Oil occurrences in crystalline basement rocks, southern Norway – comparison with deeply weathered basement rocks in southern Sweden

Linnéa Gunterberg

Dissertations in Geology at Lund University,
Bachelor's thesis, no. 344
(15 hp/ECTS credits)

Department of Geology
Lund University
2013

Oil occurrences in crystalline basement rocks, southern Norway – comparison with deeply weathered basement rocks in southern Sweden

Bachelor's thesis
Linnéa Gunterberg

Department of Geology
Lund University
2013

Table of Contents

Cover Picture: Deep weathering at Bømlo.

Oil occurrences in crystalline basement rocks, southern Norway – comparison with deeply weathered basement rocks in southern Sweden

LINNÉA GUNTERBERG

Gunterberg, L., 2013: Oil occurrences in crystalline basement rocks, southern Norway – comparison with deeply weathered basement rocks in southern Sweden. *Dissertations in Geology at Lund University*, No. 344, 14 pp. 15 hp (15 ECTS credits).

Abstract: Rising oil prices and an increasing global use of fossil fuels make the survey of alternative petroleum reservoirs of great importance. Instead of drilling in regular sedimentary successions, the possibility of investigating reservoirs in crystalline basement is in many places of economic interest. Reservoirs in crystalline basement rock are producing oil in several countries e.g. Vietnam and Yemen, and oil exploration including drillings are made continuously to look for reservoirs in basement rocks in other places. The Norwegian company Lundin Norway AS has found traces of petroleum in weathered granites in drill cores from the Utsira High, southwestern Norway. Drilling and survey offshore can be expensive and difficult while analog research onshore could result in significant information and increased knowledge. Bømlo basement is related in age and petrology with the basement of Utsira High. This makes the, easy accessed, onshore island to a high quality survey area. The weathered material with petroleum occurrences from Utsira High makes Ivön, southeastern Sweden, a key locality since the latter area yields several good exposures where the relationships between deep weathered basement and unweathered basement can be studied. This thesis details the development of petroleum occurrences in crystalline basement.

Keywords: Petroleum, crystalline basement, deep weathering, saprolite

Supervisor: Mikael Calner

External supervisor: Mats Andersson

Linnéa Gunterberg, Department of Geology, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden.
E-mail: linnea_gunterberg@hotmail.com

Oljeförekomster i kristallin berggrund, södra Norge – en jämförelse med djupt vittrad berggrund i södra Sverige.

LINNÉA GUNTERBERG

Gunterberg, L., 2013: Oljeförekomster i kristallin berggrund, södra Norge – en jämförelse med djupt vittrad berggrund i södra Sverige. *Examensarbeten i geologi vid Lunds universitet*, Nr. 344, 14 sid. 15 hp.

Sammanfattning: Ökande oljepriser och en stigande efterfrågan gör idag undersökningar av alternativa petroleumreservoarer extra intressanta. Istället för att borra i den sedimentära bergrunden ges nu möjligheten att granska kristallina bergrundsreservoarer. Den här typen av borrning i kristallin berggrund äger rum på flera platser i världen, exempelvis i Vietnam och Yemen. Det norska företaget Lundin Norway AS har funnit petroleum i vittrade graniter i kärnborrsprover från Utsira höjden, sydvästra Norge. Att utföra borrningar och undersökningar offshore kan vara både dyrt och komplicerat. Granskningar och analoga undersökningar onshore kan därför vara att föredra då de tillför viktig information och bidrar med ökad kunskap för de aktuella områdena. Bergrunden på Bømlo är nära besläktad med bergrunden på Utsira Höjden. Detta gör den lättåtkomliga ön ett högkvalitativt undersökningsområde. Det vittrade materialet med petroleumfynd från Utsira Höjden gör att även Ivön, sydöstra Sverige, med sin likartade historia i ålder och petrologi blir en viktig nyckellokal för att förstå petroleumförekomster i vittrad berggrund. Naturliga skärningar på Ivön visar skarpa konturer mellan vittrat berg och färskt, ovittrat berg. Denna uppsats tar upp samband och möjligheter till hur petroleum kan påträffas i kristallin bergrund.

Nyckelord: Petroleum, kristallin berggrund, djupvittring, saprolite.

Ämnesinriktning: Berggrundsgeologi

Linnéa Gunterberg, Geologiska institutionen, Lunds universitet, Sölvegatan 12, 223 62 Lund, Sverige.
E-post: linnea_gunterberg@hotmail.com

1 Introduction

1.1 Petroleum in crystalline basement rocks

Petroleum forms through accumulation and burial of organic material in marine shales. Deposition of sediments will bury the shale which then will experience increasing temperature and pressure. As the burial continuous and the source rock becomes heated to between 70-120°C, long chains of hydrocarbons will break away from the organic kerogen and form waxy and viscous heavy oil at a depth around 3-4.5 km. At an increased temperature, about 160°C, the cropped hydrocarbon chains generates light oil. By a depth around 5-6 km and temperatures above 160°C the hydrocarbon chains convert into gas (Arid 2011). Migration occurs by pressure and density differences between the petroleum phases and the surrounding pore water. The oil migrates towards higher permeability and lower pressure into reservoir rocks but may be restricted by capillary forces (Munz et al. 2002). The accumulation of oil or gas occur by trapping of a sealing cap rock, mostly shale or clay rocks (Arid 2011).

Petroleum reservoir rocks are generally sedimentary rocks such as sandstone and limestone. These rocks usually have high permeability and porosity in which hydrocarbons can accumulate. It is far less common that hydrocarbons are retrieved from crystalline basement rocks. Crystalline basement is mostly hard and solid, but in fractured and weathered zones the porosity and permeability can increase. Basement rocks as igneous, metamorphic and volcanic have been observed to contain petroleum through infiltration from adjacent sedimentary basins (Munz et al. 2002). Crystalline reservoirs are discussed in this thesis.

The way oil occurs in crystalline basement is shown in Fig. 1. Oil producing source rock is buried with an increasing temperature and depth. Tectonic movements create fractures and uplift in the basement. This locally forces the oil producing source rocks to a lower level relative the basement, e.g. along the lower flanks of anticlinals. The producing hydrocarbon migrates upwards along the flank of the basement and accumulates in the new convex structure. A sealing cap of shale or clay will trap the hydrocarbons. A filled trap can result in seeps toward the surface or downward into lower depth and more permeable fracture zones (Hurricaneenergy 2013). In this case the possibility of finding oil in fractured basement highs increases (Salah & Alsharhan 1998).

The porosity and permeability of matrix in the fractured and weathered basement has a significant role as it makes rock more or less capable for oil trapping. Weathered zones can contain 5-10% of matrix porosity comparing with < 0.5 % in fresh basement rocks. Fracture porosity reservoirs usually have a porosity value between 0.1 % and 1 % (Nelson 2001). Increasing permeability or extensive weathering zones as well as a sealing cap rock are the significant factors of oil trapping.

When petroleum migrates downwards to a greater depth with high temperatures it will decompose to pyrobitumen (Munz et al. 2002). According to the Landis & Castaño (1995) classification (cf. Appendix Tab. 1), based on high reflection, bitumen can be named pyrobitumen. Pyrobitumen is a black, solid substance with a main containing of carbon. Bacterial degradation and high temperatures has influenced the mentioned substance. Generally observations of pyrobitumen are important as it shows that the oil is coming from a sedimentary host rock (Pedersen 2005). Bitumen commonly occurs within fracture zones or breccias (Welin 1966; Aberg et al. 1985). It also associates with quartz veins (Munz et al. 2002).

Pyrobitumen has been observed in the Modum Complex, a Precambrian basement with quartz veins located in southern Norway. The metamorphic grade of the basement rocks is mostly amphibolites to granulite facies. A sedimentary succession including organic-rich shale overlies the basement. During late Palaeozoic and Mesozoic the area became subsequently eroded (Larson et al. 1999) and in the Carboniferous and Permian the Oslo Graben was formed (Munz et al. 2002). The Modum Complex is a well investigated area were petroleum associated with pyrobitumen has been discovered (Munz et al. 2002).

A biogenic origin is clearly indicated by the $\delta^{13}C$ composition in the pyrobitumen (Eakin 1989) and gas

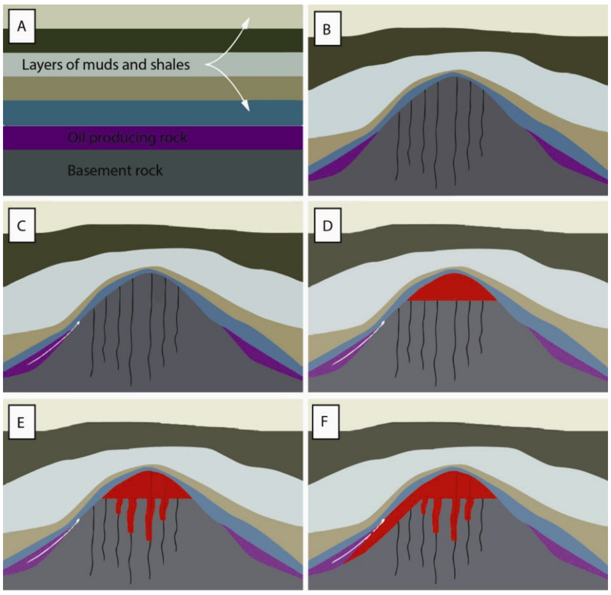


Fig. 1. Suggested way how oil can accumulate in crystalline basement rocks. **A.** Shows a sedimentary basin with and oil-producing source rock overlain by less permeable cap rocks. **B.** Shows tectonic uplift of the basement rock, and the black vertical stripes. **B-F**. Represents fractures caused by the tectonic movements. **C.** Oil migrates along the basement rock (pressure, capillary forces). **D-F.** When reaching the thick layers of muds/shales it will accumulate and migrate downwards in the fractured zones of the basement rock. Figure modified from Hurricaneenergy.

components (Karlsen et al. 1993). Both fluid inclusions and solid phases (bitumen and chlorite) are given evidences of the physical conditions of the petroleum condition during basement infiltration (Munz et al. 2002).

Pressure, temperature, time and composition (P-T-t-X) will be crucial parameters concerning downward fluid flows. The containing veins can also be of great importance as they could work as a transport system of the petroleum fluids. To make the petroleum migrate downwards a higher fluid pressure must exist in the overlying sediments, for example in a basin which has been affected by tectonic compressions. Rapid deposition and compression in the Modum Complex lead to overpressure. On the other hand, the crystalline basement was dry and fractured, which caused it to have a low pressure. Overall, these conditions made it possible for the oil to migrate and accumulate in the basement (Munz et al. 2002).

1.2 Aims and objectives

This literature study aims to outline and discuss the relationship between deep chemical weathering of crystalline basement rocks and the presence of hydrocarbons in such rocks. Oil bearing crystalline basement rocks derived from drill cores from the Utsira High has been found and are today of great interest for potential future petroleum production. During the course of this study, two field trips to two key localities have been made. The purpose was to study basement rocks with fractures and weathered material. The survey areas include the large island Bømlo, southwestern Norway, and Ivön in Lake Ivösjön, southeastern Sweden. By describing the relationship between deep chemical weathering and hydrocarbon migration in crystalline basement, together with collected data, this thesis help to improve the overall understanding of new alternative drilling offshore in crystalline basement. The rocks of the Precambrian Modum Complex, in the Oslo region, will work as a comparison as the basement of Utsira High is relative unexplored. The project and literature study was a co-operation between Lund University and Lundin Norway AS.

2. Geological background

2.1 Caledonian Orogeny of Scandinavia

The assembly of the 1800 km long Caledonian mountain belt of Scandinavia and northeast Greenland was caused by a continental collision between Baltica and Laurentia, starting in the early Ordovician and culminating in the mid Silurian to early Devonian (Roberts 2003; Fossen & Dunlap 2006; Gee et al. 2008; Slagstad et al. 2011). The roots of the mountain chain are exposed in Norway, western Sweden, westernmost Finland, on Svalbard and in northeast Greenland. Palaeozoic strata overlain by younger sedimentary successions are today covering the shelves between west-

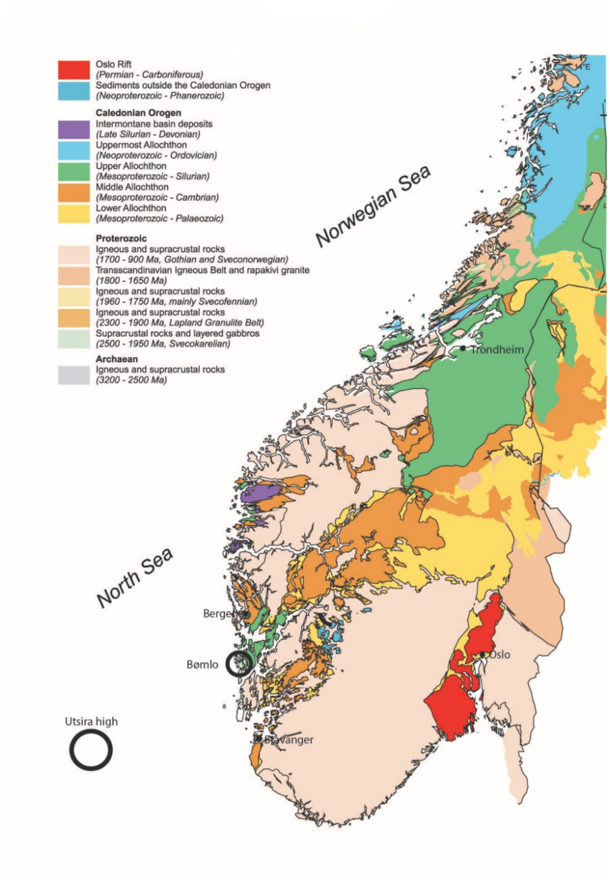


Fig. 2. Geological map of Norway, showing the location of the Utsira High, and Bømlo Island (modified from Slagstad et al. 2011).

ern Scandinavia and eastern Greenland. The collision resulted in a subduction zone where a partial melting of the underthrust (Baltica) caused island arcs and back-arc basins. Ocean-derived allochthons and Cambro-Ordovician Iapetus sea floor sediments are also preserved in the thrust sheet. The subduction of the Baltica basement resulted into Lower, Middle, Upper and Uppermost allochthons (cf. Fig. 2) with a cover of late Neoproterozoic to Silurian metasedimentary depositions (Gee et al. 2008; Labrousse et al. 2010). The Upper Allochthon is dominated by sedimentary and igneous rocks including ophiolites and island-arc complexes where mature magmatic intrusive complexes, such as the Sunnhordland Batholith, the West Karmøy Igneous Complex and the Krossneset granite, constitute the main part of the southwest part of the Upper Allochthon (Stephens 1988).

The Sunnhordland Batolith together with Krossneset granite constitute two of the magmatic intrusives that form the northern part of Bømlo (Stephens 1988). Observations of similarities in the fractures between the basement of Ona sira, southwestern Norway, and Utsira High are shown in Fig. 3. Core samples taken from Utira High have shown petroleum occurrences in

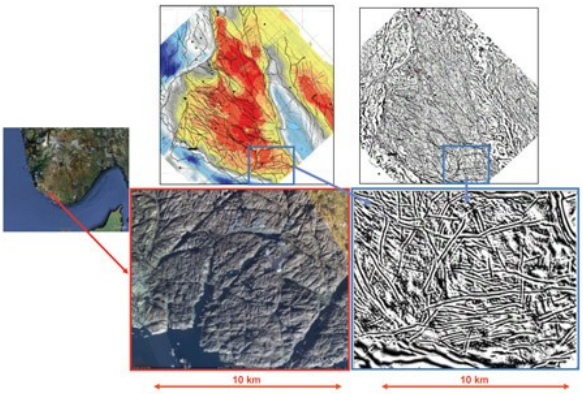


Fig. 3. Illustration by Lundin Norway AS. Similarities in the fracture pattern between Ona sira onshore and Utsira High offshore. To the left bottommost: fracture zones in basement at Ona sira, Rogaland. Above and to the right: fracture zones in basement at Utsira High (Carstens 2011).

weathered material caused by deep chemical weathering processes during the Mesozoic. The phenomenon of deep weathering has also been documented at Ivö Island where fresh granite are overlain by saprolite (Lidmar-Bergström 1997). The granites of Bømlo are related to the granites of Utsira High. Therefore Bømlo is a key locality for analog surveys.

2.2 Utsira High

The high of Utsira with the Upper Jurassic Draupne Formation has turned out to be a potentially good petroleum reservoir rock. Submarine sand fans of Paleocene and Eocen age compose a combination of stratigraphic and structural traps and the Jurassic sandstones are interpreted as high quality reservoirs (Isaksen & Ledje 2001). The Utsira High is a large basement high and is located offshore in the southwest part of Norway between the South Viking Graben and Stord Basin (Isaksen & Ledje 2001; Wild & Briedis 2010). Both the Viking Graben and the Stord Basin has been subject to rifting of the North Sea in the Triassic and Jurassic, followed by a thermally controlled subsidence in the end of Jurassic. Uplift in the Palaeogene result in a large sedimentary deposition and caused a basin-floor (Wild & Briedis 2010).

The present structure and an important phase of the Viking Graben came during the Jurassic Kimmerian tectonic phases where the mid-Kimmerian phase (Middle Jurassic) (Curtin & Ballestad 1986; Isaksen & Ledje 2001) developed in the significant Middle Jurassic sandstone reservoirs. An extensive transgression and deep water sedimentation caused by an eustatic increased sea level create the rift system in the Late Jurassic. This resulted in organic-rich shale depositions called the Kimmeridgian to Volgian-Ryazanian Draupne Formation. They are the primary source rocks at the Utsira High and the Viking Graben (Isaksen & Ledje 2001). A secondary source rock with differences of the petroleum quality generates from the Oxfordian Heather Formation. The hydrocarbons take their ways by margin pathways through faults and accumulation in the startigraphic and structural traps at the Tertiary level.

Stord Basin is located east of Viking Graben, next to Utsira high (Biddle & Rudolph 1988). Stord County lies by the coast of Stord Basin with Bømlo County as a neighbour, both belonging to Sunnanhordland. Geochemical analysis shows on similarities of ages, petrology and tectonic origin between the granites of Utira High and the granites of Sunnanhordland (Slagstad et al. 2011). Measurements on two investigated wells at the Utsira High give proof that the basement is a part of the Caledonides (Lundmark 2011).

3. Deep chemical weathering and saprolite formation

Deep weathering is a common phenomenon in many parts of Europe e.g. northern Ireland, central and northeast Scotland and southern Sweden (Migoń & Lidmar-Bergström 2001). It was long thought that relief in basement rock at high latitudes was the result of glacial erosion. However many landforms have resulted from deep chemical weathering of basement rocks in warm climates tens to hundred of million years ago. Today chemical weathering occurs in humid conditions were acid groundwater leaks its way through bedrocks along weakness zones. Therefore it is likely that the landforms observed in parts of Scandinavia resulted from deep weathering in a tropic or sub-tropic environment in the Mesozoic (Lidmar-Bergström et al. 1999). Deep weathering altered minerals in the basement rock into clay minerals when acid water leaked through fracture zones. Conversion of iron oxides (high magnetic minerals oxidise to low magnetic minerals) and silicate minerals e.g. magnetite altering to hematite and silicate minerals alterations to clay minerals. The oxidation of high magnetic minerals into low magnetic minerals will generate negative deviations in the Earth´s magnetic field (Olesen et al. 2012) and can be proved in field by measurement the magnetic susceptibility (cf. Fig. 4). As the alteration of basement leads through fracture zones denudation around the edges will form rounded structures (cf. Fig. 5 A-D). The rest product is called saprolite. Saprolite is an unsorted weathering residue than constitutes clay minerals, such as smectite and kaolinite, and coarse-grained grus, and it occurs along structural weakness zones (Olesen et al. 2012). Scandinavian clay- and grus weathered material appears from different time periods. Clay-bearing weathering is interpreted as related to the Mesozoic Era whereas grus weathering took place in the Quaternary (Peulvast 1985; Sorensen 1988; Lidmar-Bergström et al. 1999).

Discoveries of saprolite layers through geophysical studies has been made in e.g. Kjose (Vestfold) and the Oslofjord region, where the thickness reach up to 200 m (Olesen et al. 2012). A 60 m thick saprolite has been

Fig. 4. Alteration of iron oxides in the basement rock will result in negative deviations when measuring the Earth´s magnetic field. Unweathered granititc basement has higher values of magnetic susceptibility than the grus-weathered material. All magnetic susceptibility: x10^{-3} Sl **A.** Unweathered: 7.2-8.8 **B.** Weathered: 2.5-12.5 **C.** Unweathered: 5.7-12.5.

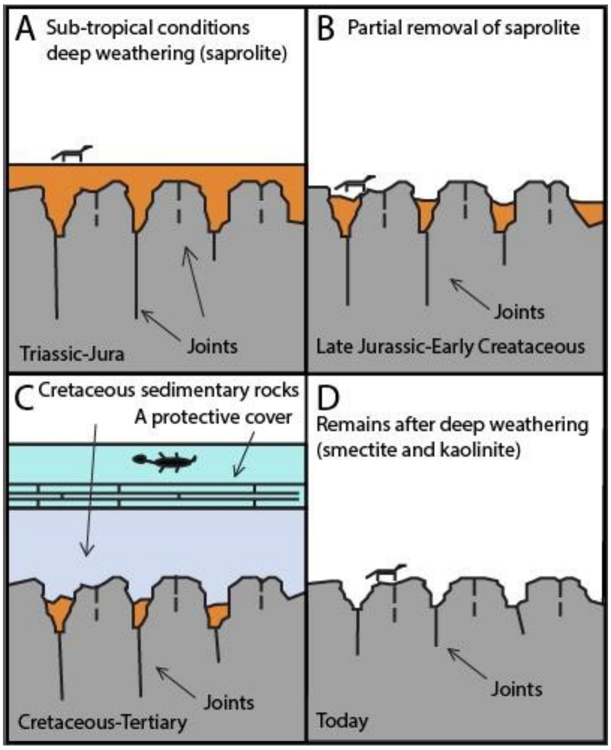


Fig. 5. Schematic illustration modified from (Olesen et al. 2012). **A.** Influences of deep weathering during Triassic-Jurassic into pre-existing joints. **B.** Partial removing and erosion of the weathered material (saprolite) during Late Jurassic or Early Cretaceous. **C.** Transgression resulted in deposition of layers of shale and limestone above the chemically weathered basement and preserved the saprolite. **D.** Uplifts in the Neogene exposed the surfaces and the saprolite is reworked and eroded. Remnants will show a joint valley landscape or an undulating hilly landscape.

observed along a structural weakness zone in Scania (Lidmar-Bergström et al. 1999). Uplift in the early Cainozoic exposed the Mesozoic erosion surface and continued denudation into Neogene (Lidmar-Bergström et al. 1999). The weathering occurs mostly all over a paleosurface of bedrock but can also be located deeper if joints and faults in the weakness zones are favourable. Evidences of deep weathering on the mainland are unfortunately often destroyed by denudation and erosion (Olesen et al. 2012).

Deep weathering can influence large scale landscapes by creating a joint valley landscape or undulating hilly landscape (cf. Fig. 5). The shape of the landform depends on the mineralogical composition of bedrock, space between the joints and weathering history (Lidmar-Bergström 1995). One theory of joint valley landscape forming is when an area during a short phase is exposed by a deep weathering, stripping, uplift and then renewed weathering. The renewed weathering will take place in the old weathered structure with a resulting expanding. Undulating hilly landscape includes longer phase of weathering and stripping and the relief amplitudes will increase into an undulating hilly landscape (Lidmar-Bergström 1995). Increased amplitude of the relief is highly depending on the prevailing climate. Tropic or sub-tropic environments create higher amplitudes and relief than arid environments. Longer influences of arid climates will at last result in a pediplain (Lidmar-Bergström 1995).

4. Field observations

4.1 Onshore basement deep weathering

A fieldwork was performed by Gunterberg in 2012 and 2013 in two locations; Bømlo, Norway, and Ivö Island, Sweden. Mapping of kaolin weathered fractures, fracture zones, cross zones and documentation of evidences for pre-glacial weathering was made. Also measurements of the magnetic susceptibility, strike and dip of the fractures, photographs and hand taken samples of kaolin were collected. The fieldwork documentation (cf. Fig. 6.) is to compare with the geology at Utsira high.

4.2 Bømlo

Bømlo is located in the Sunnanhordland region and belong to the Upper allochthon (Roberts 1980; Brekke et al. 1984). Bømlo is divided in five lithostratigrahic units: Lykling Ophiolite, Geitung Unit, Siggjo Complex, Vikafjord Group and the Langevåg group with the underlying Caledonian rocks (Brekke et al. 1984).

Around the central parts of Bømlo, the Lykling Ophiolite and the Geitung units are settled. The Lykling Ophiolite is dominated by ophiolites and is the oldest rock of Bømlo. The overlying Geitung Unit consist mostly of greenstones, quartzkeratophyres and volcaniclastic breccias. The Siggjo Complex overlies these units and comprises volcanic followed by the Vikafjord Group with e.g. conglomerate and limestones. On southernmost Bømlo the Langevåg Group appears with its marine basin.

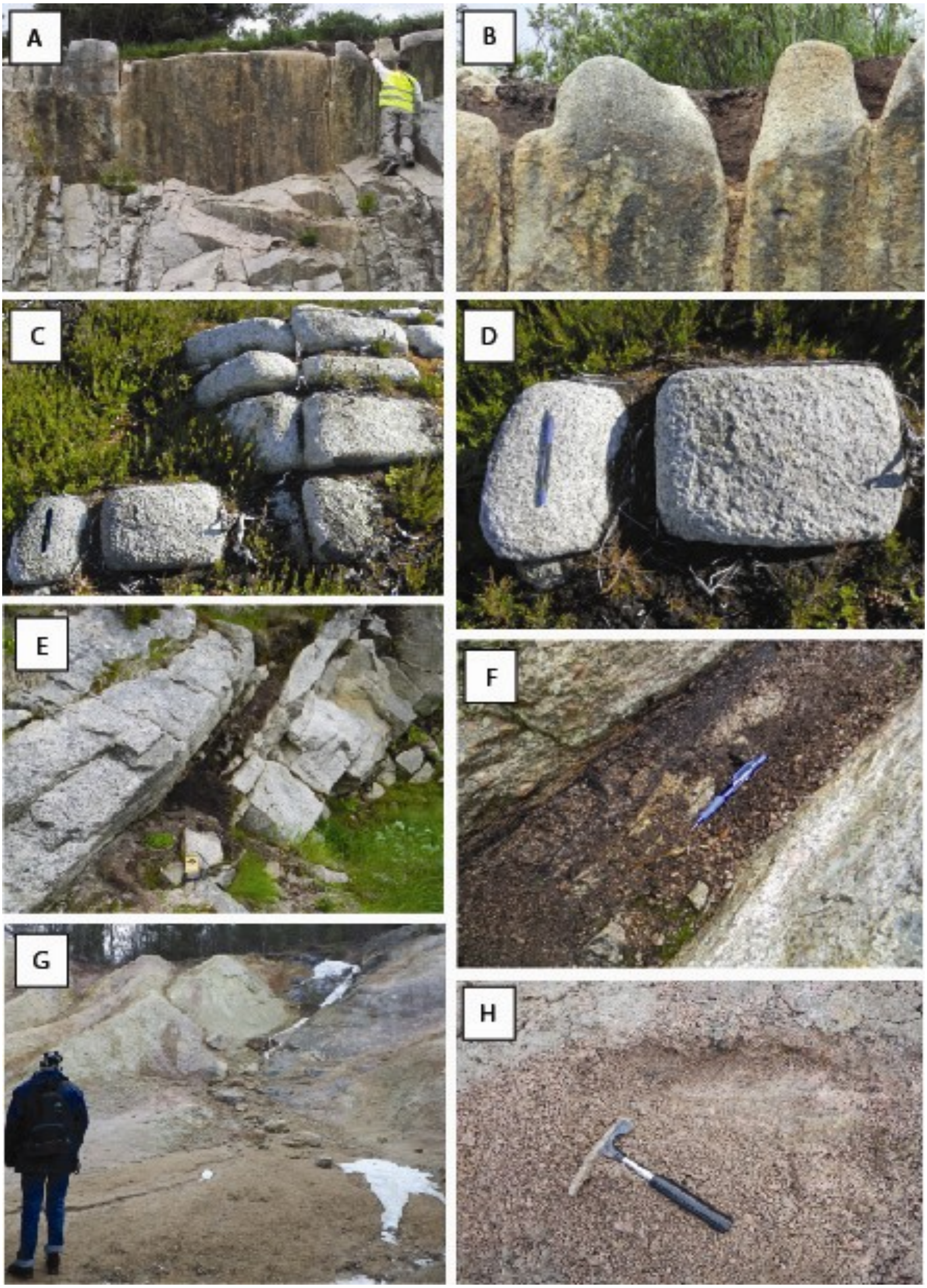


Fig. 6. Field work documentation. **A.** and **B.** Large and small scale of pre-glacial weathering, Bømlo . Fractures along the granite basement with typical rounded forms. **C.** and **D.** Rounded granite affected by deep weathering along fracture zones, Bømlo . **F.** and **E.** Granite with grus-weathering along fracture zones, Bømlo . **G.** Weathered granitic basement next to granitic unweathered basement, Ivö Island. **H.** Kaolin weathered material with a slightly weathered granitic basement beneath, Ivö Island.

Fig. 7. Map of Bømlo. Granitic basement is located north (NGU, 2013).

Stord Basin is located to the east of Viking Graben in the same area where the Utsira High is situated (Biddle & Rudolph 1988). Bømlo County lies next to Stord County and is one of the two investigated key areas in this study. Slagstad et al. (2011) describes in their article geochemical similarities between the granites of the Utsira High and the granites in Sunnanhordland. The authors show similarities of ages, petrology and tectonic origin between the granites of Utsira High and the granites of Sunnanhordland. A reference to Fossen & Austrheim dates of the north located granites of Bømlo it shows similar ages. Other related areas with comparing intrusions and basement onshore and offshore are also present in Slagstad et al. (2011) article (cf. Slagstad et al., 2011).

The northern part of Bømlo is dominated by the Rolvsnes Granit/ Granodiorite as well as Krossnes granites, (Fig. 7). Rolvsnes Granit/ Granodiorite are the largest granite pluton of the Sunnanhordland batholiths. Pegmatite and aplite veins are common in the otherwise homogeneous granite. The Krossnes Granites is dated to 430 Ma (Fossen & Austrheim 1988). These granites are related to the investigated area of Rolvsnes granite and both are located in the north of Bømlo (Fossen & Austrheim 1988). Deep weathering during the Mesozoic influenced and formed some parts of the landscape of Bømlo. Evidences of deep weathering are shown in Fig. 4 A-D.

4.3 Ivö Island

Remnants of Mesozoic saprolites resting on crystalline basement of the Fennoscandian Shield can be found in several places. Deep kaolinitic weathering is commonly found beneath or close to exposed Lower Jurassic and Upper Cretaceous sediments (Lidmar-Bergström 1995). An abandoned quarry at Ivö Island, southeastern Sweden (Fig. 8), shows an exhumed weathering front capped by a kaolinitic weathering mantle. Field work at Ivö Island was performed together with Karna Lidmar-Bergström and Länsstyrelsen of Scania. The close relationship between the relief of the Precambrian basement and the Mesozoic weathering mantle makes the area a key locality for study of the properties of altered basement rocks (cf. 5 E-F) (Migoń & Lidmar-Bergström 2001).

The abandoned quarry had earlier been covered with Cretaceous limestone. Borings have shown that the saprolite was at least 30 metres thick before quarrying. The saprolite can easily be seen, sometimes

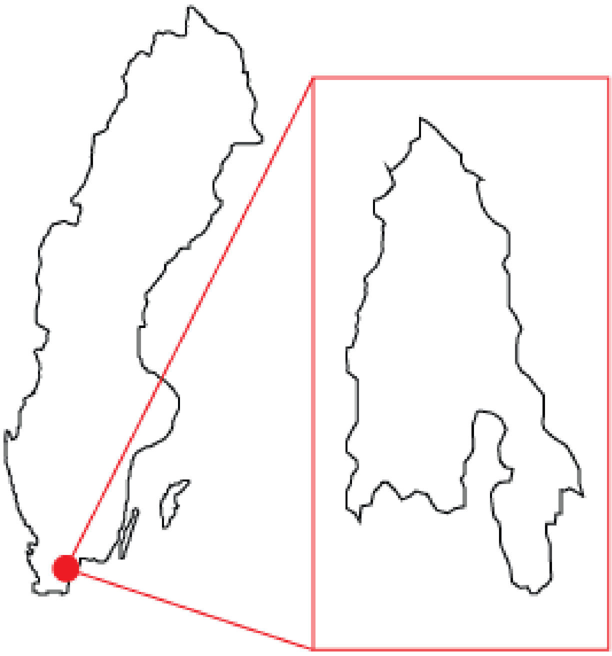


Fig. 8. Map of Ivö Island, southeastern Sweden.

together with unweathered granite boulders, and still some part of the limestone can be found in the hill slopes. The weathered material dominates by kaolinite (Migoń & Lidmar-Bergström 2001).

5. Discussion

During the Mesozoic the fractured basement at Utsira High was exposed for chemical weathering. This created an increased permeability in granites in which hydrocarbons have accumulated. Rock samples derived from coring show the evidence of these oil occurrences and make the Utsira High an important target for evaluating basement rocks as potential reservoir rocks. Although the area possesses the right geological conditions and possibilities for oil drilling, additional surveys and drillings has to be carried out before the extent of the oil occurrence can be predicted.

The granites at Bømlo are related in age, petrology and weathering with the granites at Utsira High, no oil occurrences have been found at Bømlo. But since the island is located on the mainland and is easily accessed it is a high quality analog area that can be studied and compared with Utsira High. To increase the knowledge of the Utsira High, mapping of Bømlo is of high value. An explanation for the absence of oil at Bømlo can be the lack of overlying sedimentary cover in the past. Deep weathered material has been observed in several places in Scandinavia. The weathered material can form many meters of saprolite layers with high porosity where infiltrated oil can accumulate. As samples from Utsira High has proved to contain oil in weathered basement rocks it is of a significant importance to understand the structure, composition, permeability and porosity of such material as well as the processes that are producing saprolites. In this aspect also Ivö Island, southeastern Sweden, is a key area. In outcrops at Ivö Island it is possible to study the relationship between the kaolinitic saprolite and the subjacent, both weathered and unweathered, granitic basement. The saprolite is of importance as the material can reveal the porosity and permeability of the weathered material. Different types of weathered material have been observed in the investigated areas. Bømlo as well as Utsira high contains grus-weathered and clay-weathered material whereas at Ivö Island mostly clay-bearing material occurs. Clay- and grus-weathered material of Scandinavia has, probably, formed during completely different periods of time. Clay-producing weathering is interpreted as of Mesozoic age whereas grus-weathering took place later, in the Quaternary(Peulvast 1985; Sorensen 1988; Lidmar-Bergström et al. 1999). These differences in weathered material is caused by a continued denudation in the Neogene (Lidmar-Bergström et al. 1999). As chemical weathering increases the size of fractures with an increase permeability petroleum can occur in the weakness zones. Depending on the weathered material type, it can be positive or negative considering fluid content. In some cases, fractured basement without connection to deep weathering will be of a higher value since the weathered material can act resisting of the fluid flow. Clay-bearing material will cause fluid-resistance whereas grus-bearing material, in return, can host considerably larger amounts of fluids. Ivö Island and Bømlo does not have favourable lithological conditions (e.g. no source rock) for petroleum formation. The absence of the right geology e.g. no potential source rock, Ivö Island as well as Bømlo does not increase petroleum remnants. The basement of the Utsira High and the basement of the Modum Complex have similarities in basementand geological settings. The lack of earlier studies at Utsira high concerning downward migration makes the downward migration at the Modum Comlex a potential comparison site. The Modum Complex is well investigated by Munz et al. (2002). The authors argue that the P-T-t-X is crucial parameters concerning downward fluid flows. Higher pressure must exist in the overlying sediments, for example in a basin which has been affected by tectonic compressions with resulting fractures. The similarities are well known in both basements. Today´s growing demand and elevated oil prices makes the Utsira High a specific area of great interest as an alternative petroleum resource. Further investigations of the Utsira High may result in a petroleum source rock with economic purpose. Expectations of double drilling in both sedimentary Jurassic sandstones and crystalline grus-weathered basement in the future are also high (Carstens 2011).

6. Conclusions

1) The economic interest for crystalline basement reservoirs is more common today; basis on increasing oil prices and pending decreases/exhausted sedimentary reservoirs.
2) Oil occurrences in the granites at the Utsira High lead to an analogue survey of the granites of Bømlo and the saprolite layers at Ivö Island. Drill cores prove that the oil is established in grus-weathered material found in fracture zones.
3) Deep weathering in southern Scandinavia is a phenomenon that occurred during the Mesozoic when the basement was exposed. It is found in several places in southwester Norway and southeaster Sweden.
4) Acid leaking groundwater in humid climate lead it way through fracture zones in basement and degraded the fresh basement rocks to saprolite. Alteration of iron oxides will results in a negative deviation in the Earth´s magnetic field. Mapping negative deviations will explore current weathered fractures. Deep weathering is found at Utsira High, Bømlo and Ivö Island.
5) P-T-t-X concerning downward migration is of significant importance of fluid flows.

7. Acknowledgements

First of all I want to thank my extern supervisor Mats Andersson for his engagement and helpfulness during the entire project. Futhermore, I am grateful to my supervisor Mikael Calner as with corrections and advices made my report complete. I will also thank Oliver Björnfors for a great support for providing discussions, and at last Martin Qvarström for proof-reading parts of my thesis.

8. References

Aberg, G., Lofvendahl, R., Nord, A. G. & Holm, E., 1985: Radionuclide mobility in thucholitic hydrocarbons in fractured quartzite. Canadian Journal of Earth Sciences 22, 959-967.

Arid, P. 2011. How oil drilling works. Retrieved 22 April 2011, from www.kingdomdrilling.co.uk.

Biddle, K. T. & Rudolph, K. W., 1988: Early Tertiary structural inversion in the Stord Basin, Norwegian North Sea. Journal of the Geological Society 145, 603-611.

Brekke, H., Furnes, H., Nordas, J. & Hertogen, J., 1984: Lower Paleozoic convergent platemargin volcanism on Bomlo, SW Norway, and its bearing on the tectonic environments of the Norwegian Caledonides. Journal of the Geological Society 141, 1015-1032.

Carstens, H. 2011. Gammelt grunnfjell - mettet med olje. Retrieved 16 April 2013, from http://www.geo365.no/olje_og_gass/mettet-med-olje/.

Curtin, D. P. & Ballestad, S., 1986: South Viking Graben; habitat of Mesozoic hydrocarbons. In: A. M. Spencer (ed.) Habitat of hydrocarbons on the Norwegian continental shelf; proceedings of an international conference. Graham & Trotman, London, United Kingdom. 153-157 pp.

Eakin, P. A., 1989: The origin and properties of uranium-niobium-tantalum mineralised hydrocarbons at Naresto, Arendal, southern Norway. Norsk Geologisk Tidsskrift 69, 29-37.

Fossen, H. & Austrheim, H., 1988: Age of the Krossnes Granite, West Norway. Bulletin - Norges Geologiske Undersokelse 413, 61-65.

Fossen, H. & Dunlap, J., 2006: Age constraints on the late Caledonian (Scandian) deformation in the Major Bergen Arc, SW Norway. Norsk Geologisk Tidsskrift 86, 59-70.

Gee, D. G., Fossen, H., Henriksen, N. & Higgins, A. K., 2008: From the early Paleozoic platforms of Baltica and Laurentia to the Caledonide Orogen of Scandinavia and Greenland. Episodes 31, 44-51.

Hurricaneenergy. 2013. How does oil get into the basement? Retrieved 21 May 2013, from http://www.hurricaneenergy.com/Expertise/Whatarebasementreservoirs/Howdoesoilgetintothebasement/.

Isaksen, G. H. & Ledje, H. I., 2001: Source rock quality and hydrocarbon migration pathways within the greater Utsira High area, Viking Graben, Norwegian North Sea. American Association of Petroleum Geologists Bulletin 85, 861-883.

Karlsen, D. A., Nedkvitne, T., Larter, S. R. & Bjorlykke, K., 1993: Hydrocarbon composition of authigenic inclusions: application to elucidation of petroleum reservoir filling history. Geochimica et Cosmochimica Acta 57, 3641-3659.

Labrousse, L., Hetenyi, G., Raimbourg, H., Jolivet, L. & Andersen, T. B., 2010: Initiation of crustal scale thrusts triggered by metamorphic reactions at depth; insights from a comparison between the Himalayas and Scandinavian Caledonides. Tectonics 29.

Landis, C. R. & Castano, J. R., 1995: Maturation and bulk chemical properties of a suite of solid hydrocarbons. Organic Geochemistry 22, 137-149.

Larson, S. A., Tullborg, E.-L., Cederbom, C. & Stiberg, J.-P., 1999: Sveconorwegian and Caledonian foreland basins in the Baltic Shield revealed by fission-track thermochronology. Terra Nova 11, 210-215.

Lidmar-Bergström, K., 1995: Relief and saprolites through time on the Baltic Shield. Geomorphology 12, 45-61.

Lidmar-Bergström, K., 1997: A long-term perspective on glacial erosion. Earth surface processes and landforms 22, 297-306.

Lidmar-Bergström, K., Olsson, S. & Roaldset, E. 1999: Relief Features and Palaeoweathering Remnants in Formerly Glaciated Scandinavian Basement Areas. In M. Thiry & R. Simon-Coincon (eds.): Palaeoweathering, palaeosurfaces and related continental deposits, 275-301. Special Publication 27, International Association of Sedimentologists, Blackwell Science.

Lundmark, A. M., 2011: Zircon U-Pb LA-ICPMS age determinations and Lu-Hf analyses of basement granitoids, Utsira High, the North Sea.

Migoń, P. & Lidmar-Bergström, K., 2001: Weathering mantles and their significance for geomorphological evolution of central and northen Europe since the Mesozoic. Earth-Science Reviews 56, 285-324.

Munz, I. A., Yardley, B. W. D. & Gleeson, S. A., 2002: Petroleum infiltration of high-grade basement, South Norway: Pressure-Temperature-time-composition (P-T-t-X) constraints. Geofluids 2, 41-53.

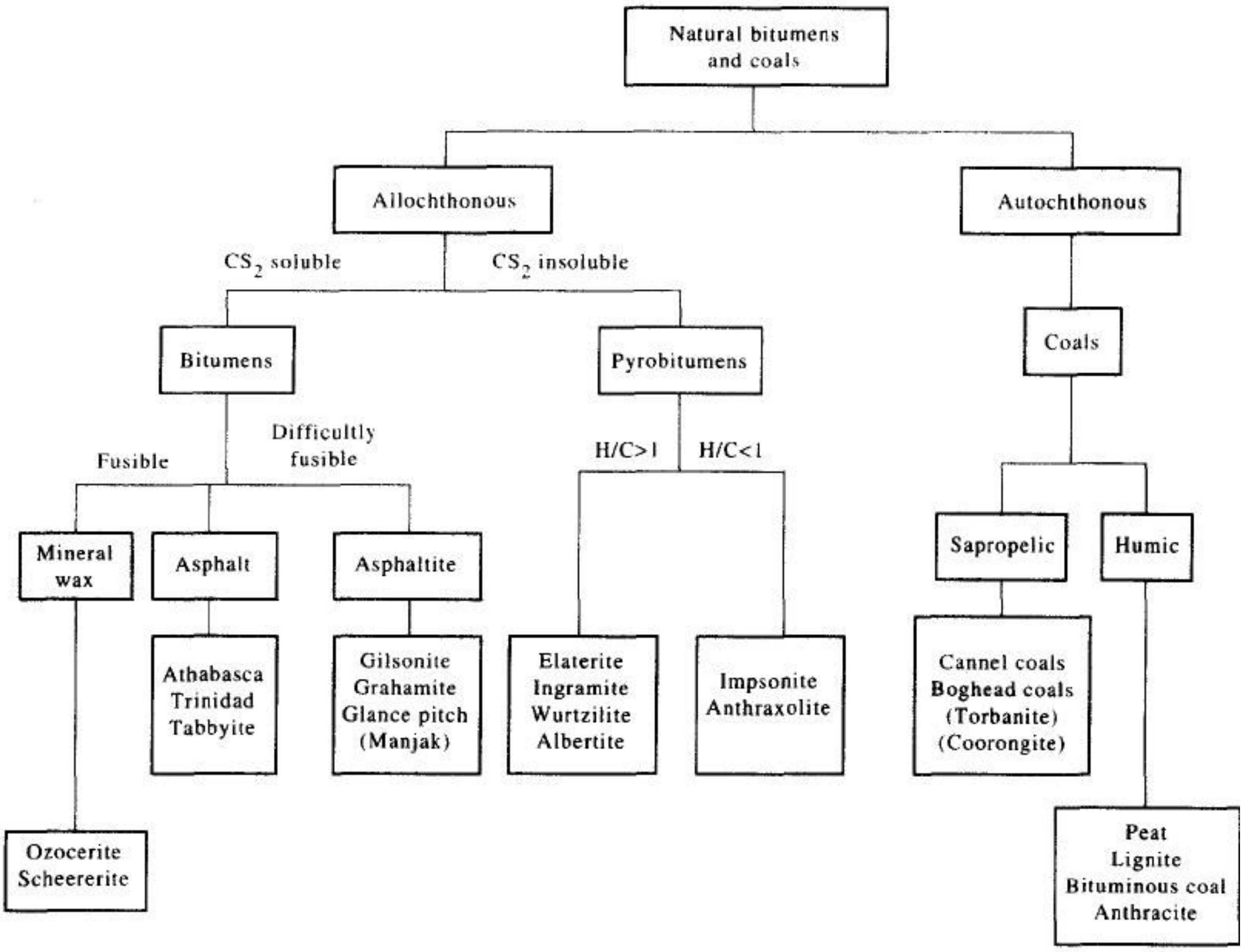
Nelson, R. A., 2001: Geologic analysis of naturally fractured reservoirs. Gulf Publishing Co. Book Division.

Norsk geologisk undersøkelse. 2013: NGU165706 [Map], 4845111 667671135. Berggrunn Nasjonal berggrunnsdatabase. Retrived from http://geo.ngu.no/servlet/lagKartbilde. 1:50 000. 15 May 2013.

Olesen, O., Bering, D., Brönner, M., Dalsegg, E., Fabian, K., Fredin, O., Gellein, J., Husteli, B., Mag-

nus, C., Rønning, S., Solbakk, T., Tønnesen, J. & Øverland, J., 2012: Tropical Weathering In Norway, TWIN Final Report.
Pedersen, J. H., 2005: Olje fra oldtiden. GEO 8, 40-42.
Peulvast, J. P., 1985: In situ weathered rocks on plateaus, slopes and strandflat areas of the Lofoten-Vesteralen, North Norway. Fennia 163, 333-340.
Roberts, D., 1980: Petrochemistry and palaeogeographic setting of the Ordovician volcanic rocks of Smola, central Norway. Norges Geologiske Undersokelse 359, 43-60.
Roberts, D., 2003: The Scandinavian Caledonides: event chronology, palaeogeographic settings and likely, modern analogues. Tectonophysics 365, 283-299.
Salah, M. G. & Alsharhan, A. S., 1998: The Precambrian basement: a major reservoir in the rifted basin, Gulf of Suez. Journal of Petroleum Science and Engineering 19, 201-222.
Slagstad, T., Davidsen, B. & Daly, J. S., 2011: Age and composition of crystalline basement rocks on the Norwegian continental margin: offshore extension and continuity of the Caledonian-Appalachian orogenic belt. Journal of the Geological Society 168, 1167-1185.
Sorensen, R., 1988: In-situ rock weathering in Vestfold, southeastern Norway. Geografiska Annaler, Series A 70 A, 299-308.
Stephens, M., 1988: The Scandinavian Caledonides: a complexity of collisions. Geology Today 4, 20-26.
Welin, E., 1966: The occurrence of asphaltite and thucholite in the Precambrian bedrock of Sweden. Geologiska Foereningen i Stockholm Foerhandlingar 87, Part 4, 509-526.
Wild, J. & Briedis, N., 2010: Structural and stratigraphic relationships of the Palaeocene mounds of the Utsira High. Basin Research 22, 533-547.

9. Appendix



Appendix. 1. Classification of solid bitumen, based on high reflection. Modified by Landis & Castano (1995).

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

294. Flodhammar, Ingrid, 2011: Lövestads åsar: En isälvsavlagring bildad vid inlandsisens kant i Weichsels slutskede. (15 hp)
295. Liu, Tianzhuo, 2012: Exploring long-term trends in hypoxia (oxygen depletion) in Western Gotland Basin, the Baltic Sea. (45 hp)
296. Samer, Bou Daher, 2012: Lithofacies analysis and heterogeneity study of the subsurface Rhaetian–Pliensbachian sequence in SW Skåne and Denmark. (45 hp)
297. Riebe, My, 2012: Cosmic ray tracks in chondritic material with focus on silicate mineral inclusions in chromite. (45 hp)
298. Hjulström, Joakim, 2012: Återfyllning av borrhål i geoenergisystem: konventioner, metod och material. (15 hp)
299. Letellier, Mattias, 2012: A practical assessment of frequency electromagnetic inversion in a near surface geological environment. (15 hp)
300. Lindenbaum, Johan, 2012: Identification of sources of ammonium in groundwater using stable nitrogen and boron isotopes in Nam Du, Hanoi. (45 hp)
301. Andersson, Josefin, 2012: Karaktärisering av arsenikförorening i matjordsprofiler kring Klippans Läderfabrik. (45 hp)
302. Lumetzberger, Mikael, 2012: Hydrogeologisk kartläggning av infiltrationsvattentransport genom resistivitetsmätningar. (15 hp)
303. Martin, Ellinor, 2012: Fossil pigments and pigment organelles – colouration in deep time. (15 hp)
304. Rådman, Johan, 2012: Sällsynta jordartsmetaller i tungsand vid Haväng på Österlen. (15 hp)
305. Karlstedt, Filippa, 2012: Jämförande geokemisk studie med portabel XRF av obehandlade och sågade ytor, samt pulver av Karlshamnsdiabas. (15 hp)
306. Lundberg, Frans, 2012: Den senkambriska alunskiffern i Västergötland – utbredning, mäktigheter och faciestyper. (15 hp)
307. Thulin Olander, Henric, 2012: Hydrogeologisk kartering av grundvattenmagasinet Ekenäs-Kvarndammen, Jönköpings län. (15 hp)
308. Demirer, Kursad, 2012: U-Pb baddeleyite ages from mafic dyke swarms in Dharwar craton, India – links to an ancient supercontinent. (45 hp)
309. Leskelä, Jari, 2012: Loggning och återfyllning av borrhål – Praktiska försök och utveckling av täthetskontroll i fält. (15 hp)
310. Eriksson, Magnus, 2012: Stratigraphy, facies and depositional history of the Colonus Shale Trough, Skåne, southern Sweden. (45 hp)
311. Larsson, Amie, 2012: Kartläggning, beskrivning och analys av Kalmar läns regionalt viktiga vattenresurser. (15 hp)
312. Olsson, Håkan, 2012: Prediction of the degree of thermal breakdown of limestone: A case study of the Upper Ordovician Boda Limestone, Siljan district, central Sweden. (45 hp)
313. Kampmann, Tobias Christoph, 2012: U-Pb geochronology and paleomagnetism of the Westerberg sill, Kaapvaal Craton – support for a coherent Kaapvaal-Pilbara block (Vaalbara). (45 hp)
314. Eliasson, Isabelle Timms, 2012: Arsenik: förekomst, miljö och hälsoeffekter. (15 hp)
315. Badawy, Ahmed Salah, 2012: Sequence stratigraphy, palynology and biostratigraphy across the Ordovician-Silurian boundary in the Röstånga-1 core, southern Sweden. (45 hp)
316. Knut, Anna, 2012: Resistivitets- och IP-mätningar på Flishultsdeponin för lokalisering av grundvattenytor. (15 hp)
317. Nylén, Fredrik, 2012: Förädling av ballastmaterial med hydrocyklon, ett fungerande alternativ? (15 hp)
318. Younes, Hani, 2012: Carbon isotope chemostratigraphy of the Late Silurian Lau Event, Gotland, Sweden. (45 hp)
319. Weibull, David, 2012: Subsurface geological setting in the Skagerrak area – suitability for storage of carbon dioxide. (15 hp)
320. Petersson, Albin, 2012: Förutsättningar för geoenergi till idrottsanläggningar i Kallerstad, Linköpings kommun: En förstudie. (15 hp)
321. Axbom, Jonna, 2012: Klimatets och människans inverkan på tallens etablering på sydsvenska mossar under de senaste århundradena – en dendrokronologisk och torvstratigrafisk analys av tre småländska mossar. (15 hp)

322. Kumar, Pardeep, 2012: Palynological investigation of coal-bearing deposits of the Thar Coal Field Sindh, Pakistan. (45 hp)
323. Gabrielsson, Johan, 2012: Havsisen i arktiska bassängen – nutid och framtid i ett globalt uppvärmningsperspektiv. (15 hp)
324. Lundgren, Linda, 2012: Variation in rock quality between metamorphic domains in the lower levels of the Eastern Segment, Sveconorwegian Province. (45 hp)
325. Härling, Jesper, 2012: The fossil wonders of the Silurian Eramosa Lagerstätte of Canada: the jawed polychaete faunas. (15 hp)
326. Qvarnström, Martin, 2012: An interpretation of oncoid mass-occurrence during the Late Silurian Lau Event, Gotland, Sweden. (15 hp)
327. Ulmius, Jan, 2013: P-T evolution of paragneisses and amphibolites from Romeleåsen, Scania, southernmost Sweden. (45 hp)
328. Hultin Eriksson, Elin, 2013: Resistivitetsmätningar för avgränsning av lakvattenplym från Kejsarkullens deponis infiltrationsområde. (15 hp)
329. Mozafari Amiri, Nasim, 2013: Field relations, petrography and 40Ar/39Ar cooling ages of hornblende in a part of the eclogite-bearing domain, Sveconorwegian Orogen. (45 hp)
330. Saeed, Muhammad, 2013: Sedimentology and palynofacies analysis of Jurassic rocks Eriksdal, Skåne, Sweden. (45 hp)
331. Khan, Mansoor, 2013: Relation between sediment flux variation and land use patterns along the Swedish Baltic Sea coast. (45 hp)
332. Bernhardson, Martin, 2013: Ice advance-retreat sediment successions along the Logata River, Taymyr Peninsula, Arctic Siberia. (45 hp)
333. Shrestha, Rajendra, 2013: Optically Stimulated Luminescence (OSL) dating of aeolian sediments of Skåne, south Sweden. (45 hp)
334. Fullerton, Wayne, 2013: The Kalgoorlie Gold: A review of factors of formation for a giant gold deposit. (15 hp)
335. Hansson, Anton, 2013: A dendroclimatic study at Store Mosse, South Sweden – climatic and hydrologic impacts on recent Scots Pine (*Pinus sylvestris*) growth dynamics. (45 hp)
336. Nilsson, Lawrence, 2013: The alteration mineralogy of Svartliden, Sweden. (30 hp)
337. Bou-Rabee, Donna, 2013: Investigations of a stalactite from Al Hota cave in Oman and its implications for palaeoclimatic reconstructions. (45 hp)
338. Florén, Sara, 2013: Geologisk guide till Söderåsen – 17 geologiskt intressanta platser att besöka. (15 hp)
339. Kullberg, Sara, 2013: Asbestkontamination av dricksvatten och associerade risker. (15 hp)
340. Kihlén, Robin, 2013: Geofysiska resistivitetsmätingar i Sjöcrona Park, Helsingborg, undersökning av områdets geologiska egenskaper samt 3D modellering i GeoScene3D. (15 hp)
341. Linders, Wictor, 2013: Geofysiska IP-undersökningar och 3D-modellering av geofysiska samt geotekniska resultat i GeoScene3D, Sjöcrona Park, Helsingborg, Sverige. (15 hp)
342. Sidenmark, Jessica, 2013: A reconnaissance study of Rävliden VHMS-deposit, northern Sweden. (15 hp)
343. Adamsson, Linda, 2013: Peat stratigraphical study of hydrological conditions at Stass Mosse, southern Sweden, and the relation to Holocene bog-pine growth. (45 hp)
344. Gunterberg, Linnéa, 2013: Oil occurrences in crystalline basement rocks, southern Norway – comparison with deeply weathered basement rocks in southern Sweden. (15 hp)

LUNDS UNIVERSITET

Geologiska institutionen
Lunds universitet
Sölvegatan 12, 223 62 Lund