

Lithostratigraphic correlations in an asymmetrical rift-basin: the Grythyttan area, W. Bergslagen, Sweden

Thea G. Van Meerten¹

*Geological Institute, University of Amsterdam, Nieuwe Prinsengracht 130,
1018 VZ Amsterdam, The Netherlands; ¹present address: Interfaculty Reactor Institute,
Delft Technical University, Mekelweg 15, 2629 JB Delft, The Netherlands*

Received 25 July 1987; accepted in revised form 25 January 1988

Key words: Lithostratigraphy, Proterozoic, subaqueous, rift zone, volcanic stages, Bergslagen Sweden.

Abstract

The predominantly felsic volcanics and intrusives of the Grythyttan basin in W. Bergslagen, are subdivided into four successive stages illustrating the development of a subaqueous continental rift zone. A change in the type of volcanism from Plinian type eruptions with thick fall deposits (stage 1) into Pelean type with extensive flows (stages 2, 3 and 4) is seen. A rift stage (stage 4) is unconformably superimposed on the former three stages and is characterized by bimodal felsic and mafic magmatism and the presence of turbiditic sediments. Fe-ore rich layers associated with fine ashes and limestones, are found throughout the sequence, with a major concentration in stage 3 preceding the rift stage proper. This ore deposition is associated with large hydrothermal activity and the ascent of basic material. Mn-rich, Fe-ores are found in the stages 2, 3 and 4, indicating the former presence of oxidation/reduction boundaries during ore formation. Ore formation and intrusive and volcanic activity should be considered as inter-related processes, linked to the development of an asymmetrical continental rift, presumably triggered by magmatic underplating.

Introduction

The Grythyttan basin in western Bergslagen was originally investigated by Sundius (1923), who divided the weakly deformed and metamorphosed supracrustals into five units (Table 1): a lower and an upper volcanic unit (hällflinta), a locally developed transitional greywacke unit and a lower and upper sedimentary (slate) unit. Conglomerates and two generations of basic rocks were recognized, the former deposited during and after a tectonic event coeval with the first granitic intrusions. More recently, a new tripartite division for W. Bergslagen was proposed by Oen et al. (1982), Oen (1987), corresponding with the successive phases of a de-

veloping continental rift. They divided the Bergslagen Supracrustal Sequence into a Lower, a Middle and an Upper Leptite Group respectively (Table 1). The Upper Leptite, Hällflinta and Slate Group is characterized by a bimodal chemical composition and the presence of sediments (Van der Velden et al. 1982), and largely coincides with the upper four units of Sundius (1923). Recently Oen (1987) and Kuipers (1987) suggested that the conglomerates should be incorporated in the Upper Leptite, Hällflinta and Slate group as well. In this paper they are considered identical with the debris flows and polymict breccias which mark the beginning of the rift stage proper (stage 4) in other parts of the area. Additionally, the Lower Leptite Group



is subdivided into two volcanic stages, while granophyric and granitic intrusives can be linked to their extrusive equivalents.

General features of the Grythyttan Basin

The area surrounding the Grythyttan basin is characterized by subcircular structures developed around subvolcanic intrusive domes, where the mainly felsic meta-volcanics are sub-vertical close to the intrusives, more gently dipping (up to 50°) further away. These structures are combined with cross-cutting narrow N-S trending basins (like Grythyttan), filled with bimodal volcanoclastics and sediments, displaying steep vertical structures. The contacts between the different structures consist of fault zones with escarpments marked by debris flows, polymict breccias and considerable amounts of often strongly altered and crushed basic material. The orientation of these rift related faults coincides with the directions of several pronounced fault systems with obscure mutual time relations that occur throughout W. Bergslagen.

In the Grythyttan-Hjulsjö region two main volcanic centres, Hjulsjö and Sundsjö (Fig. 1), can be

Table 1. Compilation of stratigraphic columns applied to the Grythyttan area. A = Sundius 1923, Magnusson 1970, B = Oen et al. 1982, Oen 1987. C = This paper. Radiometric ages compiled in Baker & Hellingwerf 1988, this volume.

A	B	C
dolerite dykes	Ga 12 13 14 15 16 17 18 19	dolerite dykes
post tectonic granites Hyttsjö intrusives	"post tectonic" younger granites	younger granites
younger greenstones	regional recrystallization Hyttsjö suite (post rift phase) compressive deformation rift phase-Upper Leptite and Slate Group Sediments-felsic volcanics- metabasic rocks- older granites	regional recrystallization- "compression"-Hyttsjö
orogenesis-folding- metamorphism- conglomerates- syntectonic granites	initial rift phase-Middle Leptite Group (felsic volcanics- limestones-BIF's) early volcanic phase - Lower Leptite Group (felsic volcanics)	Stage 4: older granites rhyolitic lavas bimodal volcanoclastics- mafic intrusives
older greenstones- grey slates-black slates-grey rocks- upper hälleflinta- lower hälleflinta		Stage 3: first basic material fine grained felsic ash flows- limestones-BIF's Stage 2: granophyres-Sundsjo granite- (spherulitic) rhyolitic lavas- felsic flows Stage 1: felsic fall tuffs

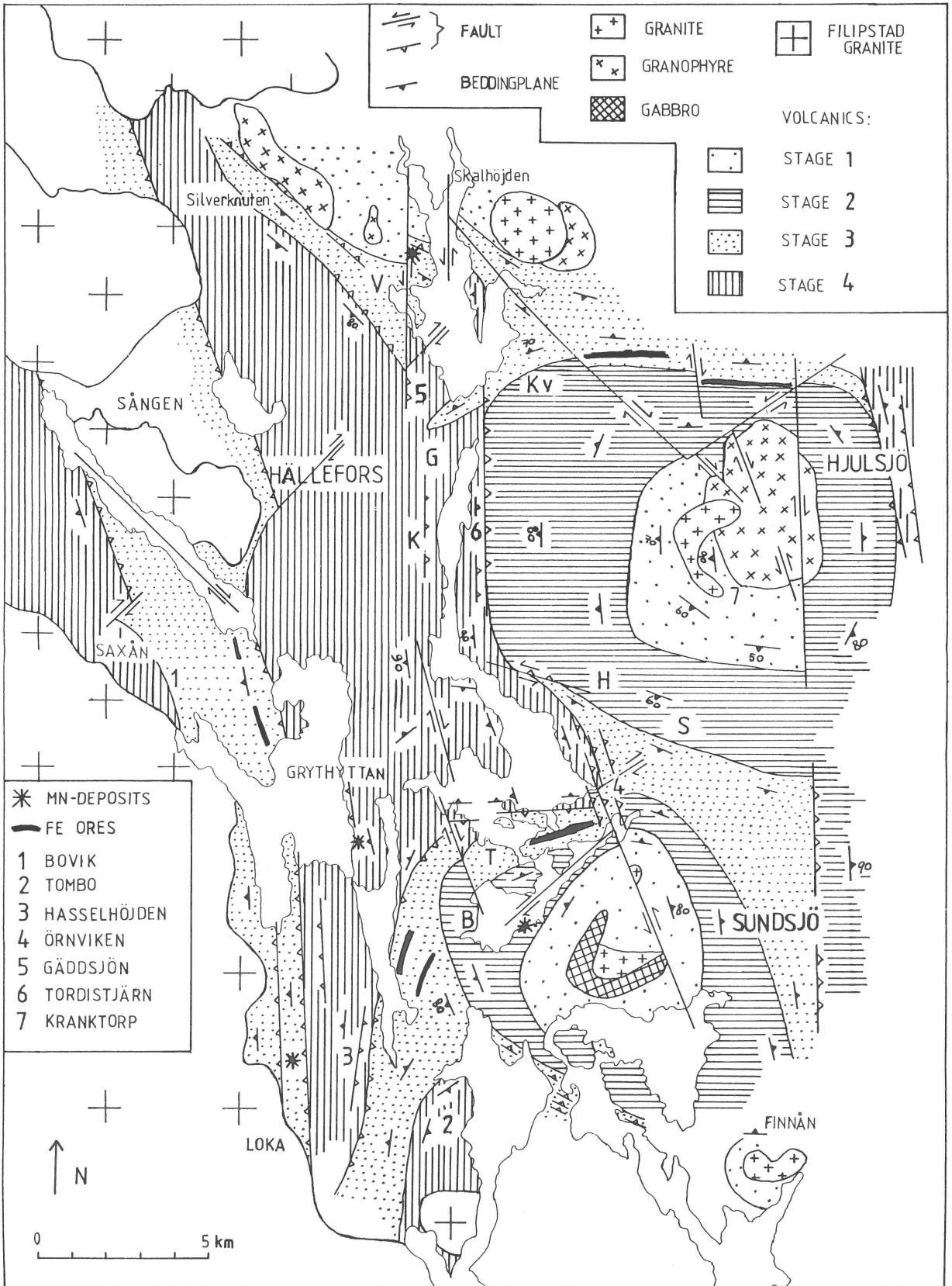
distinguished, represented by subvolcanic intrusive complexes and volcanics of the same age and composition (Baker 1985a). They reflect in part a paleotopographic phenomenon that is accentuated by the present erosion level. The Hjulsjö complex is composed of a high level (subsurface) intrusive granophyre, a hypersolvus granite, spherulitic rhyolitic lavas and numerous pyroclastic flow deposits (Baker 1985a). Several granophyric and granitic satellites (Skallhöjden, Silverknuten) and numerous lava plugs (Vinerhöjden, Kullberget) are also present. The Sundsjö complex, in the southern part, consists of a subsolvus granite, a hybrid gabbro, a crystal-rich porphyritic rhyolitic lava, less pyroclastic flows, and only one satellite (Finnån). Lava plugs are absent.

Subaqueous conditions with varying water depths prevailed throughout the whole rifting process in this part of Western Bergslagen, as is demonstrated by the presence of many limestones, exhalitic ores, hyaloclastites, pillow lavas, turbidites and reworked tuffs. Silicification and clay alteration is further evidence for submarine processes. Subaerial markers like accretionary lapilli and paleosols are absent in this area, though have been demonstrated in the Kopparberg area (Parr & Rickard 1987, Parr 1988, this volume).

Descriptions of the supracrustal rocks

The area around Grythyttan contains deposits belonging to all three stratigraphic groups defined by Oen et al. (1982). The predominantly felsic volcanics of the early volcanic phase or Lower Leptite Group, are subdivided into a lower fall tuff unit (stage 1) and an upper pyroclastic flow unit (stage 2). The initial rift phase or Middle Leptite Group, and the rift phase or Upper Leptite-Hälleflinta and Slate Group, are represented by the stages 3 and 4 respectively. All stages are composed of unique associations of rock types.

Fig. 1. Geological sketch map of the Grythyttan-Hjulsjö region. (Based on Oen et al. 1982, Baker 1985a, Hellingwerf 1986 and unpublished reports.) V = Vinerhöjden lava plug, G = Gillershöjden lava plug, K = Kullberget lava plug, Kv = Kvarnhagen lava flow, H = Holmtjärnen lava plug, S = Spikhöjden lava plug, B = Bengtsbo lava flow, T = Trolltjärnen lava flow.



Stage 1. The oldest deposits among the mainly felsic volcanics of the Grythyttan and Hjulsjö areas occur in the centres of the dome structures, around the granites of the main volcanic centres and their satellites (Fig. 1). These volcanics consist of ± 2 km thick monotonous pyroclastic fall deposits with minor ash flow intercalations in the lower and uppermost parts. The fall tuffs all show grading and sorting in upward and outward directions. The coarse basal parts are characterized by a lack of layering and the local presence of small, rounded, very fine grained, indistinct lithic fragments. The crystal and ash fall tuffs consist of abundant feldspar (albite), and fewer HT quartz phenocrysts next to rather abundant accessory minerals like orthite, zircon, and apatite (Fig. 2). Fiamme-like textures are occasionally present. The top layers are composed of extremely fine-grained ash sinks with local limestone and small, skarn-altered Fe-ore mineralizations. Many of them are reddish coloured through albitization. Some ashes contain numerous, very small, parallel orientated mica flakes. Near the contacts with the later granite intrusions the tuffs are often slightly brecciated and recrystallized, especially in the Sundsjö complex, where they show granophyric intergrowths thought to be caused by partial melting. Contact metamorphic minerals such as hornblende and biotite are common in these contact zones.

Stage 2. The stage 1 deposits are concordantly overlain by a 3–5 km thickness of pyroclastic flows (Fig. 1). At Hjulsjö these flows are initially unsorted (Fig. 3) with HT quartz and perthitic feldspar phenocrysts in a finer-grained, welded or non-welded matrix. Lithic fragments from underlying deposits are frequently found, comparable to reworked and agglomeratic intercalations, next to ash veneer deposits similar to those described by Walker et al. (1981). Flow-top breccias are cemented by either normal or jaspilitic chert. The N–S trending western outer products of the Hjulsjö complex now consist of vertically layered and sorted mass flows. Both volcanic centres (Hjulsjö and Sundsjö) contain characteristic thick, crystal-rich, flows with reworked basal layers (Fig. 4) in the E–W orientated parts of the domal structures. The area east of both

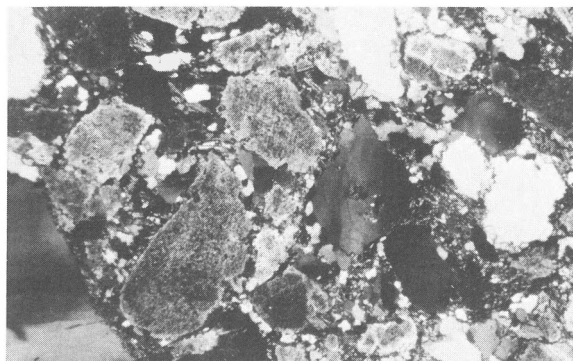


Fig. 2. Crystal fall tuff deposit (Stage 1) from the Hjulsjö area, crossed nicols, $2.5\times$ photo J.H. Baker.

centres is characterized by porphyritic flows with ignimbrite-like textures. Fine to extremely fine grained, often albitized ash flows and sinks, limestones, and skarn-altered exhalative Fe-ore mineralizations are more frequently found in stage 2 than in the stage 1 tuffs. These rock types are more frequent towards the top levels of stage 2, where they are accompanied by slightly reworked, *in situ* weathered and originally, presumably more hydrous layers.

The southern volcanic complex at Sundsjö (Fig. 1) comprises less diversified ash flows on its western side. Most of them are fine grained, recrystallized and more metamorphosed, containing hornblende and biotite as well as feldspar and quartz. This sequence ends with a lensoid, slightly unconformable, porphyritic lava, the Bengtsbo flow (Fig. 1). This inhomogeneous rhyolitic lava with crystal rich (HT quartz, perthitic feldspar) and aphyric (glass textures) parts, contains lithic ash fragments in the eastern basal layers and flow-top breccias and hyaloclastites in the west. Locally the lava shows flow deformation (shear) and quartz–feldspar, rest melt veins. Field data and chemical composition, indicate this is the extrusive equivalent of the Sundsjö granite. This granite comprises an undeformed, subsolvus and strongly albitized semi-circular granitic plug. A Långbantype, exhalative, Mn-rich Fe-ore mineralization is located at Sjögruvan (Igelström 1889), situated near an aphanitic flow breccia and a fault zone, NW of the granite. Mn rich iron ore horizons indicate the former pres-



Fig. 3. Unsorted flow from the lower part of Stage 2 in the Hjulsjö area, crossed nicols, 2.5 × photo J.H. Baker.

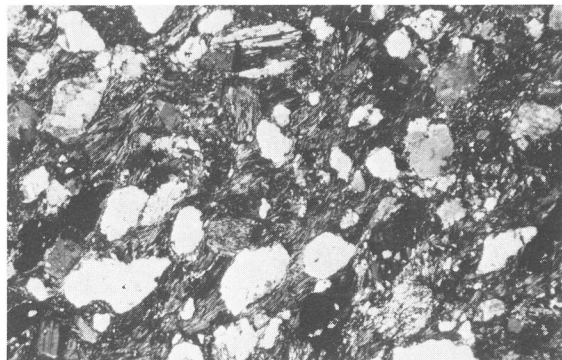


Fig. 4. Basal reworked part of crystal rich 'tuffaceous' flows of Stage 2, Sundsjö complex. Crossed nicols, 2.5 ×.

ence of oxidation-reduction boundaries during ore formation.

In the Hjulsjö area the upper parts of the stage 2 sequence are accompanied by several, single batches of volatile-rich (F, Cl) rhyolitic magma. Several granophyric intrusions (Hjulsjö, Silverknuten, Skallhöjden), spherulitic lava plugs and a flow, are all situated along radial and concentric faults related to the main volcanic summit. The plugs are accompanied by quartz-feldspar porphyritic feeder dykes. Felsic spherulitic lavas – a flow at Kvarnhammen and two plugs at Spikhöjden and Holmtjärnen (Fig. 1) – consist of lava cores surrounded and overlain by extensive flowbreccias and hyaloclastites, similar to those described by Pichler (1965), De Rosen-Spence et al. (1980) and Yamagushi & Dimroth (1985). Xenoliths are very rare, only a few rounded granophyric fragments in the lava plugs and a biotite-rich restite xenolith in one of the feeder dykes (Baker 1985a), have been found. Since the lava plugs are far smaller than the lava flows, they are more brecciated and hence open to secondary alteration processes. They also contain less F and Cl than the flows, similar to the granophyric intrusions.

The spherules in the lavas are often concentrated in zones and comprise two primary types, with microlite and aggregate cores (Figs. 5, 6), and a secondary type, with radial structure. The lavas are slightly porphyritic and contain ±10% embayed HT quartz, perthitic albite and albite phenocrysts and microlites. The matrix is composed of extreme-

ly fine grained intergrowths of quartz, LT albite or K-feldspar and chlorite, with characteristic indistinct grain boundaries. It occasionally shows plumose structures, an indication of incompletely recrystallized, devitrified or annealed glass. The more recrystallized, welded parts locally show perlitic cracks. Both phenocrysts and primary spherules are surrounded by small relict glass resorption rims and ore particles. The flow-brecciated and hyaloclastitic parts of the lavas show the breaking up of these glass rims into shardlike glass splinters with a quartz composition. The spherulitic lavas and also the granophyres, contain accessory minerals such as fluorite, rutile, orthite, sphene. Silicification and albitization of the lavas is found in various degrees, just like the forming of clay-alteration minerals like illite, smectite and chlorophyllite (XRD analysis), next to chlorite and micas.

The presumed feeder dykes at the southern side of the Hjulsjö complex contain an aphanitic matrix with slightly flow-aligned and embayed HT quartz, albite-oligoclase, microcline phenocrysts and glomeroporphyritic aggregates (Baker 1981). Contrary to the lavas they contain a small amount of interstitial biotite and more feldspar than quartz phenocrysts.

The granophyres are the intrusive equivalents of the lavas, and occur mainly as semi-circular plugs (Fig. 1). They consist of massive, mostly albitized, porphyritic rocks with HT quartz, (chessboard) albite and locally sericitized microcline phenocrysts and glomeroporphyritic aggregates in a microcryst-

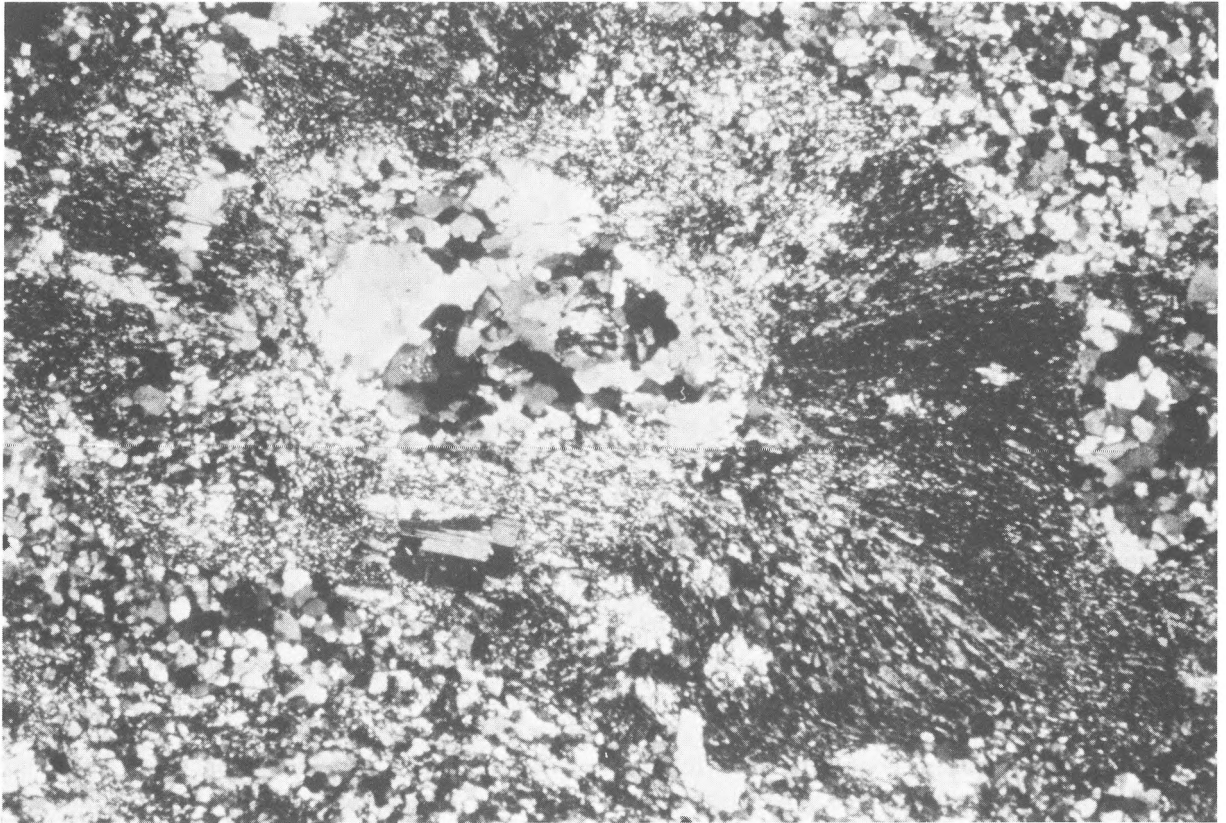


Fig. 5. Recrystallized glomeroporphyritic aggregate as core of a spherulitic outgrowth. Top of Stage 2, Spikhöjden lava plug. Crossed nicols, 3.5 \times .

talline matrix with some interstitial biotite and chlorite (Baker 1985a). Several types of granophyric qtz-fsp intergrowths have been recorded by Baker (1985a). They become indistinct towards the margins of the plugs. At Silverknuten (Fig. 1) a very coarse replacement type is found in the heavily brecciated, chlorite cemented, and stilpnomelane-bearing roof zone of the intrusion. All granophyres are cut by fine-grained, amphibolitic mafic dykes (see stage 3). An Ag-sulphide mineralization is located to the south of the intrusion (Jasiński 1983; Zakrzewski & Nugteren 1984; Hedstrom 1984). In the Loka and Sängen areas (Fig. 1) small exposures of the top levels of the stage 2 flows are found in slightly overturned sections along faults.

The stage 2 flows and accompanying lavas and subvolcanic intrusions represent a less explosive, Pelean type of volcanism.

Stage 3. The most distal, ashy deposits of Stage 1 and 2 volcanism are either reworked or weathered in situ, and accompanied by fresh, slightly coarser ash flows, thick limestones and extensive exhalative ore mineralizations. They represent a temporary period of volcanic inactivity and widespread hydrothermal alteration, defined here as stage 3. The generally finely laminated, clayey, calcareous and silicified ashes are almost invariably Na-enriched and LREE depleted during alteration (Van Meerten unpubl. data). They display abundant slump structures, in situ brecciation, and a characteristic 'snowflake' type of devitrification, which is found especially at the eastern borders of the final unconformable Stage 4. The thickest limestone beds and most distal ashes occur in the west near Bovik (Fig. 1). Near Hjulsjö the Stage 3 sequence unconformably overlies the Stage 2 flows (Baker

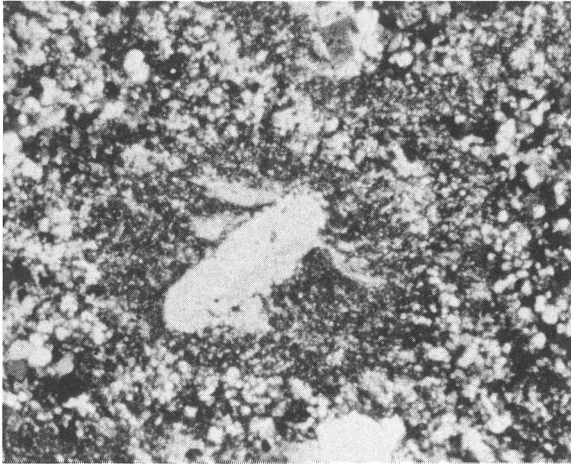


Fig. 6. Feldspar (Now LT albite) microlite as core of a spherulitic outgrowth. Crossed nicols, 2.5 \times .

1981). Exhalative volcano-sedimentary Fe-ores are found throughout Stage 3, and vary from relatively unaltered, slumped BIF-type mineralizations (e.g. Sångren) to up to a hundred metres thick magnetite skarns (e.g. Ösjöberg, Finnberget and Högborn, Fig. 1, near Hjulsjö, Grythyttan and Loka respectively). Mn-rich Fe-oxide deposits are found at Brunsjögruvan, Kextjärn, and Gåsborn (Damman 1988 this volume). The original BIF-like character of the Fe-ores is demonstrated by the remnants of sedimentary structures, glass textures in the ash layers and very low grade metamorphic minerals like greenalite and minnesotaite (Baker 1985b). Mafic rocks are often seen cross cutting these skarn horizons. They are often severely altered and crushed, and locally accompanied by carbonate-rich breccias. An original continental tholeiitic compositions is sometimes preserved in the sills and dykes (Hellingwerf & Oen 1986) which intruded at greater depths.

Stage 4. The Stage 4, or rift stage proper deposits, are characterized by a great diversity of rock types, and a bimodal chemical composition (Van der Velden et al. 1982). They are restricted to a mostly unconformable, NNW-SSE orientated, long, narrow and deep basin, that is considered to have formed by block faulting movements in the initial rift zone. The boundaries of this basin are often

marked by polymict debris flows and breccias that consist of mixtures of fresh volcanic material (glass splinters reworked immediately after deposition) and lithic fragments of the underlying deposits (Fig. 7). The southern part of the area reflects the shallower water depths in the basin compared to the northern part of the area. At Tombo (Fig. 1), a relatively thin interval with lithic fragments occurs, while at Hasselhöjden the conglomerates of Sundius (1923) are found. These are now interpreted as fragment-rich debris flows of local provenance, showing transport over only short distances. The most extreme debris flows and breccias are found in the central part of the basin along the eastern shore of lake Sor Älgen (E of Grythyttan, Fig. 1), where vertical fault movements are apparently most pronounced. In the northern part of the area (Silverknuten) this type of debris flow only occurs in a few isolated patches (e.g. lake Gaddsjön). The debris flows are overlain by Stage 4 felsic hyaloclastic flows and preceded by Stage 3/4 mafic shallow intrusives.

The final rift basin infillings show a bimodal chemistry with an approximately 9:1 felsic to mafic ratio (Van der Velden et al. 1982). They consist of pyroclastic flows, flow breccias and hyaloclastites (Fig. 8) which are accompanied and followed by several felsic and mafic lavas and intrusives. The coeval formation of felsic and mafic lavas and hyaloclastites, and their removal by turbiditic and mass-flow transport mechanisms led to the formation of chemically and mineralogically layered flows, tuffites and slates (Kuipers 1987).

Mafic magmatism is present as spilitized basaltic flows and shallow intrusives, together with deeper intrusive gabbroic sills and dykes. The spilitized flows locally contain pillow lavas (Hellingwerf 1986). Both flows and shallow intrusives are concentrated in the lower parts of the basin infillings. Several generations of crosscutting dykes near Kranktorp have been found (Fig. 1). Large gabbro bodies such as the one at Sundsjö (Fig. 1), are characterized by the assimilation of overlying felsic volcanics.

Felsic magmatism is represented by porphyritic rhyolitic lava flows near Grythyttan (Trolltjärnen, Fig. 1) and intrusions in the NW part of the basin

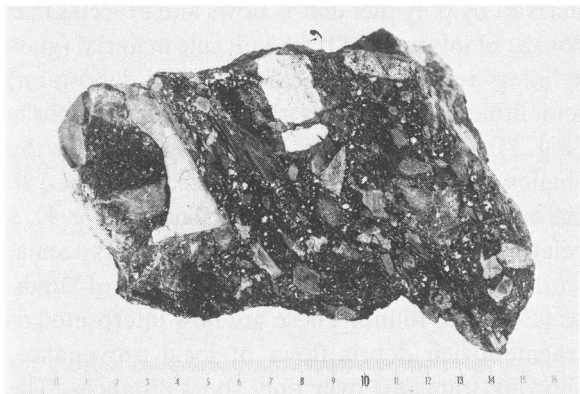


Fig. 7. Polymict breccia marking the unconformity between Stages 2/3 and 4, at the eastern shore of lake Sör Algen, east of Grythyttan.

(Vinerhögden, Kullberget, Gillershögden, Fig. 1), combined with comagmatic granite intrusions. They are intrusive in, and lie unconformably on, the surrounding Stage 3 deposits. The felsic lavas contain perthitic albite, microcline and quartz phenocrysts and show enriched In-contents (Van Meerten unpubl. data). The rhyolitic plugs show brecciated rims and are strongly K-enriched. They also cut the Stage 4 flows, and are the youngest products of this rift stage volcanism. The granites form a NNW-SSE trending zone of intrusive bodies (Baker 1985a) surrounded by dome-like structures in the volcanics to the east of the Grythyttan basin. They are apparently more deformed and altered towards the south (Baker 1985a), shifting from a hypersolvus to a subsolvus character, and largely postdate the mafic magmatic activity.

One small Mn-rich exhalative horizon is found at Sundsudden in the central part of the Stage 4 sequence, near Grythyttan (Fig. 1). It is associated with fine grained, carbonate-rich tuffites containing probable organic remnants (Oen et al. 1986), and is directly overlain by a spilitized basic flow.

Discussion

The volcanic development of the Grythyttan Basin

A proposed model to account for the volcano-stratigraphy of the Grythyttan basin is presented in Fig. 9.



Fig. 8. Acid hyaloclastitic flow, from lower parts of Stage 4. Grythyttan basin, 2.5 \times .

Large portions of rapidly formed new crustal material are characterized by long-lived unstable configurations, and as long as final accretion (= stabilization) has not taken place, linear zones of weakness due to intraplate stresses will be developed (Kröner 1984). Inside this mobile environment slight mantle upwellings will occur, causing magmatic underplating of dense and hot basic mantle material, unable to penetrate the crust. This hot upper mantle will initiate partial melting of the overlying lower crust. A few faults will result from stretching on top of this upwelling mantle, creating a small basin (Fig. 9a). The first felsic magmas will form and be explosively erupted. The ongoing melting enlarges the supply of felsic magma and with increasing water depths to suppress the magmatic gas pressures, the volcanism will change to a less explosive type (Fig. 9b). The transport of magma to the surface largely takes place along fault planes. Eventually the faults will combine to a strike-slip plane in the lower crust and form a very asymmetrical configuration of local depressions and highs (Fig. 9c). These asymmetrical fault systems are very characteristic to continental rift zones (Wernicke & Burchfiel 1982) and enable the penetration of magmas into upper crustal levels. Local central graben highs (Lister et al. 1986) are used by the granitic melts to intrude with dome-like structures as the ones described by Dixon & Summers (1983). Sub-basins are filled asymmetrically

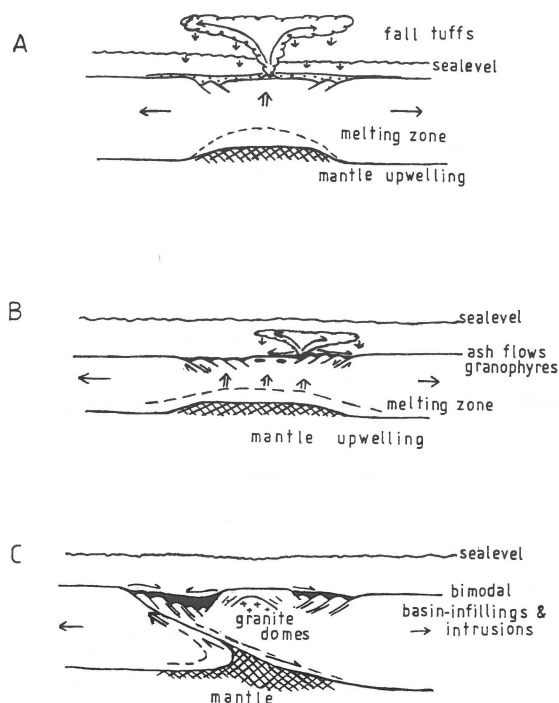


Fig. 9. Sketches of a proposed development of a rift zone in the Grythyttan-Hjulsjö region, not to scale. 9a: Magmatic underplating and upwelling cause melting of lower crust and stretching-faults in the upper parts. Explosive type of volcanism (Stage 1); 9b: Widening and subsiding of depression, listric faults in basin. Ascending melting zone and expanding magma chambers. Volcanic ridge inside basin. Less explosive type of volcanism (Stage 2). Combination of faults to strike-slip plane in lower crust; 9c: Local depressions and central graben highs inside rift zone. Intrusion of felsic and basic magmas along strike-slip plane and listric faults. Granitic diapirs in central graben high (Stage 4) and bimodal volcanics and sediments in the sub-basins.

as is shown by the existence on one side of the Grythyttan basin of debris flows and breccias. The vertical structures that characterize the Stage 4 deposits are probably caused by rotating processes inside the rift basins, as suggested by Kuipers (1987). With the emptying of the magma chambers during this period of bimodal volcanism the rifting processes came to an end. The remnants of the cooled underplating mafic material sank back into the mantle (Fyfe 1978, Kröner 1984) and automatically some compression occurred. This produced a schistosity in the shaley volcanic sediments of Stage 4, and the reactivation and rotation of several faults inside the basins.

The intense reworking of an older continental crust in Bergslagen produced a volcanic pile of approximately 10 km in the Grythyttan area.

Implications for the development of W. Bergslagen

The products of the four successive stages in the volcano sedimentary development of the Grythyttan area reflect the melting and reworking of an older, continental crust in an extensional, predominantly subaqueous environment. Evidence for the felsic nature of this crust is given by the felsic compositions of the metavolcanics, and by their Nd-Sm isotopic data, which suggests a crustal residence age of 2.4–2.1 Ga (Beunk et al. 1985, Miller et al. 1986, Patchett et al. 1987). An Archean crustal component of only $\pm 10\%$, is also indicated.

Large scale recycling of this older basement is the main reason for the non-recognition of a basement in this region (Baker 1985a). The former basement must have been largely incorporated in the melting cycle and remnants of the pre-rift configuration will be characterized by the absence of distinct chemical and isotopic differences, compared to the volcanic products. This is especially valid in areas, like Bergslagen, where large scale alteration systems influencing even immobile elements like REE have been active. The existence of remnants of a basement can however not be excluded.

Acknowledgments

I thank I. Lundström, Th. Lundqvist, I.S. Oen, J.H. Baker & R.H. Hellingwerf for critical reviews and stimulating discussions. Jan Outhuis made XRD mineral determinations; Toon van Eunen, Jan Boer and Goos Stoffel prepared thin and polished sections; and Jan Wiersma made the photographs. Finally, I thank most of all Barbara Luca-Muyen, Simon Pen, Adrie van de Raad, Sandra de Maesschalck, Hans Kobesen, Willem van der Velden, Pier de Groot and Ignace van Campenhout; without their internal reports this article would never have been written.

References

- Baker, J.H. 1981 The geology of the country around Hjulsjö, Bergslagen, Central Sweden – MSc thesis, Univ. Amsterdam, Internal Rept, (unpubl.): 228 pp
- Baker, J.H. 1985a The petrology and geochemistry of 1.8–1.9 Ga granitic magmatism and related sub-seafloor hydrothermal alteration and ore-forming processes, W. Bergslagen, Sweden – GUA Papers of Geology, 1–21: 204 pp
- Baker, J.H. 1985b Greenalite, Mg-rich minnesotaite, and stilpnomelane from the Osjöberg and Sirsjöberg iron-ore mines, Hjulsjö, W. Bergslagen, Sweden – *Miner. Mag.* 49: 611–613
- Beunk, F.F., Baker J.H. & van Raaphorst, J.G. 1985 A Sm-Nd study of felsic igneous rocks from the Hjulsjö area of Central Sweden. (Abstract) – *Terra Cognita* 5: 278
- Damman, A.H. 1988 Exhalative sedimentary manganiferous iron ores from the Gåsborn area, W-Bergslagen, Central Sweden. In: Baker, J.H. & R.H. Hellingwerf (eds): The Bergslagen Province, Central Sweden-Structure, stratigraphy and ore-forming processes. I.G.C.P. project 247 – *Geol. Mijnbouw*, 67: 433–442 (this issue).
- De Rosen-Spence, A.F., Provost, G., Dimroth, E., Gochner, K. & Owen, V. 1980 Archean subaqueous felsic flows, Rouyn-Noranda, Quebec, Canada and their Quaternary equivalents – *Precamb. Res.* 12: 43–77
- Dixon, J.M. & Summers, J.M. 1983 Patterns of total and incremental strain in subsiding troughs: experimental centrifugal models of inter-diapir synclines – *Can. J. Earth Sci.* 20: 1843–1861
- Fyfe, W.S. 1978 The evolution of the earth's crust: modern plate tectonics to ancient hot spot tectonics? – *Chem. Geol.* 23: 89–114
- Hedström, P. 1984 Geological and genetic aspects of the Hällefors sulfide ores, Bergslagen, Sweden – *Geol. För. Förh.* 106: 151–166
- Hellingwerf, R.H. 1986 Contributions to the geology and ore genesis of western Bergslagen, Sweden – GUA Papers of Geology, 1–25: 260 pp
- Hellingwerf, R.H. & Oen, I.S. 1986 Some geochemical aspects of altered and less altered metabasic rocks in the Saxa area, Bergslagen, Sweden – *N. Jahrb. Miner. Monatsh.* 2: 65–81
- Igelström, L.J. 1889 Tvenne nya mineral fran Sjögrufvefallet, Grythytte socken, Orebro Län – *Geol. För. Förh.* 11: 209–211
- Jasinski, A.W. 1983 Some aspects of the silver mineralizations in the Hällefors region (Bergslagen, Sweden) – *Miner. Mag.* 47: 507–514
- Kröner, A. 1984 Changes in plate tectonic styles and crustal growth during the Precambrian – *Soc. Geol. France Bull.* (7), 26: 297–319
- Kuipers, G. 1987 Volcaniclastic facies associations in the Mid-Proterozoic Grythyttan rift-basin and their lithostratigraphic relationship, West Bergslagen, Central Sweden – GUA Papers of Geology, 1–28: 162 pp
- Lister, G.S., Etheridge, M.A. & Symonds, P.A. 1986 Detachment faulting and the evolution of passive continental margins – *Geology* 14: 246–250
- Miller, R.G., O'Nions, R.K., Hamilton, P.J. & Welin, E. 1986 Crustal residence ages of clastic sediments, orogeny and continental evolution – *Chem. Geol.* 57: 87–99
- Oen, I.S. 1987 Rift-related igneous activity and metallogenesis in SW Bergslagen, Sweden. – *Precamb. Res.* 35: 367–382
- Oen, I.S., de Maesschalck, A.A. & Lustenhouwer, W.J. 1986 Mid-Proterozoic exhalative-sedimentary Mn-skarns containing possible microbial fossils, Grythyttan, Bergslagen, Sweden – *Econ. Geol.* 81: 1533–1543
- Oen, I.S., Helmers, H., Verschure, R.H. & Wiklander, U. 1982 Ore deposition in a Proterozoic incipient rift zone environment: a tentative model for the Filipstad-Grythyttan-Hjulsjö region, Bergslagen, Sweden – *Geol. Rundsch.* 71: 182–194
- Parr, J.M. 1988 The metasediments associated with stratabound base metal mineralization, Ljusnarsberg district, Central Sweden. In: Baker, J.H. & R.H. Hellingwerf (eds): The Bergslagen Province, Central Sweden – Structure stratigraphy and ore-forming processes. I.G.C.P. project 247 – *Geol. Mijnbouw*, 67: 189–202 (this issue)
- Parr, J. & Rickard, D.T. 1987 Early Proterozoic subaerial volcanism and its relationship to Broken Hill-type mineralization in Central Sweden – *Geol. Soc. London Spec. Pub.* 33: 81–93
- Patchett, P.J., Todt, W. & Gorbatschev, R. 1987 Origin of continental crust of 1.9–1.7 Ga age: Nd isotopes in the Svecofennian orogenic terrains of Sweden – *Precamb. Res.* 35: 145–160
- Pichler, H. 1965 Acid hyaloclastites – *Bull. Volcanol.* 28: 293–310
- Sundius, N. 1923 Grythyttfältets Geologi – *Sver. Geol. Unders.* C312: 354 pp
- Van der Velden, W., Baker, J.H., de Maesschalck, A.A. & van Meerten, Th. 1982 Bimodal early Proterozoic volcanism in the Grythytte field and associated volcano-plutonic complexes, Bergslagen, Central Sweden – *Geol. Rundsch.* 71: 171–181
- Walker, G.P.L., Wilson, C.J.N. & Froggatt, P.C. 1981 An ignimbritic veneer deposit: the trail marker of a pyroclastic flow – *J. Volcanol. Geotherm. Res.* 9: 409–421
- Wernicke, B. & Burchfiel, B.C. 1982 Modes of extensional tectonics – *J. Struct. Geol.* 4: 105–115
- Yamagushi, H. & Dimroth, E. 1985 A comparison of Miocene and Archean rhyolite hyaloclastites: evidence for a hot and fluid rhyolitic lava – *Geotherm. Res.* 23: 337–355
- Zakrzewski, M.A. & Nugteren, H.W. 1984 Mineralogy and origin of the distal volcanosedimentary deposit at the Hällefors silver mine, Bergslagen, Central Sweden – *Can. Mineral.* 22: 583–593