular grain with rounded edges on the lower left of the grain. A straight groove can be seen on the left. Small conchoidal fractures with crescentic marks can be identified on some areas of the grain. B. Enlargement of grain seen in A. showing the rounded and abraded edge left of the groove. C. Two conchoidal fractures (<100 µm) with arcuate steps can be seen on the same grain as in A. D. Crescentic marks. E. Flakes probably originating from another grain are adhering on the surface (top). F. Angular grain with sharp edges and conchoidal fractures.

features were not found but the possibility of the features occurring could not be fully excluded. No scaling was identified on the grains and features with silica globules and silica pellicles were not identified with certainties. Features representing silica flowers have been found on two grains (Fig. 5). Elongated depressions often occurred together with regular depressions on grains in this sample. 87% of the grains had medium relief with abraded edges while only 7% of the grains examined had high relief and 7% had low relief.

5.2 Brattforsheden sample (061320)

A frequency diagram of the occurrences of different microtextures in percentages for this sample can be seen in Fig. 16.

The Brattforsheden sample consists of 80% of

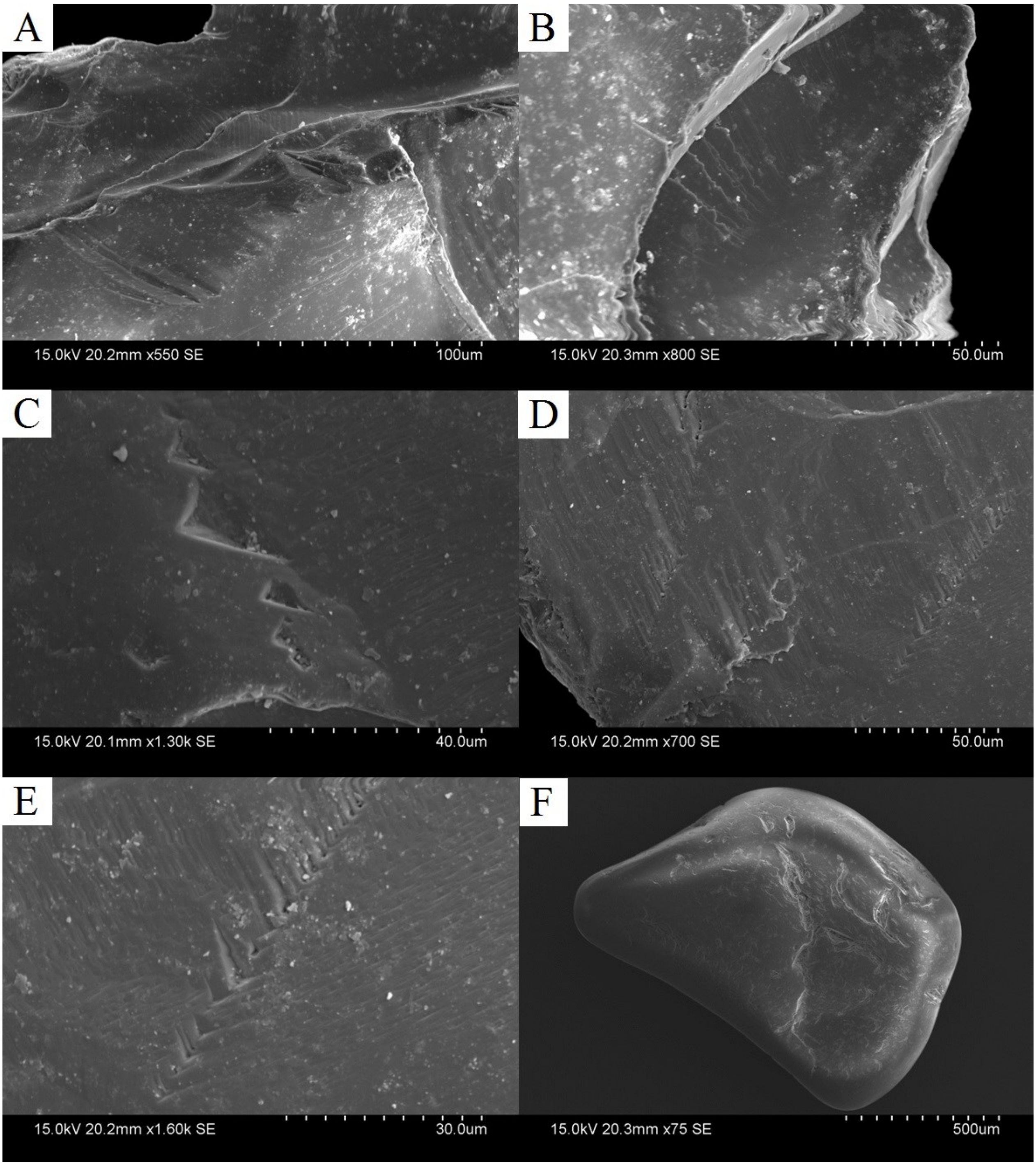


Fig. 7. (Sample V 0.2) A, B, C, D and E belong to the grain in Fig. 6A. A. Subparallel linear fractures (center). B. Radial fractures can be seen as lines in the center, inside a conchoidal fracture. C. Oriented etch pits. D. A pattern of oriented etch pits having developed along planes. E. An enlargement of the oriented etch pits seen in D. F. Subangular grain with smooth surfaces and abraded edges.

subangular grains (Fig. 9A) and 20% of angular grains. No rounded grains were present in the sample. Flat cleavage surfaces were seen on 27% of the grains examined (Fig. 9B). 80% of the grains exhibit grooves with straight grooves being more common than curved grooves (Fig. 9C and D).

Conchoidal fractures smaller than 100 μm were identified on 93% of the grains. Conchoidal fractures larger than 100 μm and smaller than 100 μm can be seen in Fig. 9E and F. Chemically affected grains with precipitation and dissolution were noticed in this sample (Fig. 9A and B). Radial fractures have been identified within conchoidal fractures (Fig. 9E and F). Arcuate steps are present on 87% of the grains examined (Fig 9F).

Vague structures of what are probably upturned plates can be seen in Fig. 10A. The cause of the upturned plates on this grain is presumed to be of chemical

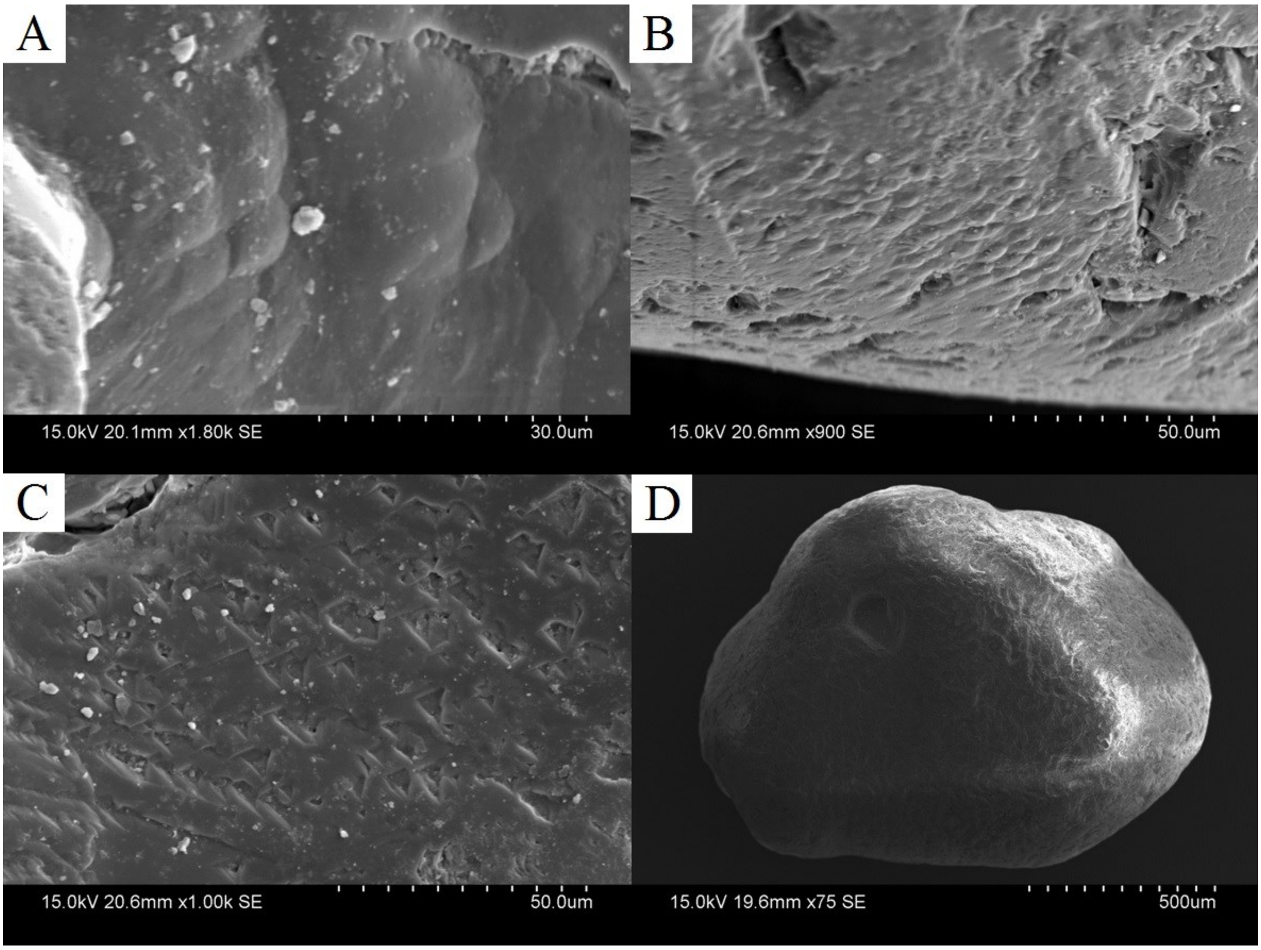


Fig. 8. (Sample V 0.2) A and B. Bulging overgrowths probably caused by silica precipitation. C. Numerous oriented etch pits on a flat surface. D. A subangular to subrounded grain with bulbous edges and a vug present near the center of the grain.

origin. An almost flat surface can be seen on a grain in Fig. 10B. The surface appears to have been broken up in plates along the crystal planes, probably first by mechanical impact and later by chemical impact (Fig. 10C). Parallel striations occur on 40% of the grains examined. Some rough and vaguely appearing striations can be seen in Fig. 10D. A subangular to angular grain can be seen in Fig. 10E and a cavity with conchoidal fractures and subparallel fractures can be seen on the same grain in the enlargement of Fig. 10F.

Grains with chemically affected surfaces where noticed in the sample (Fig. 11A). Some clear radial fractures can be seen in Fig. 11B. Sharp edges (Fig. 11C) were noticed on grains with conchoidal fractures. Some grains had abraded edges and ridges which can be seen in Fig. 11D. Imbricated blocks were identified on a few grains and no exact percentages were determined for this feature (Fig. 11E and F).

Subparallel linear fractures and arcuate steps can also be seen in Fig. 11E and F. Solution pits and dissolution features were identified on grains (Fig. 12A). One grain exhibited features indicative of dissolution by having what seems like a cracked up surface (Fig. 12B). Straight grooves can be seen in Fig. 12C. A conchoidal fracture with radial fractures and arcuate steps can be seen in Fig. 12D. V-shaped cracks have been noticed on a few grains and their presence is estimated to 20% (Fig. 12E). More or less compacted subparallel linear fractures can be seen in Fig. 12F, within a conchoidal fracture.

Arcuate steps larger than 100 µm have been noticed on a grain (Fig. 13A). Fig. 13B shows an angular grain with high relief. An enlargement of the same angular grain can be seen in Fig. 13C with features which have not been seen on the other grains examined. The origin of these features will be discussed later.

Oriented etch pits less than 10 µm in size can be seen in Fig. 13D. High frequency fractures (similar to those described by Mahaney 2002) have been found on another grain with conchoidal fractures enclosing the high frequency fractures (Fig. 13E). Solution pits inside a conchoidal fracture can be seen in Fig. 13F. Radial fractures occurring inside of several conchoidals less than 100 µm in size and clustered together have been observed on a subangular grain (Fig. 14A).

A grain with two conchoidal fractures forming a ridge where the plates have been slightly upturned can be seen in Fig. 14B. Abraded edges similar to Fig. 14C have been noticed on subangular grains. A deep straight groove can be seen in Fig. 14D. Slightly upturned plates can be seen in Fig. 14E where they are pre-

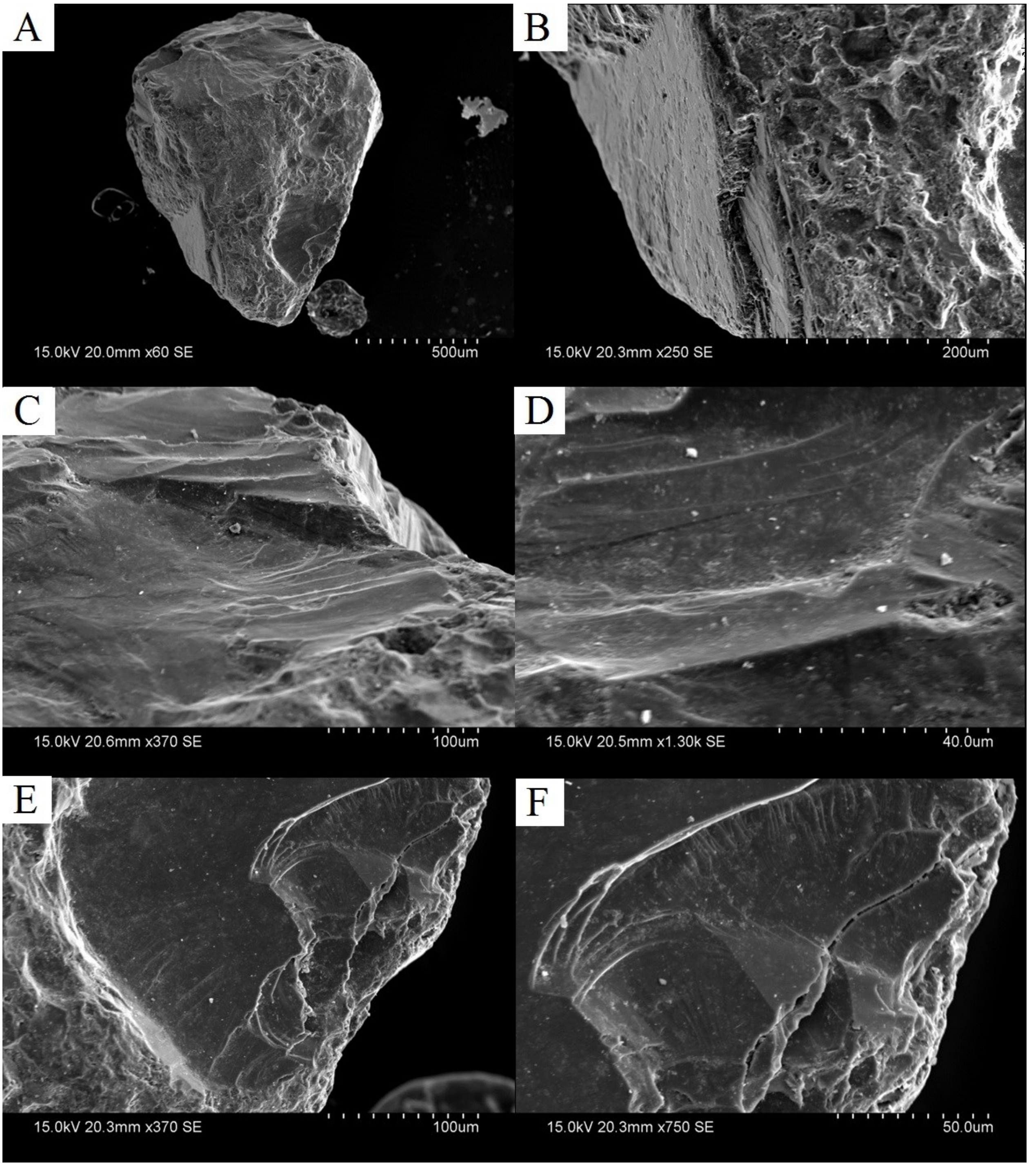


Fig. 9. (Sample 061320) A. Subangular grain affected by precipitation and dissolution. B. Flat cleavage surface (left of the grain). This grain is an enlargement of the grain in A. C. Straight grooves ending towards the edge on the right. D. Slightly curved grooves. E. Conchoidal fracture (>100 µm) with smaller fractures (<100 µm) and arcuate and straight steps. The edge to the right has been abraded. Radial fractures can be seen inside the conchoidal fractures. F. An enlargement of the conchoidal fractures seen in E. showing additional fractures along the edges of the conchoidals together with some radial fractures and arcuate steps.

sent within a conchoidal fracture. Upturned plates in Fig. 14F appear to have been caused by chemical processes.

Adhering particles are present on all of the grains examined with each grain exhibiting different amounts of particles on their surfaces. Fresh surfaces were found on grains. Conchoidal fractures less than 10µm (60%) had a same amount of presence on grains as conchoidals larger than 100 µm though not as common as conchoidal fractures of less than 100 µm (93%). Straight steps (73%) were less common than arcuate steps (87%) and meandering ridges (53%) were found on a few grains with conchoidal fractures.

No graded arcs where identified in this sample.

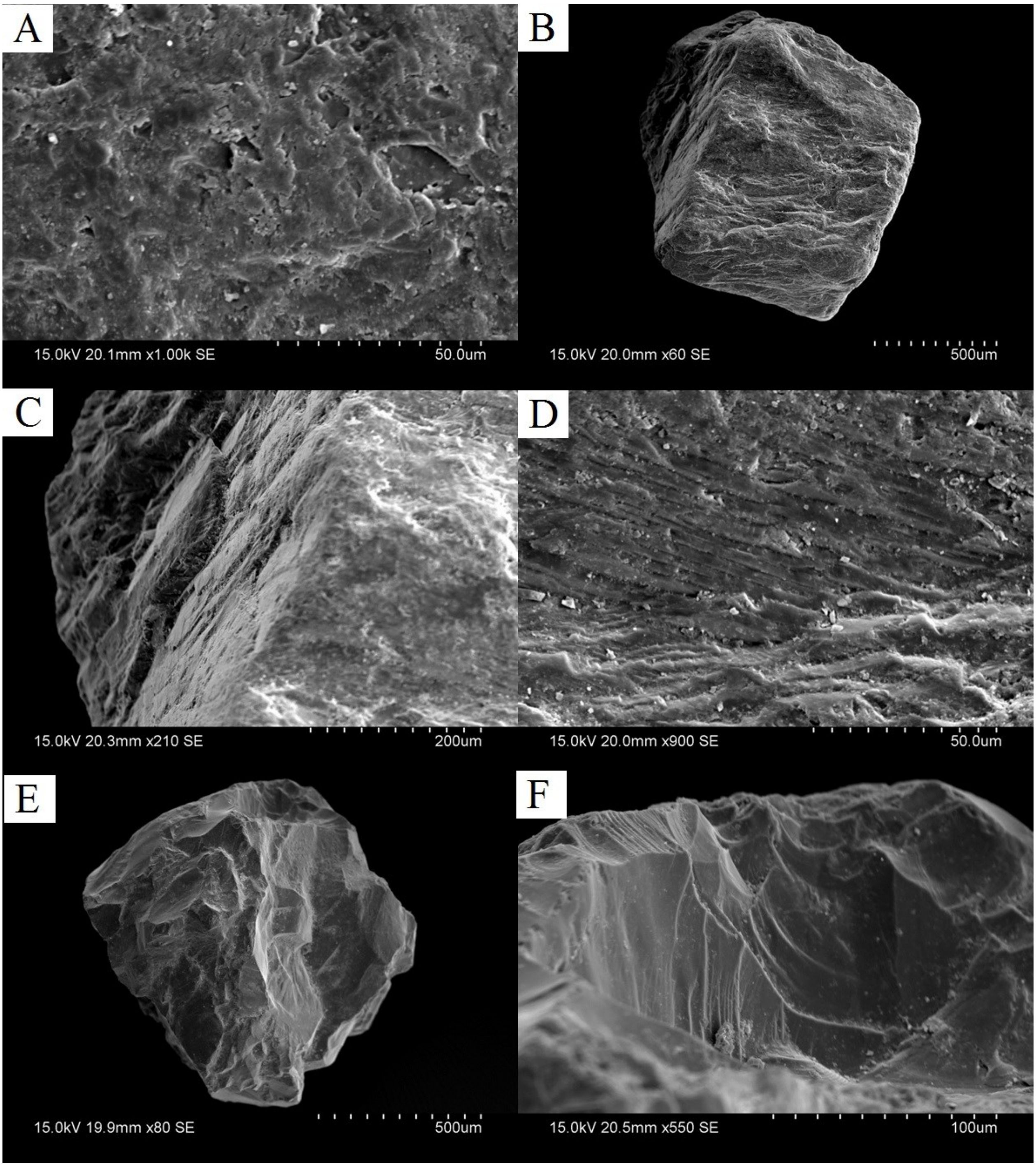


Fig. 10. (Sample 061320)A. Probably upturned plates of chemical origin. B. Subangular grain with an almost flat surface on the left side of the grain. C. An enlargement of the grain in A. showing broken up plates, probably caused by a combination of mechanical and chemical processes. D. Parallel striations with a rough appearance. E. Subangular to angular grain with conchoidal fractures. F. Subparallel fractures within conchoidal fractures (enlargement of grain in E.).

13% of the grains exhibited bulbous edges and only 7% of the grains had crescentic marks. No imbricated grinding features where found in this sample and the possibility of these features occurring on some grains in the sample cannot be fully excluded. No features resembling solution crevasses were identified. Features resembling scaling, silica globules, silica flowers and silica pellicles were not identified with certainties on the grains in this sample.

Crystalline overgrowths were noticed on 20% of the grains. Large and small breakage blocks were noticed on 27% of the grains. The majority of the grains in this sample had medium reliefs (67%). 7% of the grains were characterized by low relief and 27% of the grains had high reliefs. Depressions were identified on 47% of the grains and elongated depressions were identified on 27%. No dulled surfaces were noticed on the grains examined.

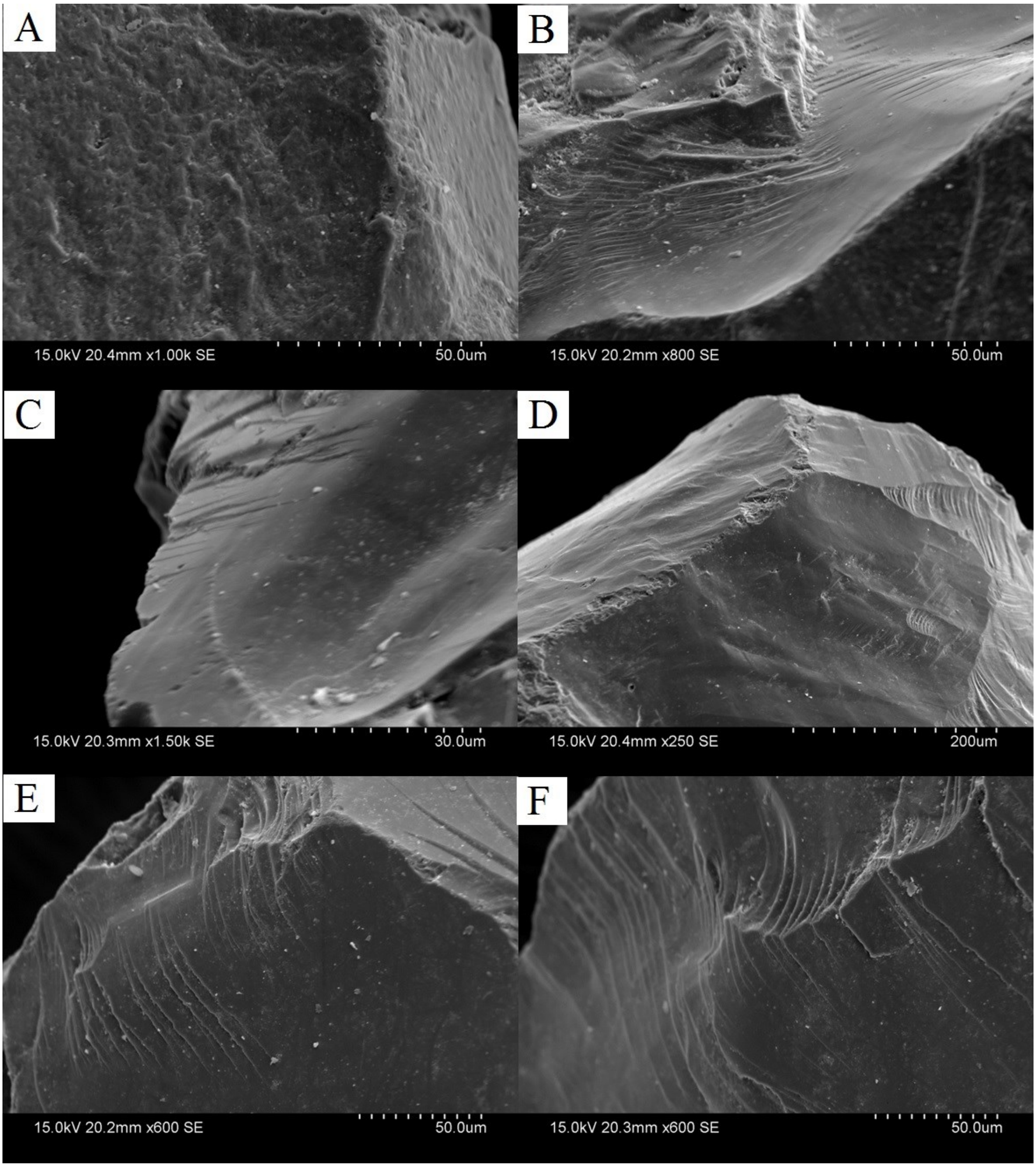


Fig. 11. (Sample 01320) A. Chemically affected grain. B. Radial fractures on a conchoidal fracture. C. Sharp edges of a fresh conchoidal fracture. D. Flat cleavage surfaces with an abraded ridge in the center. E, F. Imbricated blocks (similar to those identified by Helland et al. 1997) with subparallel linear fractures.

5.3 Comparison of the occurrences of microtextures of the two samples with additional explanations

A total of 37 microtextures or features were searched for when browsing grains. The amount of textures identified from sample V 0.2 were 30/37 and 28/37 for sample 061320 (Table 2). 18 different microtextures had a frequency above 50% and 8 of these had a frequency above 75% in sample V 0.2 (Fig. 15). Sample 061320 showed a number of 11 different textures with a frequency above 50% and only 5 of these had a frequency above 75% (Fig. 16).

Sample V 0.2 from a coastally influenced aeolian dune contained a higher number of microtextures as well as a higher number of textures with frequencies above 50% compared to sample 061320 from an aeolian inland dune (Table 2).

Textures identified with frequencies higher than

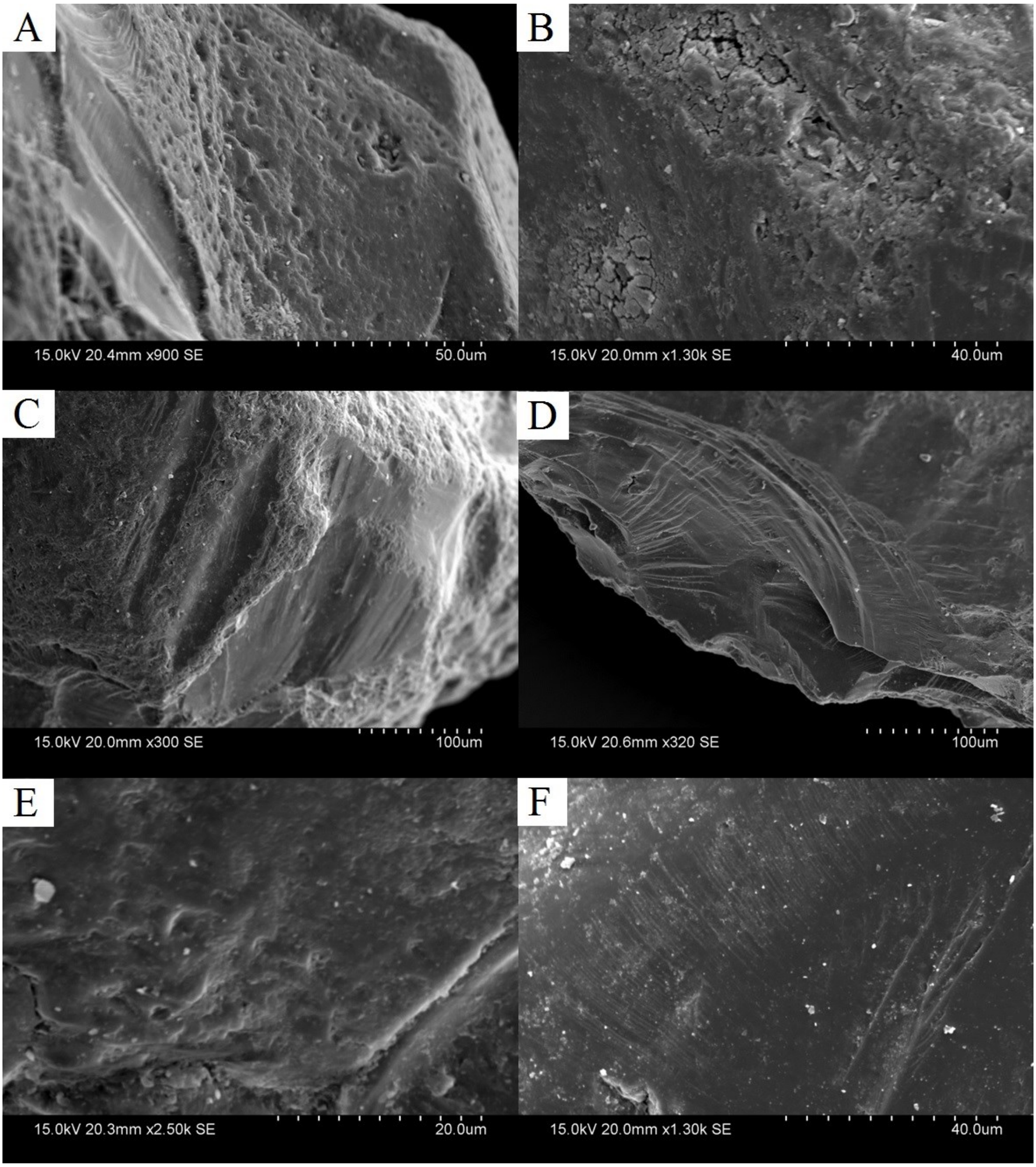


Fig. 12. (Sample 061320) A. Surface affected by dissolution with solution pits. B. Surface with cracked plates probably caused by dissolution. C. Straight grooves. D. Conchoidal fracture (>100 µm) with arcuate steps and radial fractures. E. V-shaped cracks. F. Subparallel linear fractures occurring compacted on a conchoidal fracture.

50% for sample V 0.2 were: conchoidal fractures (<100 µm and >100 µm), arcuate steps, straight steps, V-shaped cracks, grooves (straight and curved counted together), crescentic marks, bulbous edges, abraded edges, parallel striations, solution pits, precipitation, adhering particles, elongated depressions, depressions, dulled surfaces and subangular grains with medium relief.

The textures with occurrences above 75% for sample V 0.2 were subangular, conchoidal (<100 µm), straight steps, V-shaped cracks, grooves (straight and curved), bulbous edges, adhering particles and medium relief.

Textures with frequencies higher than 50% for sample 061320 were: Conchoidal fractures (<10 µm, <100 µm and >100 µm), arcuate steps, straight steps, meandering rivers, grooves (straight and curved counted together), precipitation, adhering particles and subangular grains with medium relief.

The textures with occurrences above 75% for

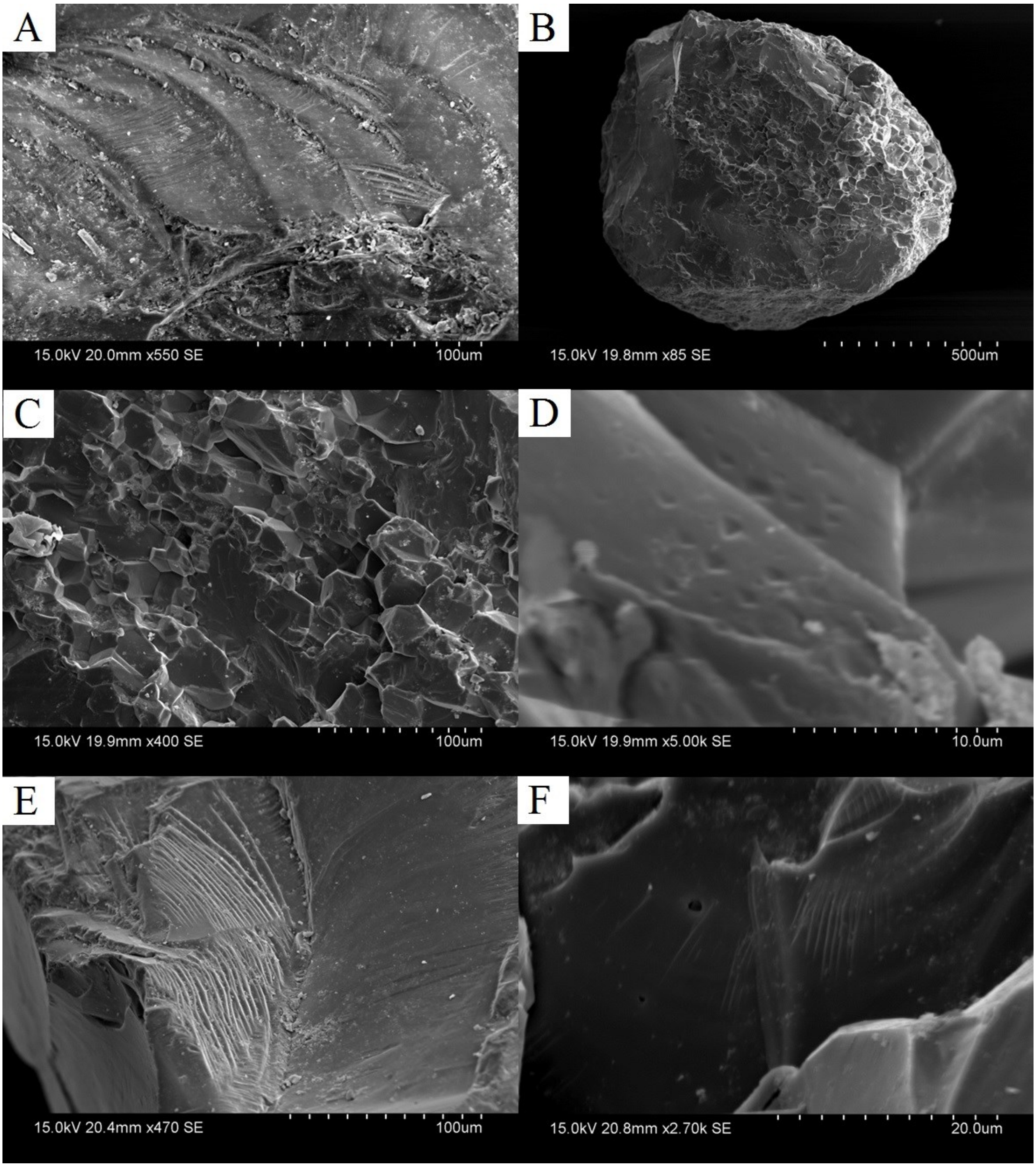


Fig. 13. (Sample 061320) A. Arcuate steps (<100 µm). B. Angular grain with high relief. C. Enlarged grain of the surface seen in B. showing angular features. D. Small oriented etch pits (<10 µm). E. Fractures occurring closely packed on a surface with conchoidal fractures. F. A conchoidal fracture with solution pits.

sample 061320 were subangular, conchoidal (<100 µm), arcuate steps, grooves (straight and curved) and adhering particles. Textures representing dulled surfaces, solution crevasses and graded arcs together with some rounded grains were present in sample V 0.2 while they were not identified in sample 061320.

Sample 061320 exhibited grains with flat cleavage surfaces with 20% of the grains being angular compared to sample V 0.2 with no flat cleavage surfaces and only 7% of the grains being angular. The grains of sample 061320 also appeared to have less abraded edges and sharper edges than the grains of sample V 0.2 which seemed to have been transported longer distances. This is also seen in Table 2 were grains from sample 061320 had a higher percentage of grains with high relief than grains from sample V 0.2. A connection between grains with sharp edges and having high relief at the same time is indicated by Mahaney (2002).

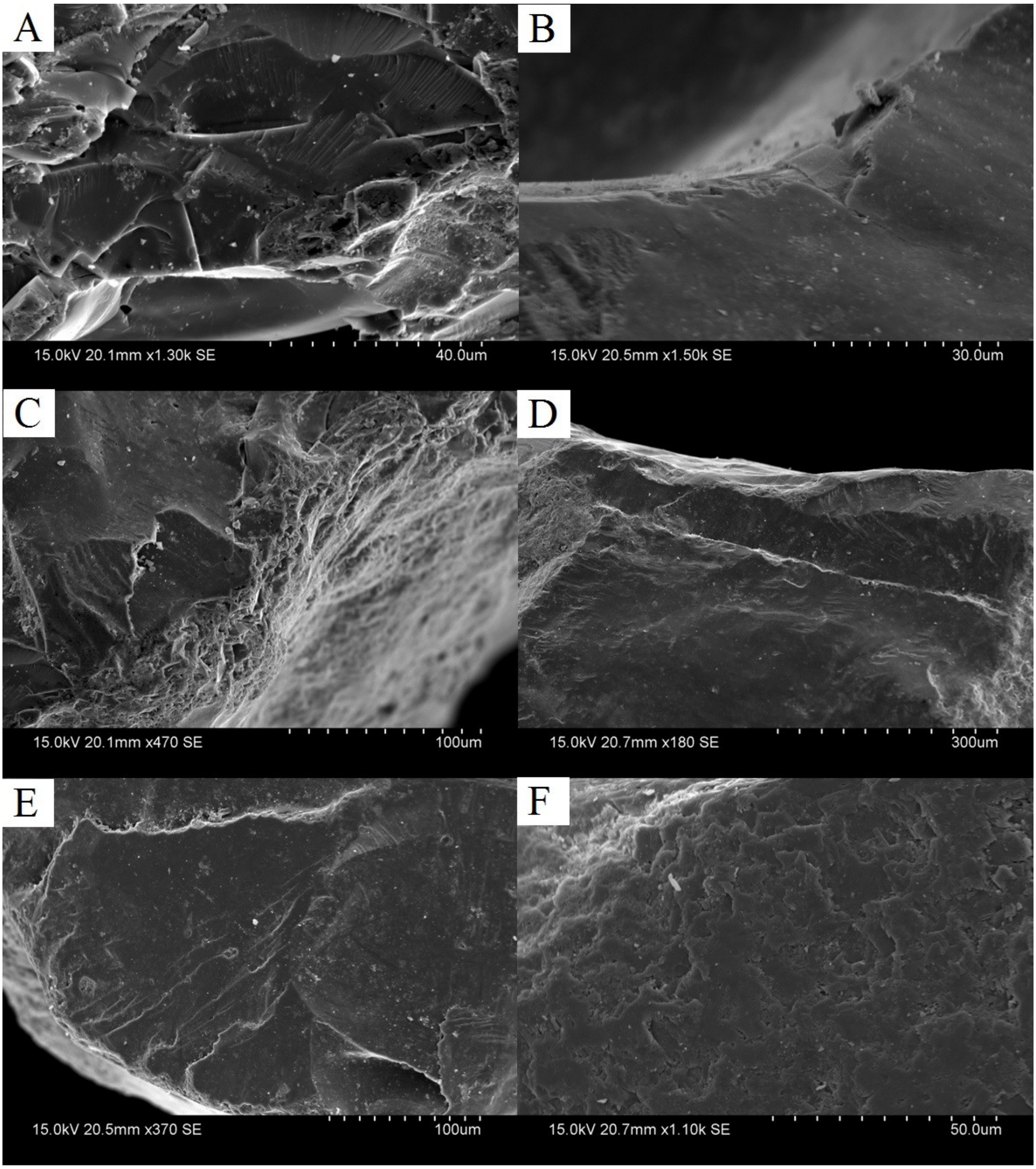


Fig. 14. (Sample 061320) A. Several conchoidal fractures (<100 µm) with radial fractures from a subangular grain. B. Two conchoidal fractures separated by a ridge with plates having been upturned on the ridge. C. Abraded edge of a subangular grain. D. Straight groove which have scoured deep into the surface. E. Slightly upturned plates within a conchoidal fracture (< 100 µm) with traces of adhering particles. F. Upturned plates appear to have been produced by chemical processes.

6 Discussion

Understanding and recognizing the origin of different microtextures together with the dominant processes can offer a great deal of information about the original environment (Mahaney 2002). The "imprint energy", the diagenetic processes and the age of the grains are important factors to analyze for a more accurate view on which environments are behind certain textures (Mahaney 2002). This author also recognized the importance of studying sand grains in greater detail and searching for both chemical and physical factors so that several generations of imprints can be found.

The number of grains studied is also important though several grains in one sample can exhibit great amounts of chemical weathering which could have overprinted underlying mechanical textures (Mahaney

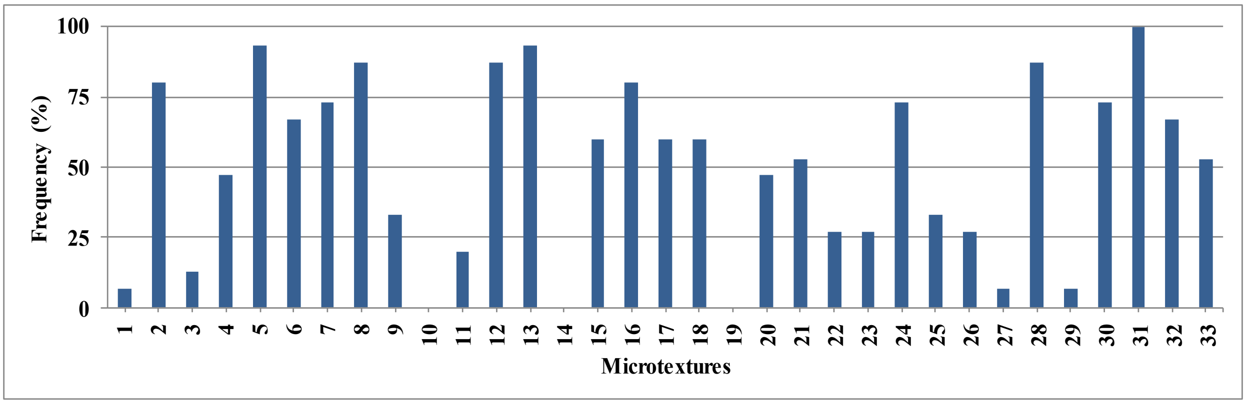


Fig. 15. Frequencies of the different microtextures identified for sample V 0.2. Frequencies have been calculated in percentages for 15 grains studied. The numbers 1–33 are the numbers of different microtextures in Table 2.

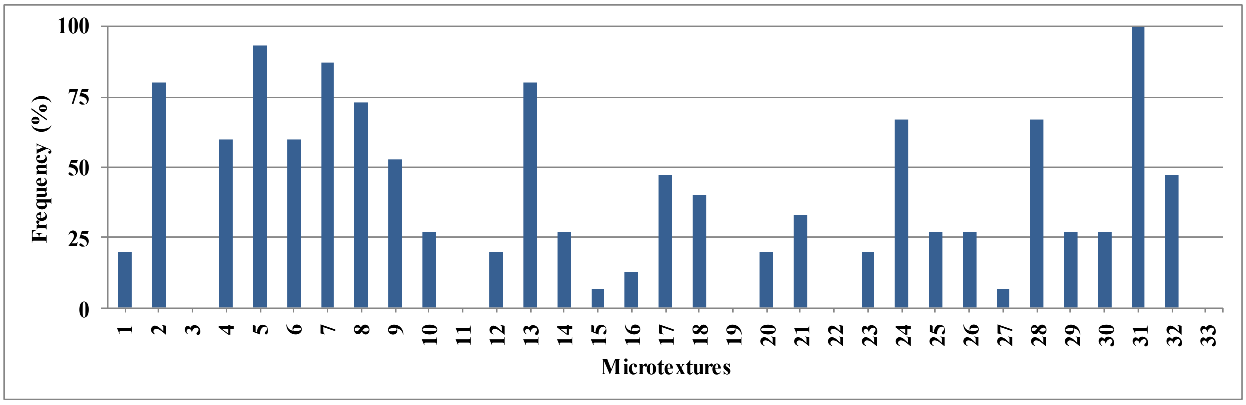


Fig. 16. Frequencies of the different microtextures identified for sample 061320. Same frequency analysis was done for this sample as for sample V 0.2 (Fig. 15). Numbers 1–33 represent the numbers of microtextures in Table 2.

2002). This means that if a few grains are studied, a lesser number of microtextures would be identified in the samples indicating a lesser variability than if a larger number of grains were studied for the same sample (Mahaney 2002).

Therefore by studying a larger amount of quartz grains, several microtextures and more than one single generation of imprints can be identified, which would produce representative results (Mahaney 2002). Larger samples offer generally a better result of which textures are the most common while smaller samples can produce errors in the result with some textures being overrepresented (Mahaney 2002).

In this project a total number of 30 grains were studied (15 grains per sample) which is due to the restricted time and a limited budget for the sessions in the SEM lab. For the purpose of this study, the number of 15 grains per sample has proven to be adequate, considering the time required to search and identify microtextures. The size of grains and the number of grains studied for samples has varied between previous studies. Some studies found the number of ca. 15 grains per sample suitable (Krinsley & Funnell 1965; Kotilainen 2004), while others found that 21 grains (Manker & Ponder 1978) or 10–25 grains (Vos et al. 2014) were enough to produce representative results and recognize the variability present.

The size of the grains studied has been explained to be important by Manker & Ponder (1978) where grains with similar sizes of approximately 1.0 mm were studied to increase the level of confidence and identifying fairly similar amounts of textures on the grains.

In this project the sizes of the grains slightly differ between two samples. The grains from sample 061320 were picked randomly though each grain picked would have the diameter of approximately 0.8–1.0 mm which was not regarded as a great difference when analyzing the grains under the SEM. The grains picked from sample V 0.2 were grains ranging from 0.5–1.0 mm in diameter. The grains were chosen carefully so that the largest grains close to 1.0 mm were picked. The possibility of one or two grains being smaller cannot be excluded but the variability and the amount of textures identified should not have been affected negatively compared to if all grains were exactly the same sizes.

The presence of upturned plates in sample V 0.2 was not certain, therefore represented by a question mark in Table 2. The texture was searched for in all of the grains but due to their shapes not being recognized when browsing the first few grains, the number of grains exhibiting these textures could not be included in the results. This initial uncertainty would have created slightly unrepresentative results if included in

Table 2 and Fig. 15.

The presence of upturned plates was noted on a few grains from sample 061320 throughout the analysis of this sample and could therefore be included in the results (Table 2). Imbricated grinding features could not be identified with certainties in both samples and is therefore represented by a question mark for both samples in Table 2 and as not present in the diagrams of Fig. 15 and 16.

Adhering particles had a presence of 100% in both samples. This is because a few particles which seemed to be adhering to the surface of one grain would be marked as present for that grain. All grains exhibited larger or lesser amounts of adhering particles though grains from sample 061320 had generally more grains with larger amounts of particles present than grains from sample V 0.2.

Uncertainties about the presence of silica globules, silica pellicles, silica flowers and scaling in both samples was due to some initial misunderstandings about their shapes and the impression of there being a possibility of these features having multiple shapes. Therefore the occurrences of these textures could not be calculated and added to the results in Table 2.

The uncertainties about the shapes were attained when analyzing the first sample (sample V 0.2) and the only information regarding the shapes of these features were gained from Vos et al. (2014) and later from Madhavaraju et al. (2009). A later analysis of photos taken on microtextures from sample V 0.2 showed one grain exhibiting crystals which could possibly be silica flowers. This was confirmed by comparing the photo which is seen in Fig. 5D with a figure with identified silica flowers on a grain from beach sediments studied by Madhavaraju et al. (2009).The identification of microtextures was based on similarities and available descriptions of different microtextures to make sure that textures seen would not be confused with some other textures studied.

Grains from sample 061320 exhibited certain features which were not seen on grains from sample V 0.2. These features which can be seen in Fig. 13B and C are very angular in shape and were only seen on one single grain. Their development is most likely due to frost weathering in a cold climate causing cracks to form between quartz crystal overgrowths on quartz grains (Woronko & Hoch 2011). Similar types of features were found in fluvial sediments in Mongolia by Woronko & Hoch (2011) where most of the grains were shaped by frost weathering. The presence of frost weathered surfaces in sample 061320 could therefore indicate a cold climate having affected the grains at least once in the sample's sedimentary history.

Upturned plates recognized in Fig. 14E were also considered to be similar to "layered breakage" which is recognized on ice rafted quartz grains from colder environments (Immonen 2013). Similar upturned plates were observed on fluvially transported grains in China, and further termed as "fractured plates" (Helland et al. 1997).

A study on quartz grains from aeolian dunes from Borlänge in Sweden showed that the sediments consisted mainly of grains that have not been abraded (Mycielska-Dowgiałło 1993). This was seen on grains with low magnifications and a further analysis showed that only some grains from the same sample had been abraded by wind action.

According to Mycielska-Dowgiałło (1993), grains from Borlänge resemble glaciofluvial conditions due to their fresh fractures and that they differ from the rounded grains examined from aeolian deposits in Poland. Therefore the "degree of aeolization" was very low in Sweden and high in the samples studied in Poland which indicated that transportation by the wind has not been long in Sweden compared with the Polish dunes during the Holocene (Mycielska-Dowgiałło 1993). The similarities between the quartz grains from Borlänge and the grains from sample 061320 studied here may indicate a common sedimentary history pointing towards a shorter transport and a previously glacially-influenced setting prior to dune formation.

Microtextures which are commonly found in aeolian environments are meandering ridges and graded arcs (Krinsley & Funnell 1965; Krinsley & Donahue 1968). Meandering ridges were found commonly in sample 061320 and lesser in sample V 0.2 which could be due to sample 061320 having a slightly higher abundance of conchoidal features. Mahaney (2002) found that textures resembling elongated depressions, upturned plates and smoothed surfaces and depressions are found on grains in aeolian environments. Sample V 0.2 had more grains with elongated depressions compared to sample 061320. These could indicate that sample V 0.2 had been affected by aeolian processes a bit earlier or for longer periods than sample 061320.

Margolis & Krinsley (1971) recognized upturned plates, meandering ridges and graded arcs as textures belonging to coastal dune environments and V-shaped cracks indicating influence from beach environments. This is perhaps most similar to sample V 0.2 though sample 061320 had more grains with meandering ridges. Krinsley et al. (1976) found that coastal aeolian grains could exhibit elongated depressions and that upturned plates were restricted to smaller areas on grains.

Smooth surfaces were found on grains from desert environments together with highly chemically affected grains rounded by solution (Margolis & Krinsley 1971; Krinsley et al. 1976). With this in mind, grains from both samples in this project showed an approximately equal amount of grains having been affected by chemical processes.

V-shaped cracks, grooves (straight and curved) and blocky conchoidal fractures were recognized on grains in littoral settings with high energies (Krinsley & Funnell 1965; Krinsley & Donahue 1968; Van Hoesen & Orndorff 2004). Kleesment (2009) found that grains with V-shaped cracks, grooves and subparallel linear fractures with rounded outlines could give clear indications of grains having been transported in fluvial- or beach environments. Additionally, V-shaped cracks could also be found in marine environments (Kleesment 2009). This was also partially recognized by Immonen et al. (2014) where similar features were found to belong to both fluvial and aeolian environments. Mahaney (2002) concluded that the feature which is the most common in fluvial environments is the V-shaped cracks. This was also supported by Mahaney & Kalm (2000) who also added that abraded grains with rounded shapes are also common in the same environment.

The recognition of fairly similar amounts of grains exhibiting grooves in both sample V 0.2 and 061320 indicates that quartz grains can have been transported by water before being deposited as dunes. This is particularly true for sample V 0.2 where V-shaped cracks occur on numerous grains. In contrast, only a few grains with V-shaped cracks were observed at the Brattforsheden site.

Bulbous edges were recognized on Siberian quartz grains and thought to belong in fluvial environments (Mahaney 1998) and further on grains which are generally transported in aeolian environments (Mahaney 2002). Grains from sample V 0.2 exhibit greater amounts of grains with bulbous edges compared to very few bulbous-edged grains present in sample 061320. The fact that bulbous edges are found on grains from two environments as mentioned above, indicates that sample V 0.2 had experienced transportation in more than one environment.

Microtextures found in the samples studied in this project had a couple of textures which could be related to glacial environments. One such characteristic feature is the adhering particles which are explained by Immonen (2013) to be found in abundance on grains of glacial origin. However, this abundance of adhering particles might not be used to separate sample V 0.2 from 061320 environmentally due to all grains exhibiting adhering particles.

Other features which were recognized in sample V 0.2 and 061320 are conchoidal fractures, steps, striations and grains exhibiting high relief, which are collectively subjected to the glacial environment (Krinsley & Funnell 1965; Krinsley & Donahue 1968; Mahaney & Kalm 2000). Grains exhibiting subparallel linear fractures were found in both samples, offering another indication of glacial environment having previously affected the grains (e.g. Mahaney et al. 1996; Mahaney 2002; Van Hoesen & Orndorff 2004; Immonen 2013; Immonen et al. 2014). Mahaney et al. (1991) examined grains from supraglacial deposits and found many grains with fractured faces and angular shapes. This is similar to sample 061320 where no rounded grains were observed.

Etch features were recognized by Margolis (1968) on grains from marine environments with low energy waters, where chemical actions are more abundant than mechanical. Immonen (2013) also recognized etch features on most of the grains studied from ice rafted deposits and correlated them with seawater environment. These etch features were also found on grains in both sample V 0.2 and 061320, meaning that grains were most likely in contact with either seawater (sample V 0.2) or fluids with similar properties (sample 061320).

Importantly, grains studied have been affected by numerous processes belonging to several environments. Similarly, Immonen et al. (2014) pointed at new microtextures imprinting on older ones, indicating a change in the deposition. A similar environmental transition was observed by Mahaney et al. (2001) where quartz grains from both fluvial and aeolian had experienced glacial environments. This is a likely scenario for both sediment samples studied in this project.

7 Conclusions

The following conclusions have been made out of the discussion above. The amount of microtextures identified in each sample was different. With sample V 0.2 indicating a presence of 30 microtextures, sample 061320 revealed slightly less with 28 microtextures identified. Both samples studied indicate that the grains have been through different environments on different occasions. Correlations of microtextures together with their frequencies in this project with previous publications and studies have made it possible to delineate the past environments of the two samples.

7.1 Sample 061320

Sample 061320 collected from Brattforsheden from an aeolian inland dune show grains which has been affected by processes related to glacial environments. The grains from this sample have most likely been transported by water at least on one occasion which is related to the presence of grooves. Chemically affected grains with oriented etch pits within this sample indicate contact with fluvial environments.

The scarce occurrence of V-shaped cracks and bulbous edges lower the probability of a fluvial environment having affected the grains. The small amount of grains with bulbous edges gives indications of shorter transportation. Because no grains with rounded outlines were found in this sample (061320), the grains have not been transported longer distances or for a longer time. A single grain indicative of frost weathering has been recognized.

7.2 Sample V 0.2

Sample V 0.2 was collected from a coastal dune from Vittskövle. Elongated depressions were more frequent in sample V 0.2 together with regular depressions which indicate that grains in this sample have been transported slightly longer distances or for a longer time than sample 061320.

The presence of graded arcs and higher frequencies of elongated depressions support their coastal dune origin. Grains exhibiting abraded edges and bulbous edges were more common in sample V 0.2 signifying two possible environments having affected the grains. V-shaped cracks were highly abundant in sample V 0.2, indicating wave action within a beach environment which is strengthened by the presence of grooves.

Oriented etch pits are found in a slightly higher abundance on grains from sample V 0.2 indicating the influence of a marine environment. Grains in sample V 0.2 have probably been affected by aeolian activities a longer period than sample 061320. Some traces of glacial influence are present in this sample but to a lesser degree than in sample 061320.

Indications of silica flowers being present on grains in sample V 0.2 have been found. Features resembling upturned plates have not been recognized due to some misunderstandings on the characteristics of this feature.

7.3 Both samples

Adhering particles were found on all grains studied and a difference in the environment between the two samples cannot be concluded based on the occurrence of this feature alone. Grains with conchoidal fractures, striations and steps are present in both samples indicative of glacial environments. Sample 061320 exhibit a higher number of small conchoidal fractures (<10 µm) with a higher frequency of meandering ridges while parallel striations are more abundant in sample V 0.2. Straight steps are found on a higher number of grains in sample V 0.2 and curved steps are more frequent in sample 061320.

The frequency of imbricated grinding features has not been established. The order of which microtextures where imprinted on the grains in the samples studied has not been confirmed. The microtextures present on the grains give indications of different environments having affected the grains at different times but no certainties of which processes were active first were made.

The inland dune deposits of Brattforsheden have most probably been originating from a glacial environment, while the coastal dunes of Vittskövle indicate a longer period under aeolian conditions compared to the inland dune sample.

Both samples have at least once been affected by marine or fluvial conditions with the Brattforsheden sample having been affected a shorter period than the Vittskövle sample. A larger number of grains might indicate slightly different sedimentary histories for these samples.

8 Acknowledgements

I am very grateful to my supervisor, Edyta Kalińska-Nartiša, for all the help provided when working with the SEM and for always answering questions and giving me advices whenever needed. A special thank you to prof. Helena Alexanderson for being able to use grains from sample 061320 and to my supervisor for the use of sample V 0.2. I also wish to thank prof. Helena Alexanderson for answering questions about my research plan and giving me advice in the construction of my timeline. Lastly, I am grateful to the Department of Geology for the opportunity to work with the SEM and for the hours provided for my work in the lab.

9 References

Agrell, H., 1981: Subrecent Inland Dunes on the Kristianstad Plain, Southern Sweden. In L. K. Königsson. & K. Paabo (ed.): Florilegium Florinis Dedicatum. Striae 14, 48–51.

Alexanderson, H. & Fabel, D., 2015: Holocene chronology of the Brattforsheden delta and inland dune field, SW Sweden. Geochronometria 42, 1–16.

Bull, P. A., 1981: Environmental reconstruction by electron microscopy. Progress in Physical Geography 5, 368–397.

Costa, P.J.M., Andrade, C., Mahaney, W.C., Marques da Silva, F., Freire, P., Freitas, M.C., Janardo, C., Oliviera, M.A., Silva, T. & Lopes, V., 2013: Aeolian microtextures in silica spheres induced in a wind tunnel experiment: Comparison with aeolian quartz. Geomorphology 180–181, 120–129.

Helland, P.E. & Holmes, M.A., 1997: Surface textural analysis of quartz sand grains from ODP Site 918 off the southeast coast of Greenland suggests glaciation of southern Greenland at 11 Ma. Palaeogeography, Paleoclimatology, Palaeoecology 135, 109 –121.

Helland, P.E., Huang, P-H. & Diffendal, R.F., 1997: SEM Analysis of Quartz Sand Grain Surface Textures Indicates Alluvial/Colluvial Origin of the Quaternary "Glacial" Boulder Clays at Huangshan (Yellow Mountain), East-Central China. Quaternary Research 48, 177–186.

Immonen, N., 2013: Surface microtextures of ice-rafted quartz grains revealing glacial ice in the Cenozoic Arctic. Palaeogeography, Paleoclimatology, Palaeoecology 374, 293–302.

Immonen, N., Strand, K., Huusko, A. & Lunkka, J.P., 2014: Imprint of late Pleistocene continental processes visible in ice-rafted grains from the central Arctic Ocean. Quaternary Science Reviews 92, 133–139.

Kleesment, A., 2009: Roundness and surface features of quartz grains in Middle Devonian deposits of the East Baltic and their palaeogeographical implications. Estonian Journal of Earth Sciences 58, 71–84.

Kotilainen, M., 2004: Dune Stratigraphy as an Indicator of Holocene Climatic Change and Human Impact in Northern Lapland, Finland. Ph.D. thesis, Annales Academiae Scientiarum Fennicae, Geologica Geographica 166, 154 pp.

Krinsley, D.H. & Donahue, J., 1968: Environmental Interpretation of Sand Grain Surface Textures by Electron Microscopy. Geological Society of American Bulletin 79, 743–748.

Krinsley, D.H. & Funnell, B.M., 1965: Environmental history of quartz sand grains from the Lower and Middle Pleistocene of Norfolk, England. Quaternary Journal of the Geological Society 121, 435–456.

Krinsley, D.H., Friend, P.F. & Klimentidis, R., 1976: Eolian transport textures on the surfaces of sand grains of Early Triassic age. Geological Society of American Bulletin 87, 130–132.

Madhavaraju, J., García y Barragán, J.C., Hussain, S.M. & Mohan, S.P., 2009: Microtextures on quartz grains in the beach sediments of Puerto Peñasco and Bahaia Kino, Gulf of California, Sonora, Mexico. Revista Mexicana de Ciencias Geológicas 26, 367–379.

Mahaney, W.C., 1998: Scanning electron microscopy of Pleistocene sands from Yamal and Taz Peninsulas, Ob river eustary, northwestern Siberia. Quaternary International 45/46, 49–58.

Mahaney, W.C., 2002: Atlas of Sand Grain Surface Textures and Applications. Oxford University Press, New York. 237 pp.

Mahaney, W.C. & Kalm, V., 2000: Comparative scanning electron microscopy study of oriented till blocks, glacial grains and Devonian sands in Estonia and Latvia. Boreas 29, 35–51.

Mahaney, W.C., Claridge, G. Campbell, I., 1996: Microtextures on quartz grains in tills from Antarctica. Palaeogeography, Paleoclimatology, Palaeoecology 121, 89–103.

Mahaney, W.C., Stewart, A. & Kalm, V., 2001: Quantification of SEM microtextures useful in sedimentary environmental discrimination. Boreas 30, 165–171.

Mahaney, W.C., Vaikmae, R. & Vares, K., 1991: Scanning electron microscopy of quartz grains in supraglacial debris, Adishy Glacier, Caucasus Mountains, USSR. Boreas 20, 395–404.

Margolis, S., 1968: Electron microscopy of chemical solution and mechanical abrasion features on quartz sand grains. Sedimentary Geology 2, 243–256.

Margolis, S.V. & Krinsley, D.H., 1971: Submicroscopic Frosting on Eolian and Subaqueous Quartz Sand Grains. Geological Society of American Bulletin 82, 3395–3406.

Manker, J.P. & Ponder, R.D., 1978: Quartz grain surface features from fluvial environments of northeastern Georgia. Journal of Sedimentary Petrology 48, 1227–1232.

Moral Cardona, J.P., Gutiérrez Mas, J.M., Sánchez Bellón, A., López-Aguayo, F. & Caballero, M.A., 1997: Provenance of multicycle quartz arenites of Pliocene age at Arcos, southwestern Spain. Sedimentary Geology 112, 251–261.

Mycielska-Dowgiałło, E., 1993: Estimates of Late Glacial and Holocene aeolian activity in Belgium, Poland and Sweden. Boreas 22, 165–170.

Porter, J.J., 1962: Electron microscopy of sand surface texture. Journal of Sedimentary Petrology 32, 124–135.

Soutendam, C.J.A., 1967: Some methods to study surface textures of sand grains. Sedimentology 8, 281–290.

Van Hoesen, J.G. & Orndorff, R.L., 2004: A comparative SEM study on the micromorphology of glacial and nonglacial clasts with varying age and lithology. Canadian Journal of Earth Sciences 41, 1123–1139.

Vos, K., Vandenberghe, N. & Elsen, J., 2014: Surface textural analysis of quartz grains by scanning electron microscopy (SEM): From sample preparation to environmental interpretation. Earth-Science Reviews 128, 93–104.

Waugh, B., 1970: Formation of quartz overgrowths in the Penrith sandstone (Lower Permian) of northwest England as revealed by scanning electron microscopy. Sedimentology 14, 309–320.

Whalley, W.B. & Krinsley, D.H., 1974: A scanning electron microscope study of surface textures of quartz grains from glacial environments. Sedimentology 21, 87–105.

Widdowson, M. (ed.) 1997: Palaeosurfaces: Recognition, Reconstruction and Palaeoenvironmental Interpretation. Geological Society of London. 330 pp.

Woronko, B. & Hoch, M., 2011: The Development of Frost-weathering Microstructures on Sand-sized Quartz Grains: Examples from Poland and Mongolia. Permafrost and Periglacial Processes 22, 214–227.

Tidigare skrifter i serien ”Examensarbeten i Geologi vid Lunds universitet”:

398. Särman, Kim, 2014: Utvärdering av befintliga vattenskyddsområden i Sverige. (15 hp)
399. Tuvesson, Henrik, 2014: Från hav till land – en beskrivning av geologin i Skrylle. (15 hp)
400. Nilsson Brunlid, Anette, 2014: Paleoeko logisk och kemisk-fysikalisk undersökning av ett avvikande sedimentlager i Barsebäcks mosse, sydvästra Skåne, bil dat för ca 13 000 år sedan. (15 hp)
401. Falkenhaug, Jorunn, 2014: Vattnets kretslopp i området vid Lilla Klåveröd: ett kunskapsprojekt med vatten i fokus. (15 hp)
402. Heingård, Miriam, 2014: Long bone and vertebral microanatomy and osteohistology of ’Platecarpus’ ptychodon (Reptilia, Mosasauridae) – implications for marine adaptations. (15 hp)
403. Kall, Christoffer, 2014: Microscopic echinoderm remains from the Darriwilian (Middle Ordovician) of Västergötland, Sweden – faunal composition and applicability as environmental proxies. (15 hp)
404. Preis Bergdahl, Daniel, 2014: Geoenergi för växthusjordbruk – Möjlig anläggning av värme och kyla i Västskåne. (15 hp)
405. Jakobsson, Mikael, 2014: Geophysical characterization and petrographic analysis of cap and reservoir rocks within the Lund Sandstone in Kyrkheddinge. (15 hp)
406. Björnfors, Oliver, 2014: A comparison of size fractions in faunal assemblages of deep-water benthic foraminifera—A case study from the coast of SW-Africa.. (15 hp)
407. Rådman, Johan, 2014: U-Pb baddeleyite geochronology and geochemistry of the White Mfolozi Dyke Swarm: unravelling the complexities of 2.70-2.66 Ga dyke swarms on the eastern Kaapvaal Craton, South Africa. (45 hp)
408. Andersson, Monica, 2014: Drumliner vid moderna glaciärer — hur vanliga är de? (15 hp)
409. Olsenius, Björn, 2014: Vinderosion, sanddrift och markanvändning på Kristianstadsslätten. (15 hp)
410. Bokhari Friberg, Yasmin, 2014: Oxygen isotopes in corals and their use as proxies for El Niño. (15 hp)
411. Fullerton, Wayne, 2014: REE mineralisation and metasomatic alteration in the Olserum metasediments. (45 hp)
412. Mekhaldi, Florian, 2014: The cosmic-ray events around AD 775 and AD 993 - Assessing their causes and possible effects on climate. (45 hp)
413. Timms Eliasson, Isabelle, 2014: Is it possible to reconstruct local presence of pine on bogs during the Holocene based on pollen data? A study based on surface and stratigraphical samples from three bogs in southern Sweden. (45 hp)
414. Hjulström, Joakim, 2014: Bortforsling av kaxblandat vatten från borrningar via dagvattenledningar: Riskanalys, karaktärisering av kaxvatten och reningsmetoder. (45 hp)
415. Fredrich, Birgit, 2014: Metadolerites as quantitative P-T markers for Sveconorwegian metamorphism, SW Sweden. (45 hp)
416. Alebouyeh Semami, Farnaz, 2014: U-Pb geochronology of the Tsineng dyke swarm and paleomagnetism of the Hartley Basalt, South Africa – evidence for two separate magmatic events at 1.93-1.92 and 1.88-1.84 Ga in the Kalahari craton. (45 hp)
417. Reiche, Sophie, 2014: Ascertaining the lithological boundaries of the Yoldia Sea of the Baltic Sea – a geochemical approach. (45 hp)
418. Mroczek, Robert, 2014: Microscopic shock-metamorphic features in crystalline bedrock: A comparison between shocked and unshocked granite from the Siljan impact structure. (15 hp)
419. Balija, Fisnik, 2014: Radon ett samhällsproblem - En litteraturstudie om geologiskt sammanhang, hälsoeffekter och möjliga lösningar. (15 hp)
420. Andersson, Sandra, 2014: Undersökning av kalciumkarbonatförekomsten i infiltrationsområdet i Sydvattens vattenverk, Vombverket. (15 hp)
421. Martin, Ellinor, 2014: Chrome spinel grains from the Komstad Limestone Formation, Killeröd, southern Sweden: A high-resolution study of an increased meteorite flux in the Middle Ordovician. (45 hp)
422. Gabrielsson, Johan, 2014: A study over Mg/Ca in benthic foraminifera sampled across a large salinity gradient. (45 hp)

423. Ingvaldson, Ola, 2015: Ansvarsutredningar av tre potentiellt förorenade fastigheter i Helsingborgs stad. (15 hp)
424. Robygd, Joakim, 2015: Geochemical and palaeomagnetic characteristics of a Swedish Holocene sediment sequence from Lake Storsjön, Jämtland. (45 hp)
425. Larsson, Måns, 2015: Geofysiska undersökningsmetoder för geoenergisystem. (15 hp)
426. Hertzman, Hanna, 2015: Pharmaceuticals in groundwater - a literature review. (15 hp)
427. Thulin Olander, Henric, 2015: A contribution to the knowledge of Fårö's hydrogeology. (45 hp)
428. Peterffy, Olof, 2015: Sedimentology and carbon isotope stratigraphy of Lower–Middle Ordovician successions of Slemmestad (Oslo-Asker, Norway) and Brunflo (Jämtland, Sweden). (45 hp)
429. Sjunnesson, Alexandra, 2015: Spårämnesförsök med nitrat för bedömning av spridning och uppehållstid vid återinfiltrationav grundvatten. (15 hp)
430. Henao, Victor, 2015: A palaeoenvironmental study of a peat sequence from Iles Kerguelen (49° S, Indian Ocean) for the Last Deglaciation based on pollen analysis. (45 hp)
431. Landgren, Susanne, 2015: Using calcein-filled osmotic pumps to study the calcification response of benthic foraminifera to induced hypoxia under *in situ* conditions: An experimental approach. (45 hp)
432. von Knorring, Robert, 2015: Undersökning av karstvittring inom Kristianstadsslättens NV randområde och bedömning av dess betydelse för grundvattnets sårbarhet. (30 hp)
433. Rezvani, Azadeh, 2015: Spectral Time Domain Induced Polarization - Factors Affecting Spectral Data Information Content and Applicability to Geological Characterization. (45 hp)
434. Vasilica, Alexander, 2015: Geofysisk karaktärisering av de ordoviciska kalkstensenheterna på södra Gotland. (15 hp)
435. Olsson, Sofia, 2015: Naturlig nedbrytning av klorerade lösningsmedel: en modellering i Biochlor baserat på en fallstudie. (15 hp)
436. Huitema, Moa, 2015: Inventering av föroreningar vid en brandövningsplats i Linköpings kommun. (15 hp)
437. Nordlander, Lina, 2015: Borrningsteknikens påverkan vid provtagning inför dimensionering av formationsfilter. (15 hp)
438. Fennvik, Erik, 2015: Resistivitet och IP-mätningar vid Äspö Hard Rock Laboratory. (15 hp)
439. Pettersson, Johan, 2015: Paleoekologisk undersökning av Triberga mosse, sydöstra Öland. (15 hp)
440. Larsson, Alfred, 2015: Mantelplymer - realitet eller *ad hoc*? (15 hp)
441. Holm, Julia, 2015: Markskador inom skogsbruket - jordartens betydelse (15 hp)
442. Åkesson, Sofia, 2015: The application of resistivity and IP-measurements as investigation tools at contaminated sites - A case study from Kv Renen 13, Varberg, SW Sweden. (45 hp)
443. Lönsjö, Emma, 2015: Utbredningen av PFOS i Sverige och världen med fokus på grundvattnet – en litteraturstudie. (15 hp)
444. Asani, Besnik, 2015: A geophysical study of a drumlin in the Åsnen area, Småland, south Sweden. (15 hp)
445. Ohlin, Jeanette, 2015: Riskanalys över pesticidförekomst i enskilda brunnar i Sjöbo kommun. (15 hp)
446. Stevic, Marijana, 2015: Identification and environmental interpretation of microtextures on quartz grains from aeolian sediments - Brattforsheden and Vittskövle, Sweden. (15 hp)

LUNDS UNIVERSITET

Geologiska institutionen
Lunds universitet
Sölvegatan 12, 223 62 Lund