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THE GEOLOGY AND GEOPHYSICS OF THE OSLO RIFT

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THE GEOLOGY AND GEOPHYSICS OF THE OSLO RIFT

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ABSTRACT

A review of the regional geology and geophysical characteristics of the Oslo graben is presented. The graben is part of a Permian-age failed continental rift. Alkali-olivine, tholeiitic, and monzonitic intrusives as well as basaltic lavas outline the extent of the graben. Geophysical evidence indicates that rifting activity covered a much greater area in Paleozoic time, possibly including the northern Skagerrak Sea as well as the Oslo graben itself. Much of the surficial geologic characteristics in the southern part of the rift have since been eroded or covered by sedimentation. Geophysical data reveal a gravity maximum along the strike of the Oslo graben, local emplacements of magnetic material throughout the Skagerrak and the graben, and a slight mantle upwarp beneath the rift zone. Petrologic and geophysical maps which depict regional structure are included in the text. Also presented is an extensive bibliography of pertinent literature published in English between 1960 and 1980.

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INTRODUCTION

Numerous aspects of continental geology require further refinement within the context of plate tectonic theory. Many intraplate processes are poorly understood and remain to be examined quantitatively by proponents of plate tectonics. Forces which create and propagate or abandon continental rift zones constitute some of these poorly understood processes. Geologic characteristics and geophysical expressions of continental rift zones often have been presented in piecemeal fashion; frequently no fusion of data types, and hence, no comprehensive interpretation has been attempted. The Geophysics Branch of the Goddard Space Flight Center has undertaken a research effort to compile all available geologic and geophysical data for approximately forty continental rift zones. The data types will be presented in a common format which will promote not only comparative analyses of the data available for a single rift zone, but also cross-correlations of geologic and geophysical characteristics of different rift zones.

The results of the compilation and synthesis will be published in the form of an atlas. Representative rifts from every continent, ranging in scale up to several hundreds of kilometers in length, will be included.

The Oslo Rift has been chosen as a model entry in the atlas. This report is designed to provide a brief introduction to and overview of its geology and geophysics for scientists interested in rifting processes e.g., heat flow (Figure 1); detailed petrology (Figure 2); generalized petrology (Figure 3). Available data is presented in map form: A comprehensive selected bibliography of pertinent literature published (in English) between 1960 and 1980, a subject index to available literature, and a list of published maps and their publishers are included in the Appendix. A brief discription of the data collection process and of the difficulties encountered during its compilation and synthesis appear at the end of this report.

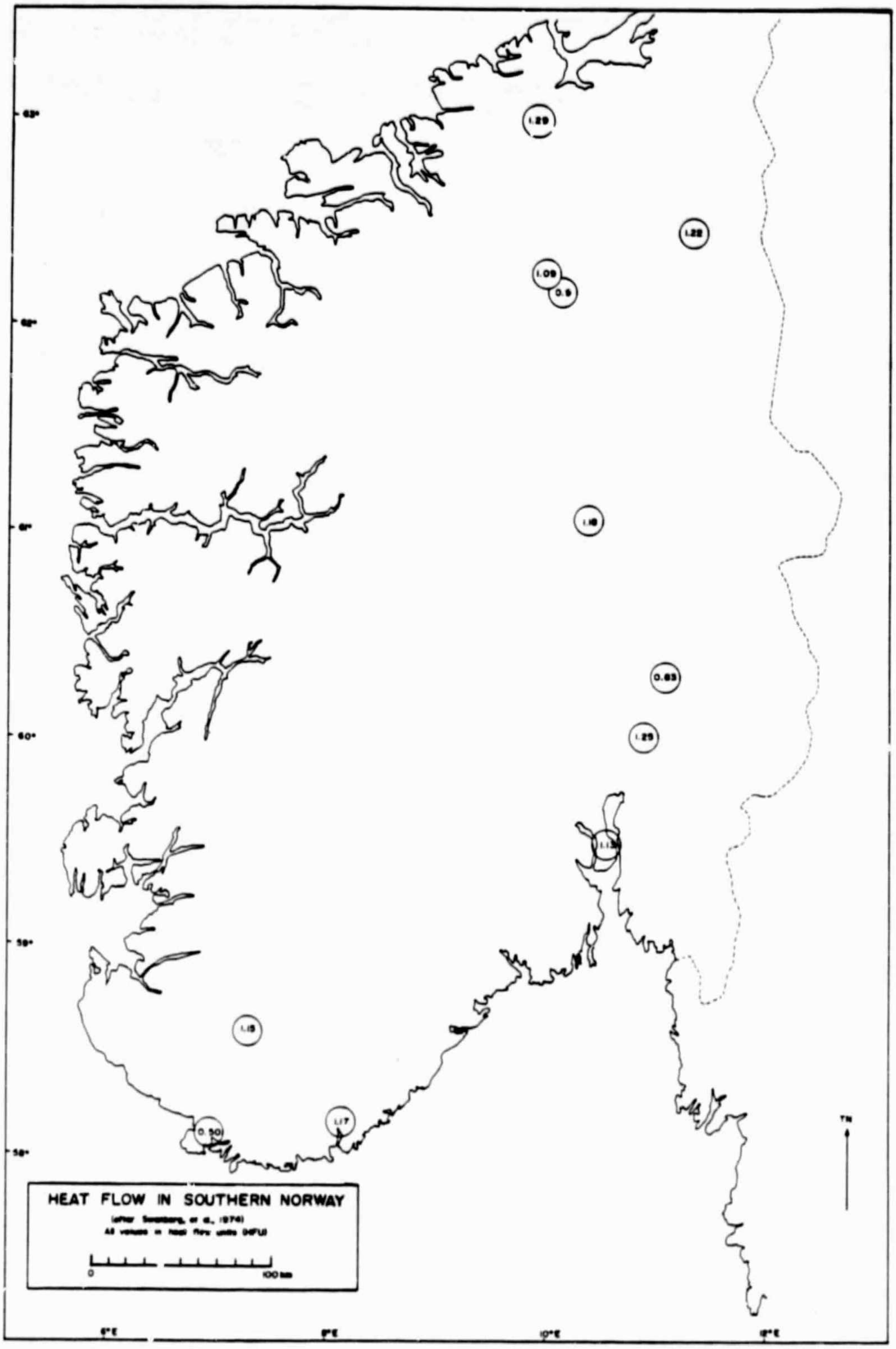

Figure 1: Available Heat Flow Data for Southern Norway, from Swanberg et al. (1974).

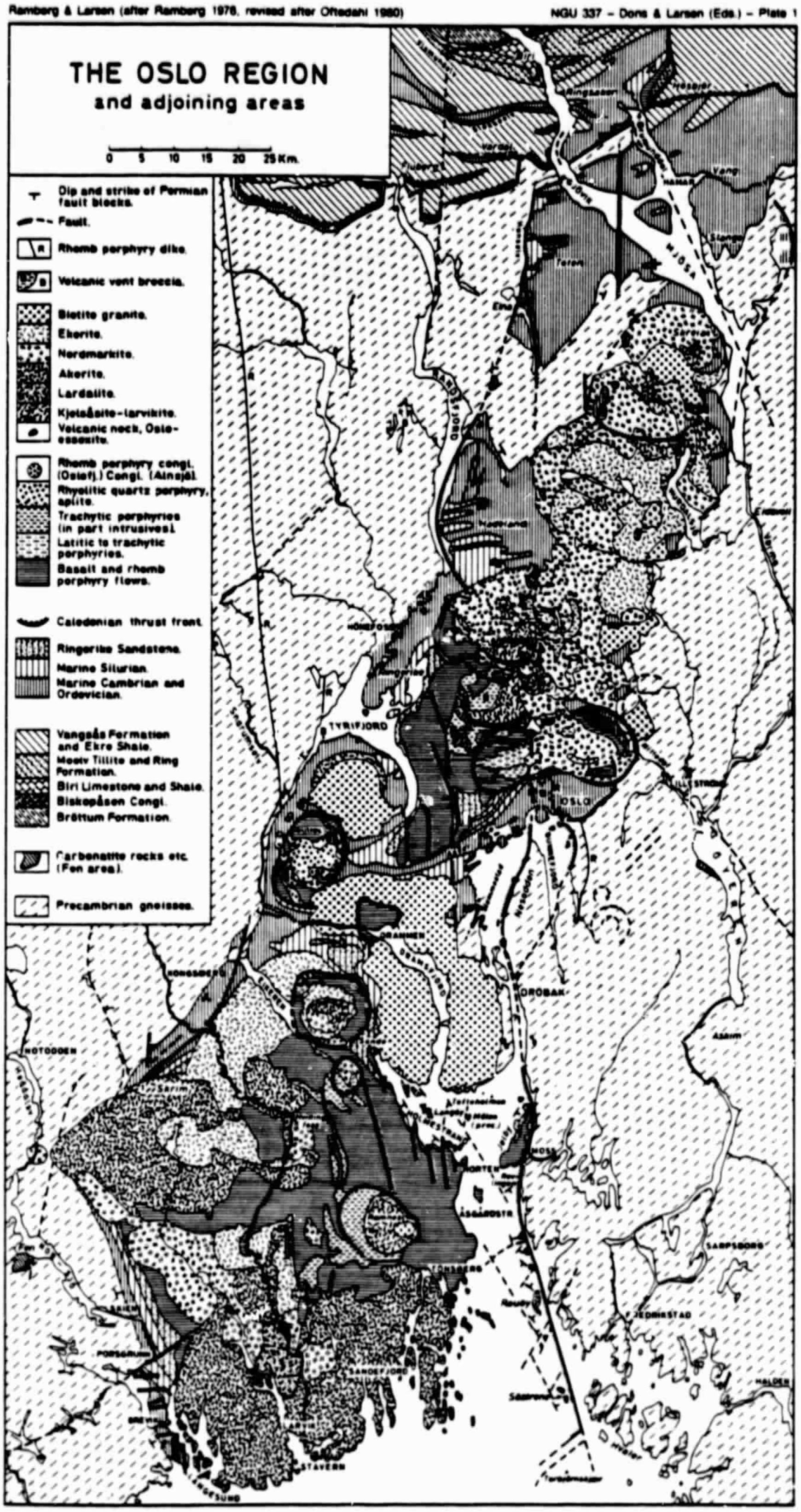

Figure 2: Detailed map of Oslo Region Petrology, from Ramberg (1976). Compare with Figure 3.

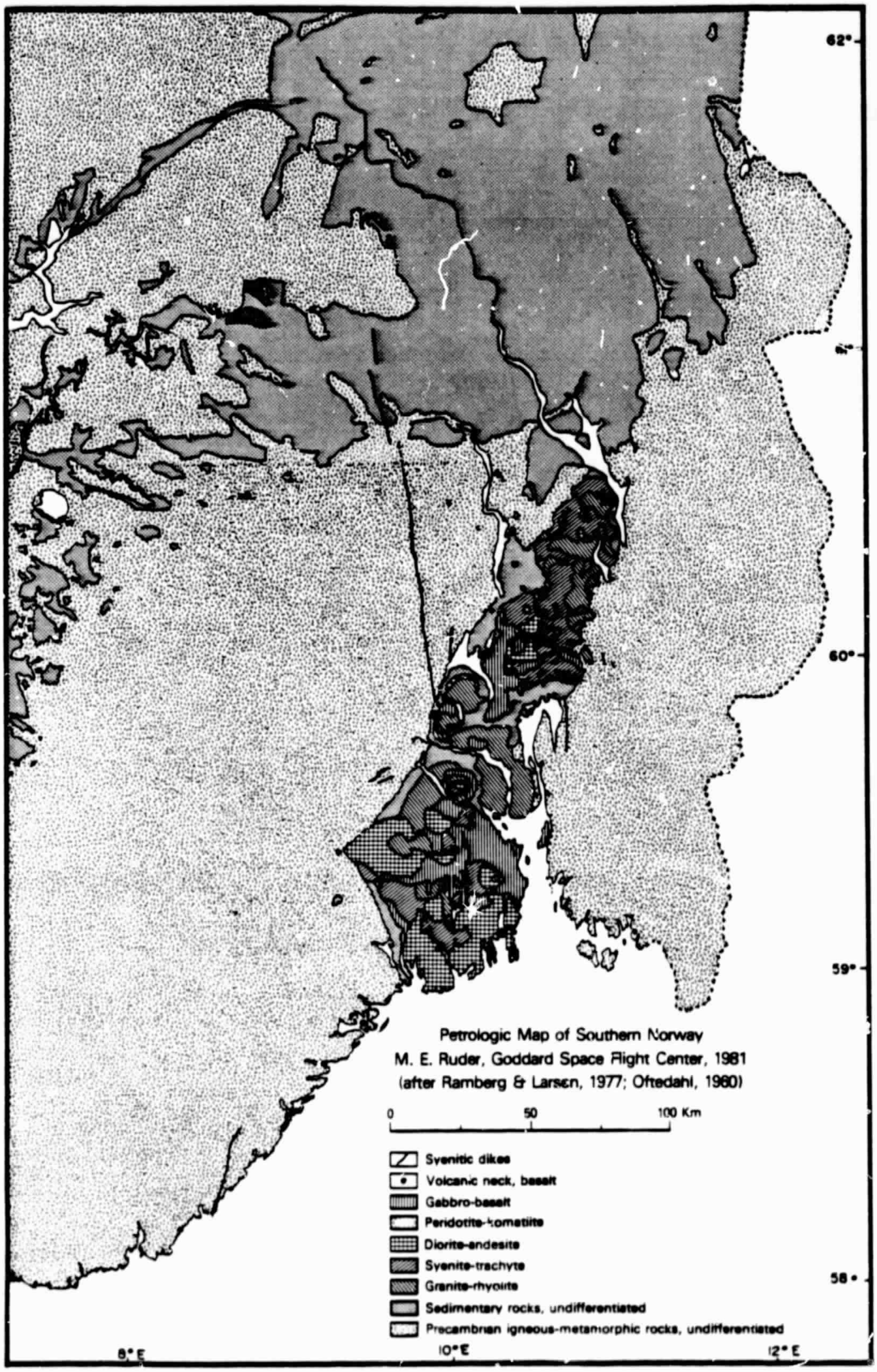

Figure 3: Generalized Petrologic Map of the Oslo Rift, Employing the New Generalized Rock Classification Scheme. Compare with Figure 2.

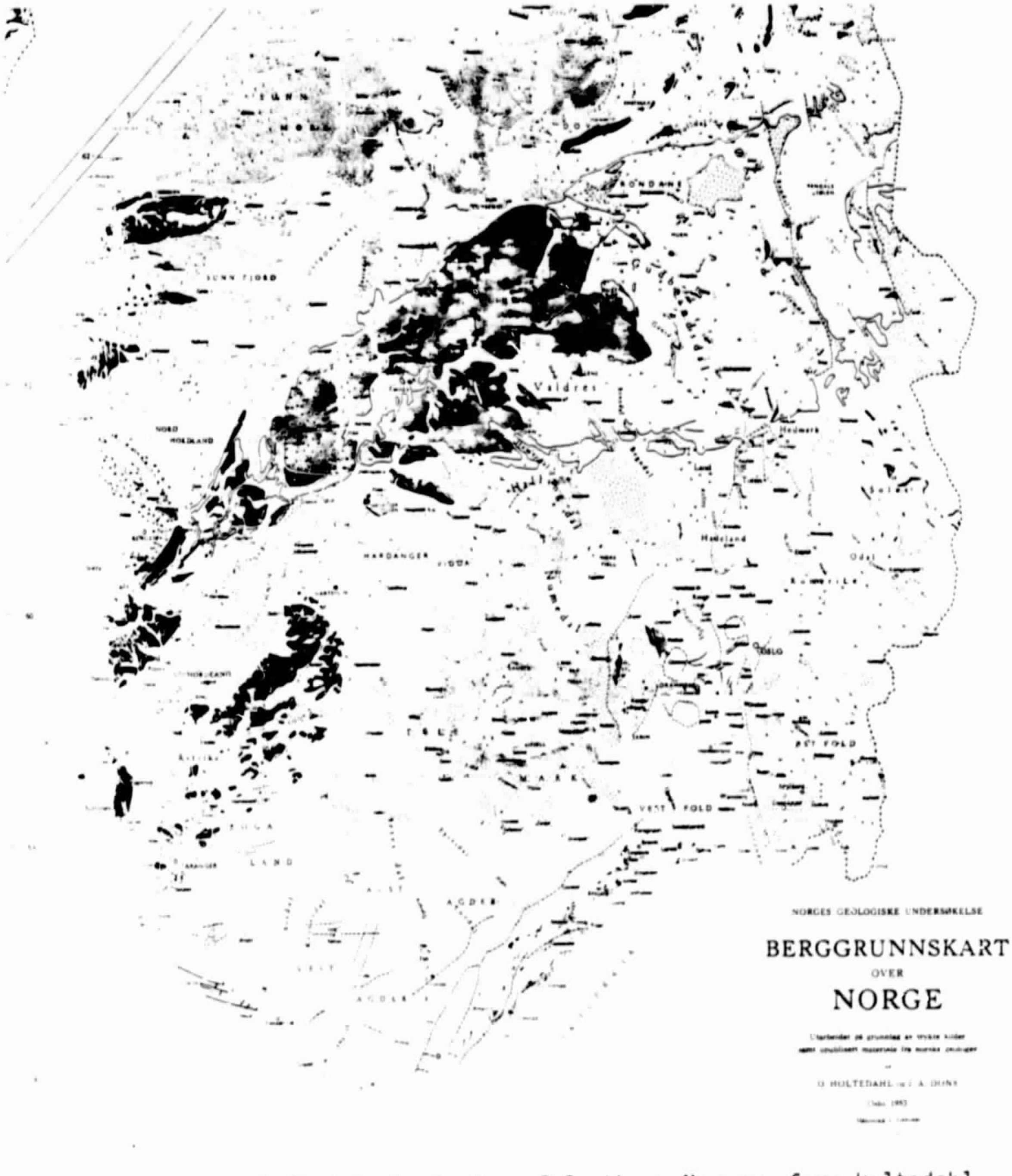

Figure 4: Simplified Geologic Map of Southern Norway, from Holtedahl and Dons (1953). Note Lack of Detail in the Oslo Region.

GEOLOGY AND GEOPHYSICS OF THE OSLO RIFT

The Oslo graben is a 200 x 40 kilometer landform located on the Fennoscandian shield. It is bordered by Lake Mjøsa on the north (60°55'N), the Skagerrak Sea on the south (59°00'N), and it extends east from longitude 9°30'E to 11°20'E. The graben is distinguished from the surrounding land mass by its unique petrologic province and a series of normal faults. Many geophysical features of the graben extend well beyond its geomorphic limits. Due to this trend, it is necessary to consider the Skagerrak and southern coastal Norway when discussing the nature of the Oslo Rift. A brief summary of Precambrian geology, Cambro-Silurian sedimentation, and pre-rifting orogenic episodes as well as an account of the Permian rifting event is presented below. Geophysical features of the graben and the surrounding area and an overview of the regional Paleozoic rift system are included.

Much of the Precambrian basement of southern Norway is exposed today (see Figure 4). Migmatites, metavolcanics, metasediments, granitic gneisses, mylonites, and dike swarms provide evidence of considerable tectonic activity (collision and extension) throughout Proterozoic time (Berthelsen, 1980). Structurally, a NNW-NNE lineament pattern dominates the region (Gabrielsen and Ramberg, 1979). Several orogenic episodes, from 1700 my ago to the Caledonian in Cambrian-Devonian time, have affected local structures. East of the graben, a line of thrust faults and volcanics parallels the Norway-Sweden border, trending N and NW (see Figure 5).

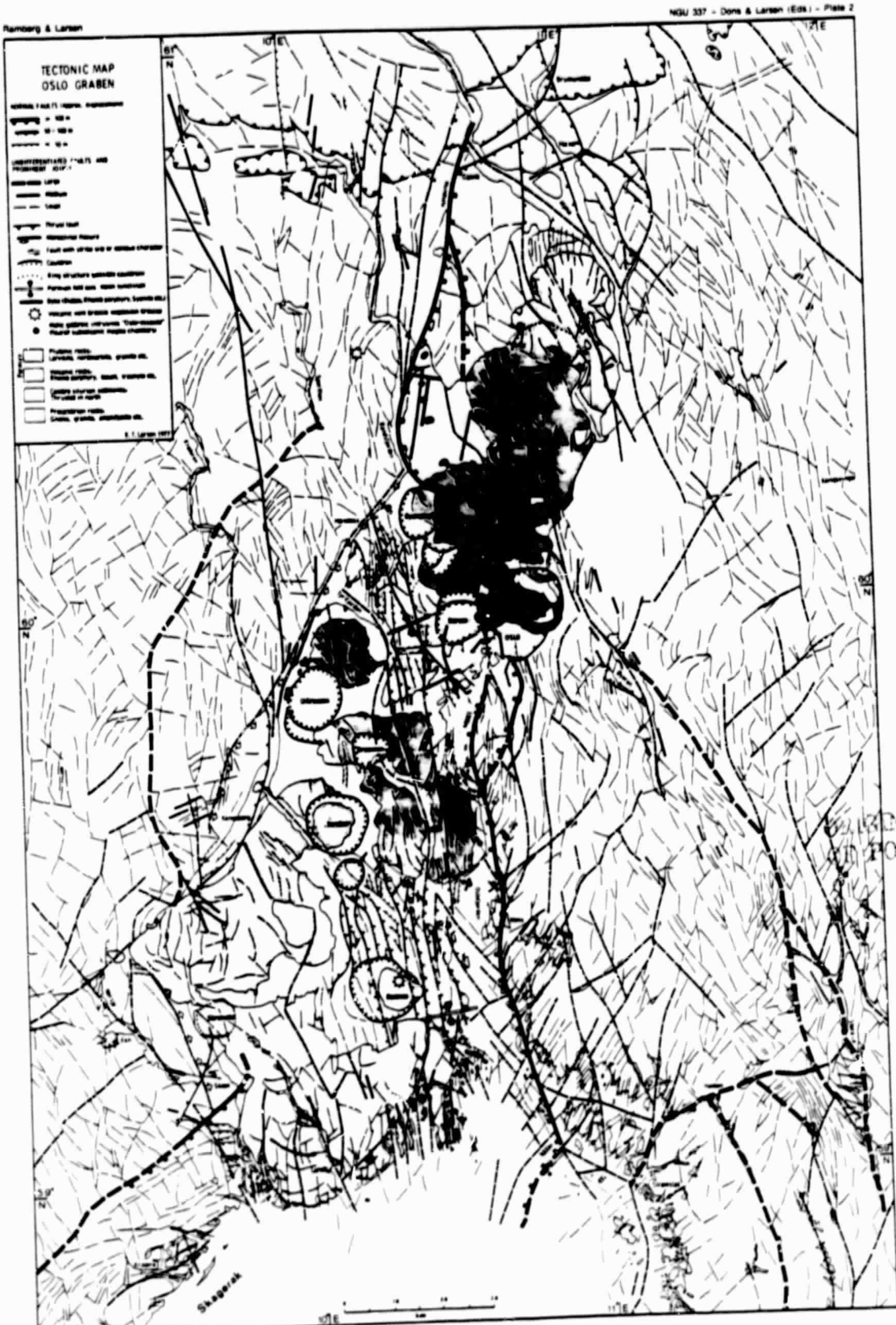

Figure 5: Tectonic Map of the Oslo Graben. Note the Master Fault, Aligned N-S in the Center of the Page, the NNW Trending Alignment of Cauldrons, and the Northerly Trending Faults and Lineaments. From Ramberg and Larsen, 1978.

Cambro-Silurian sedimentation in the Oslo region is extensive and well-documented by Henningsmoen (1978) and others. The 2 km sequence of fossiliferous shales and limestones includes the Kolsas, Tanum, and Skaugum Formations. Together, they compose the Asker Group. Within the group, volcanic debris is found in increasing amounts near Permian age sediments: evidence of short, pre-rift periods of volcanic activity. After the initial basalt floods in Permian time, sedimentation resumed. Throughout the rest of the epoch, volcanic and depositional episodes alternated. The Alnsjø sedimentary succession, more than 1000 m thick, overlies the main lava complex in Oslo, and the Brumund Sandstone, more than 400 m thick, overlies the Brumunddal lavas in the northern part of the graben. The Rhomb Porphyry Conglomerate is a poorly sorted conglomerate composed of fanglomerates and arkoses of volcanic origin.

Permian rifting in the Oslo region occurred in several stages. Ramberg and Larsen (1978) describe four distinct volcano-tectonic periods: initial basaltic volcanism, rhomb porphyry eruption and normal faulting, central volcano and cauldron stage, and emplacement of major batholiths. Basaltic extrusion at the outset of rift activity reflects the period of maximum tensile stress (Neumann, 1978). Fissures opened first in the south, then moved north with time. Flows were extensive, covering twice the area of today's graben. The volume of basalt within the graben is 500 km^3; original volume could have exceeded 10,000 km^3 (Ramberg and Larsen, 1978). Although domal uplift usually occurs at the outset of the rifting, no definitive evidence has been found. Erosion may make such doming impossible to substantiate. Rift valley formation began in earnest during the second stage of activity. Rhomb porphyry extrusion was accompanied by normal faulting. The master faults (trending N) formed during this period, with vertical displacements of 1 to 3 km and a horizontal extension of 4 km (Ramberg, 1976). Rhomb porphyry sediments provide evidence of a large scarp on the eastern flank of the graben. Rhomb porphyry dikes were intruded throughout the rift valley, well to the south and north of the graben itself. Further development of the rift occurred in the third stage of central volcanism and cauldron subsidence. A northern and a southern section formed en echelon, separated by the Østfold horst and a scissor fault. A rectilinear cauldron pattern developed along a northerly trend, parallel to the axial fault, and along an easterly trend, parallel to the offset between the small grabens. Regular spacing between the cauldrons is 29 km, indicating a Moho depth of 23 km during volcanism (Ramberg and Larsen, 1978). The final stage of activity was the emplacement of granitic and monzonitic batholiths in the southern parts of each graben.

The Oslo petrologic province (Figures 2,3) coincides with the graben itself. It also includes the Fen alkaline province, located 12 km south-west of the city of Oslo, volcanic necks far south in Kristiansand, and rhomb porphyry dikes south and north of the graben. This unusual igneous suite is characterized by ultramafic, alkali-olivine, and tholeiitic basalts, and alkaline, monzonitic, and granite intrusives. U/Th ratios of the rocks divide them into two subgroups which were derived from one parent magma, believed to be of upper mantle origin (Sundvoll, 1978). According to Ramberg (1976), initial mantle upwarp was followed by injection of a magmatic pillow into the lower crust, causing partial melting. This created the period of maximum crustal tension and alkaline basalt flows. Subsequently, stoping and fractional crystallization led to alkaline and monzonitic intrusions which characterize the later stages of rift development.

Radiometric dating of the igneous rocks has produced inconclusive results. Ages vary from 355 to 136 my. Most current researchers date the age of the emplacement of the intrusive complex at about 280 my. There is disagreement as to the duration of the rifting episode. Oftedahl (1977) suggests a 3 to 4 my period; Larsen (1975) argues for at least a 10 my period.

Unlike the igneous petrologic province, the metallogenic rift province extends well beyond the graben, as is shown in Figure 6. The igneous suite has a sharp contact with the surrounding exposed Precambrian basement. By contrast the ore types found in the graben abound to the west and south. They are epigenetic and their spatial distribution parallels or continues lineaments and tectonic zones of Precambrian basement (Ihlen and Vokes, 1978). The deposits are numerous, including molybdenum, copper, and lead and zinc sulphides, but they are economically not very extensive, relative to Norway's other mineral deposits.

A wealth of geophysical information is available on the Oslo Rift. Numerous seismic, gravitational, magnetic, and heat flow investigations have been performed. A distinct thinning of the crust by as much as 8 km (Ramberg and Smithson, 1975; Ramberg et al., 1977) occurs along a SSW trend, nearly along the axis of the graben (see Figure 7). The rift is characterized by a gravity high, probably due to crustal thinning, mantle upwarp and dense ultramafics; see Figures 8,9 (Husebye and Ramberg, 1978). A small dip in the high is recorded over many cauldrons, indicating differential changes in density between mildly alkaline and ultramafic rock types. A strong gravity gradient traverses the Bamble-Arendal area, southwest of the graben. This coincides with the Great Friction Breccia Fault Zone of Precambrian age. The fault separates the Telemark unit to west, consisting of granites, migmatites, and

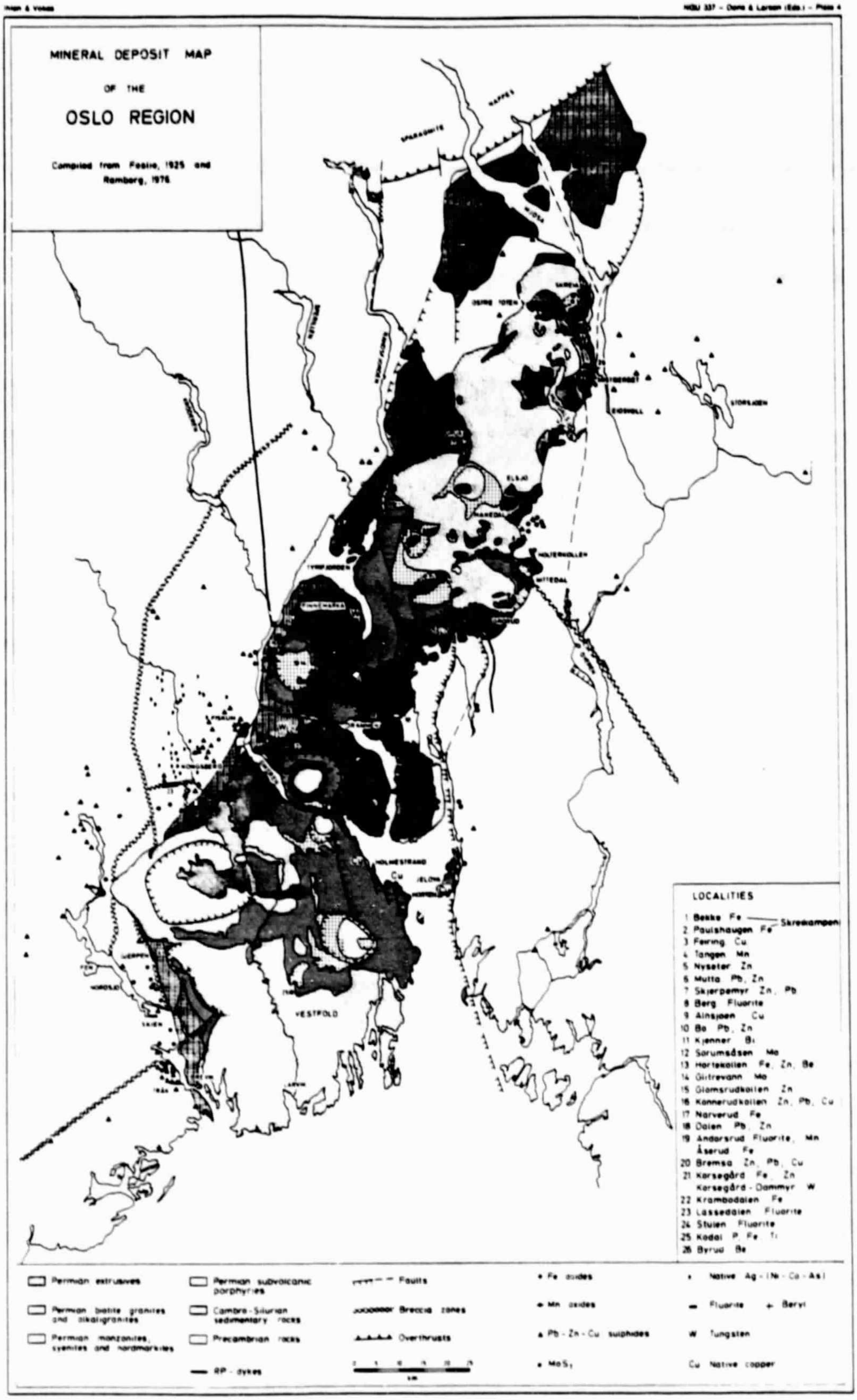

Figure 6: Mineralized Province extends beyond the Limits of the Igneous Petrologic Suite, from Ihlen and Vokes, 1978.

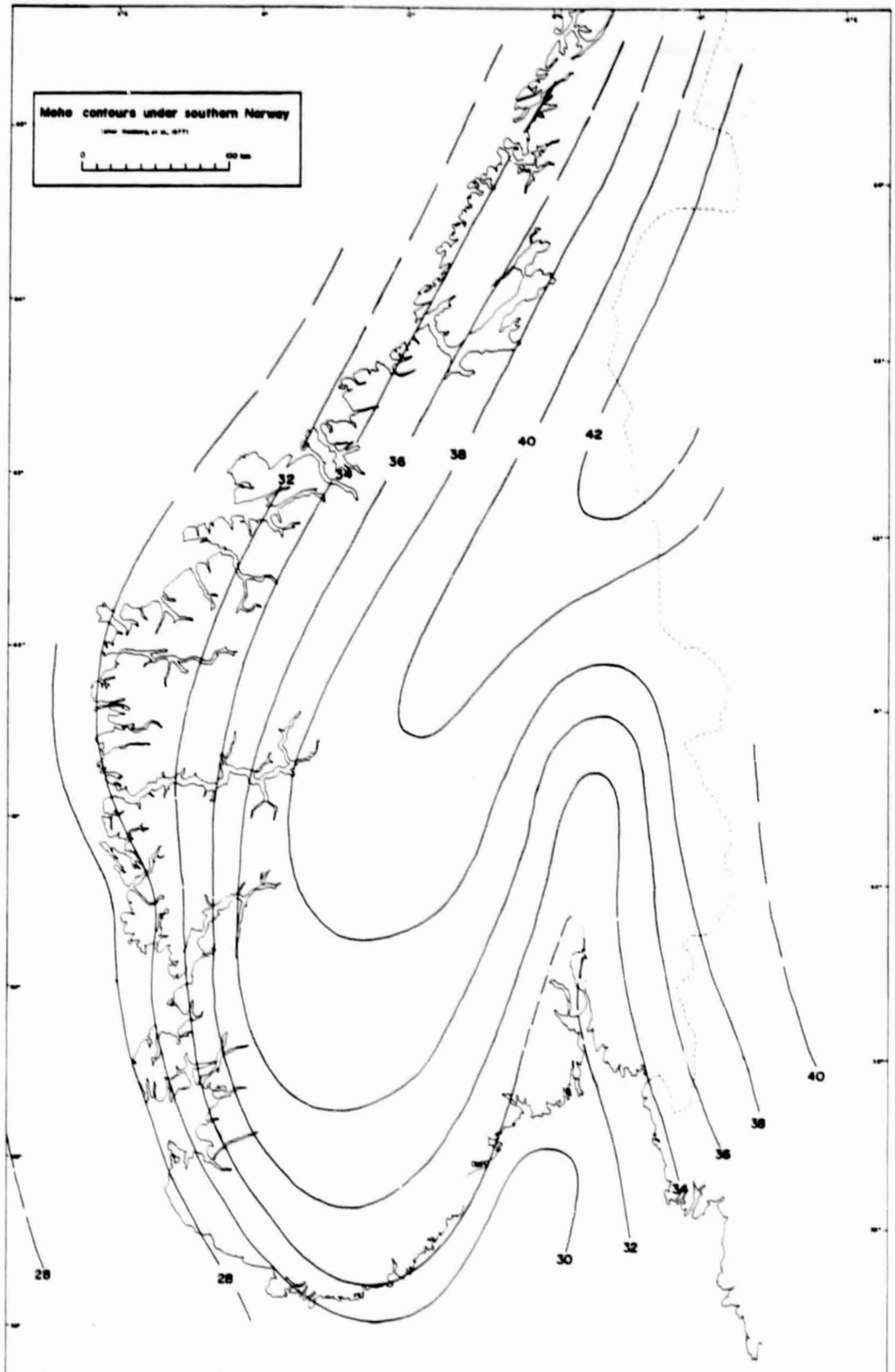

Figure 7: Depth to Moho, after Ramberg et al. (1977). Note that the Crust Thins Under the Rift Area.

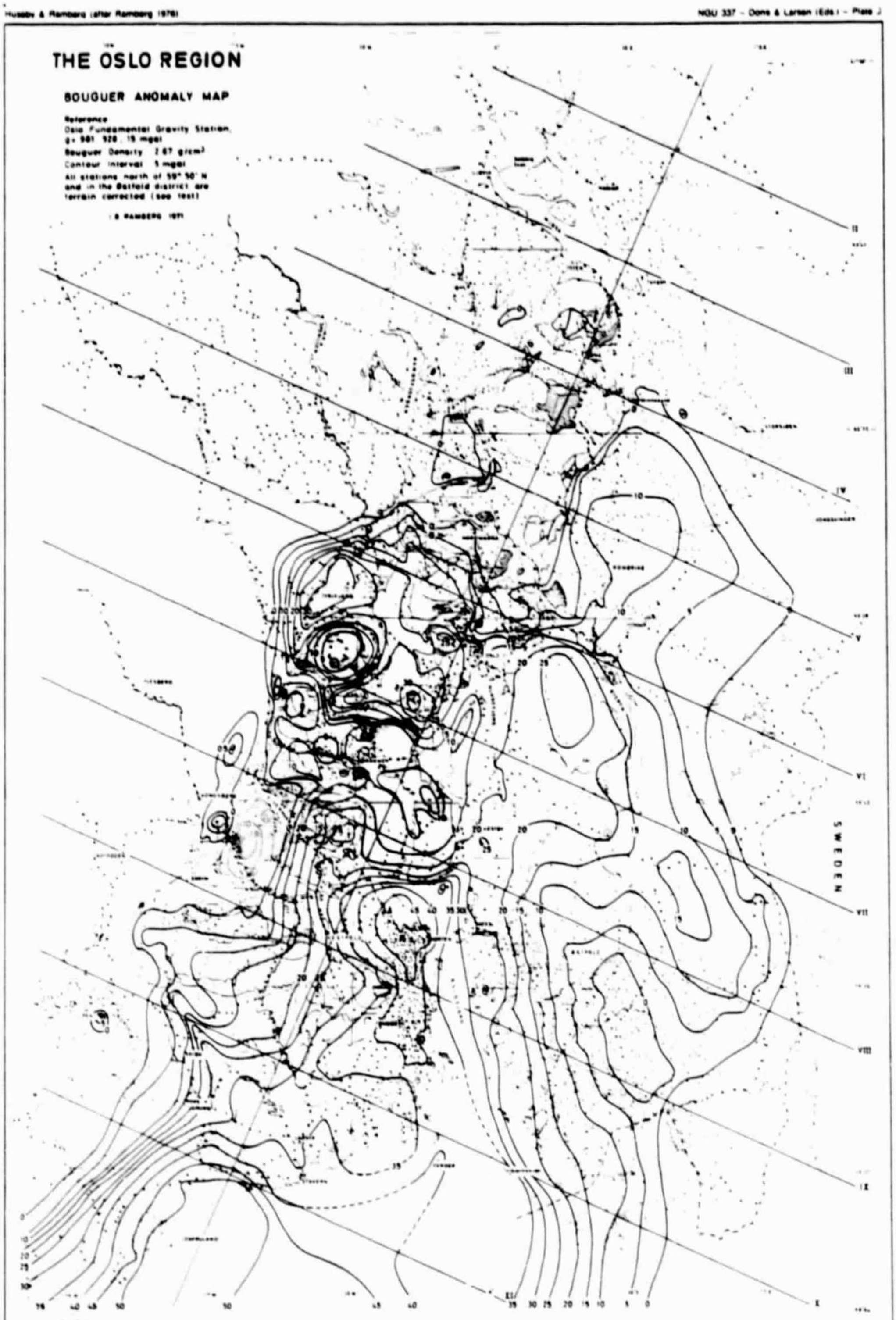

Figure 8: Bouguer Gravity Anomaly Map, from Ramberg (1971). Note the High Gravity Values of the Oslo Rift Relative to the Surrounding Areas.

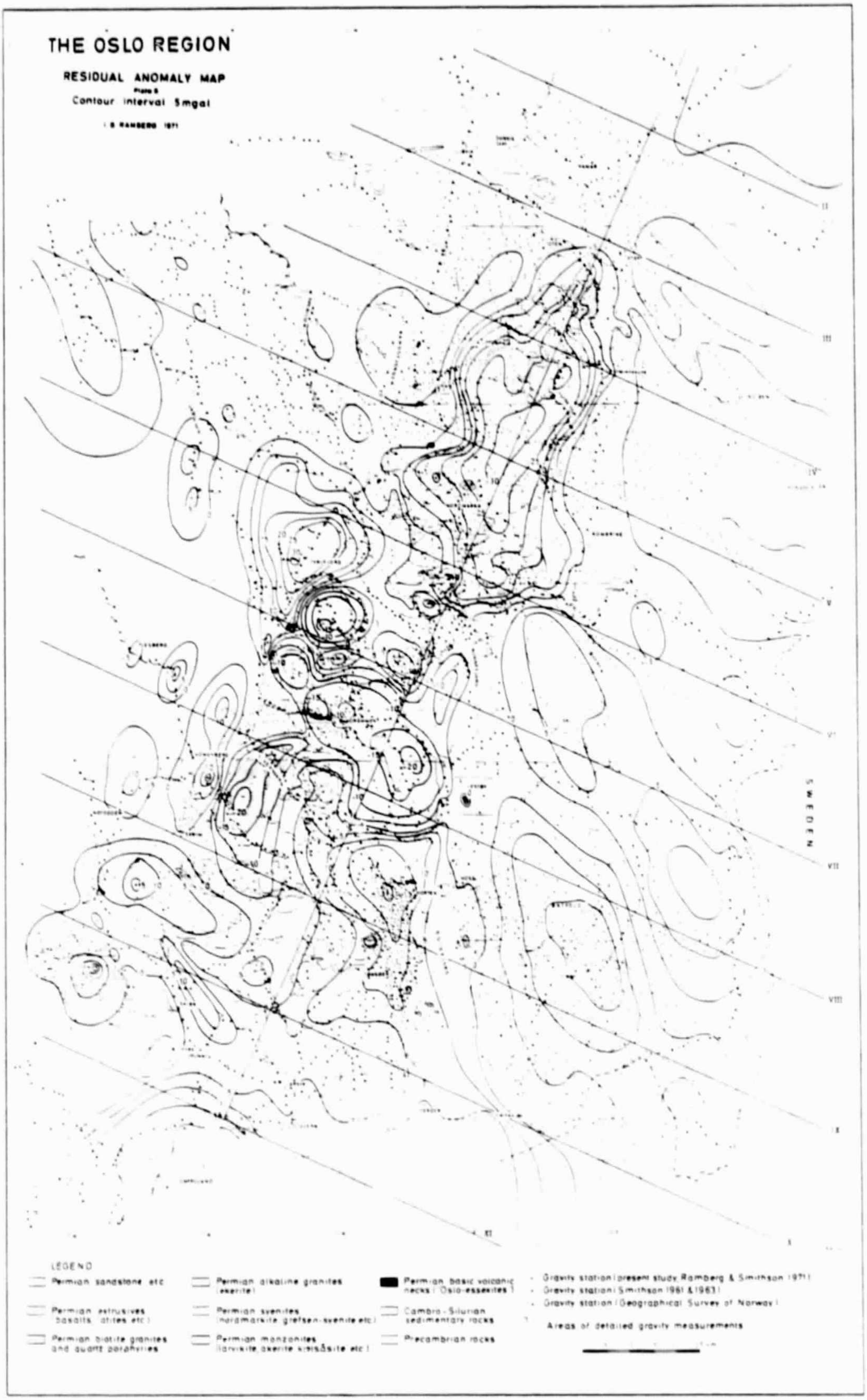

Figure 9: Residual Gravity Anomaly Map, from Ramberg (1971). Local Gravity Relief Reflect Structure and Petrology as Shown.

gneisses, from the Bamble unit to the east, composed of quartzite, amphibolite, mica schist, granite, and gabbro (Ramberg and Smithson, 1975). The Friction Breccia is a multistage fracture zone, full of mylonites. It is characterized by a strong positive magnetic signature.

Directly east of the Friction Breccia lies the Skagerrak's Norwegian Channel. The channel parallels the curve of the coastline southwest and ultimately north to the Norwegian Sea. There is much debate as to its glacial vs. tectonic origin (Sellevoll and Aastad, 1971; Talwani and Eldholm, 1972). Off the southeastern coast of Norway, seismic profiles show channel scarps that seem too deep to be of glacial origin. An initial tectonic period may have been followed by glacial scouring in this region where the channel attains its greatest depths. Five to six km of sediments fill the Skagerrak, masking most of the gravity and magnetic signatures of the underlying basement. These signatures do not dampen quickly, however, suggesting continuation of the rift zone into the Skagerrak (Ramberg and Smithson, 1975; Ramberg, 1976; Husebye and Ramberg, 1978). An area of extreme magnetic relief is located off the coast of Kristiansand. This may represent a southern extension of the rift, an 'Oslo-type batholith' (Ramberg, 1976). Heat flow in the area is normal; the rifting episode ended long ago (see Figure 1). Crustal rebound due to glacial melting averages 3 mm/yr in Oslo (Husebye and Ramberg, 1978). Local seismicity is typical of intraplate activity, although the graben itself is somewhat more active than either of its flanks (see Figure 10).

Many researchers have attempted to connect the Oslo rift with other regional features. The rift's general NNE trend can be extended south to a triple junction (Dewey and Burke, 1974) with the Danish-Polish Depression.

EARTHQUAKE ACTIVITY IN FENNOSCANDIA, 1951 - 1975

(AFTER HUSEBYE, ET AL., 1978)

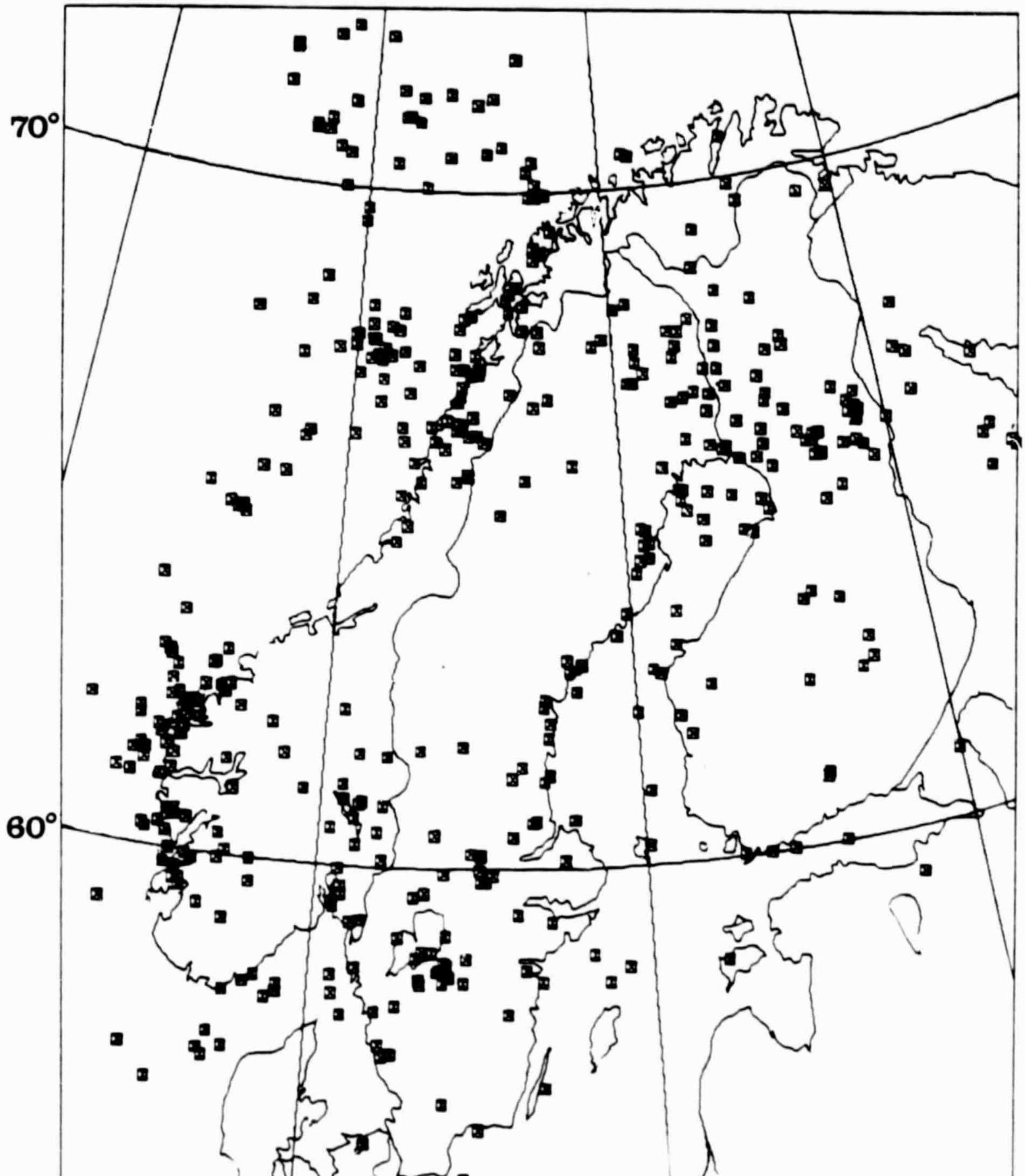

Figure 10: Recent Seismic Activity in Scandinavia.

The Oslo Graben itself may represent a failed arm of the rift. The Danish Embayment (the western portion of the Danish-Polish Depression) was also tectonically and volcanically active during Permian-Triassic time. Doig (1970) and Ramberg (1976) suggest that rifting in this area is connected to a much larger system of rejuvenated graben structures that also is genetically related to a major episode of carbonatite emplacement in Canada and Scandanavia that occurred 565 mya. Illies (1970) prefers to associate the Oslo Graben with European rifts to the southeast, such as the Rhone Valley and the Rhine Graben. More definitive investigation must be performed before either hypothesis can be accepted. It is clear, however, that the Oslo Graben is part of a larger rift zone, extending along the coast of southern Norway and into the Skagerrak. It is repesentative of the Upper Paleozoic-Early Mesozoic period of extensive crustal deformation and rifting.

REMARKS: DATA COLLECTION PROCESS

During the compilation process, several obstacles were encountered which may occur again when investigating other areas. Availability and quality of data types proved to be the biggest problems. For some types, data were sparse (e.g., heat flow, see Figure 1); for others, there was too much information available to conveniently display at a scale suitable for comparative presentation (e.g., pertrology, see Figure 2). Incomplete data is represented by point values, to indicate the paucity of observations. In the case of overabundant data, a generalized version was derived and presented. The petrologic map shown in Figure 3 is a case in point. This was derived from two existing petrologic maps: Holtedahl and Dons (1953),

Figure 4, was too simplified, and Ramberg (1978), Figure 2, was too detailed. The igneous rock classification used in Figure 3 was generalized enough to facilitate comparative study of rift petrology without masking the distinguishing petrologic suites of individual rifts.

Norwegian earth scientist provided a great deal of the high quality data for the Oslo region. Much of the geophysical information was received from the principal investigators themselves. Background research at Goddard included on-line literataure searches of the GEOREF and GEOARCHIVE data bases.

Future compilation and synthesis studies on other continental rift zones scheduled to be included in the rift atlas will parallel this report's format. Well documented and geographically accessible structures such as the Rio Grande Rift and the East African Rift have comparable data sets to that presented above, both in quality and breadth of available findings. It is noted, however, that many rift structures, due to their geologic history and location, have incomplete or sparse coverage. The rift atlas will serve as a comparative tool, and it will highlight those structures for which more research and documentation is needed. In light of its relative wealth of geologic and geophysical information, the Oslo Rift is an excellent example of a high quality data set for the atlas.

ACKNOWLEDGEMENTS

Paul Lowman and Herman Thomas were instrumental in devising a generalized igneous rock classification scheme for the author's petrologic map. Their help and encouragement is greatly appreciated. Special thanks to Herb Frey, project manager of the geophysical atlas, who provided direction and advice during the data collection process and constructive criticism during preparation of the report. Thanks also to Mrs. Barbara Lueders for careful typing of the manuscript.

LITERATURE CITED

Berthelsen, A. (1980) Towards a Palinspastic Tectonic Analysis of the Baltic Shield. International Geological Congress, 26th, Colloquium C6, Geology of Europe from Precambrian to Post-Hercynian Sedimentary Basins, 5-21.

Dewey, J.F. and K. Burke (1974) Hot Spots and Continental Break-Up: Implications for Collisional Orogeny. Geology, 2, 57-60.

Doig, R. (1970) An Alkaline Rock Province Linking Europe and North America. Canadian J. Earth Sci., 7, 22-28.

Gabrielsen, R.H. and I.B. Ramberg (1979) Fracture Patterns in Norway from Landsat Imagery: Results and Potential Uses. Norwegian Sea Symposium, Trømso, Proceedings, 24 p.

Henningsmoen, G. (1978) Sedimentary Rocks Associated with the Lava Series. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 17-24, Norges Geol. Unders., nr. 337.

Holtedahl, O. and J.A. Dons (1953) Berggrunnskart over Norge. Scale 1:1,000,000, Norges Geol. Unders.

Husebye, E.S. and I.B. Ramberg (1978) Geophysical Investigations. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 41-54, Norges Geol. Unders., nr. 337.

Ihlen, P.M. and F.M. Vokes (1978) Metallogeny. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 75-90, Norges Geol. Unders., nr. 337.

Illies, J.H. (1970) Graben Tectonics and Relation to Crust-Mantle Interaction. In Graben Problems, ed. by J.H. Illies and S. Mueller, 4-27, Schweizerbart, Stuttgart.

Larsen, B.T. (1975) Geology and Tectonics of the Oslo Rift Zone, Appendi A2. Unpublished Report, Norwegian Geotechnical Institute.

Neumann, E.-R. (1978) Petrology of the Plutonic Rocks. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 25-34, Norges Geol. Unders., nr. 337.

Oftedahl, C. (1977) Main Geologic Features of the Oslo Graben. In Tectonics and Geophysics of Continental Rifts, ed. by I.B. Ramberg and E.-R. Neumann, 167-194, D. Reidel Publ. Company, Holland.

Ramberg, I.B. (1976) Gravity Interpretation of the Oslo Graben and Associated Igneous Rocks. Norges Geol. Unders., nr. 325, 194 p.

Ramberg, I.B., R.H. Gabrielsen, B.T. Larsen and A. Solli (1977) Analysis of Fracture Pattern in Southern Norway. Geologie en Mijnbouw, 56, 295-310.

Ramberg, I.B. and B.T. Larsen (1978) Tectonomagmatic Evolution. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 55-74, Norges Geol. Unders., nr. 337.

Ramberg, I.B. and S.B. Smithson (1975a) Geophysical Interpretation of Crustal Structure along the Southeastern Coast of Norway and Skagerrak. Geol. Soc. America Bull., 86, 769-774.

Ramberg, I.B. and S.B. Smithson (1975b) Gridded Fault Patterns in a Late Cenozoic and a Paleozoic Continental Rift. Geology, 3, 201-205.

Sellevoll, M.A. and I. Aalstad (1971) Magnetic Measurements and Seismic Profiling in the Skagerrak. Marine Geophys. Res., 1, 284-302.

Sundvoll, B. (1978) Isotope- and Trace-Element Chemistry, Geochronology. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 35-40, Norges Geol. Unders., nr. 337.

Talwani, M. and O. Eldholm (1972) Continental Margin off Norway: A Geophysical Study. Geol. Soc. America Bull., 83, 3575-3606.

APPENDIX

SUBJECT GUIDE FOR SELECTED BIBLIOGRAPHY ON THE OSLO RIFT*

(Subjects Arranged Alphabetically)

*Complete Bibliography Begins on Page 27

ECONOMIC GEOLOGY

Bergstøl, S. (1972)
Ihlen, P.M. and F.M. Vokes (1978)
Ineson, P.R., I.G. Mitchell and F.M. Vokes (1975)
Vokes, F.M. (1960)
Vokes, F.M. (1973)
Vokes, F.M. and G.H. Gale (1976)

GEOCHRONOLOGY

Heier, K.S. and W. Compston (1969)
Ineson, P.R., I.G. Mitchell and F.M. Vokes (1975)
Jacobsen, S.B. and G. Raade (1975)
O'Nions, R.K., R.D. Morton and H. Baadsgaard (1969)
Sundvoll, B. (1978)

GRAVITY

Åm, K. (1973)
Grønlie, G. (1971)
Grønlie, G. and I.B. Ramberg (1973)
Husebye, E.S., P.C. England and I.B. Ramberg (1977)
Husebye, E.S. and I.B. Ramberg (1978)
Lind, G. and S. Saxov (1970)
Ramberg, I.B. (1972b)
Ramberg, I.B. (1973)
Ramberg, I.B. (1976)
Ramberg, I.B. and S.B. Smithson (1971)
Ramberg, I.B. and S.B. Smithson (1975a)
Ramberg, I.B. and S.B. Smithson (1975b)

HEAT FLOW

Grønlie, G., K.S. Heier and C.A. Swanberg (1977)
Husebye, E.S. and I.B. Ramberg (1978)
Swanberg, C.A., M D. Chessman, G. Simmons, S.B. Smithson, G. Grønlie, and K.S. Heier (1974)

MAGNETICS

Åm, K. (1973)
Haines, G.V., W. Hannaford and P.H. Serson (1970)
Halvorsen, E. (1972)
Hannaford, W. and G.V. Haines (1969)
Husebye, E.S. and I.B. Ramberg (1978)
Kristoffersen, Y. (1973)
Lind, G. and S. Saxov (1970)
Sellevoll, M.A. and I. Aalstad (1971)
Storetvedt, K.M., S. Pedersen, R. Løvlie and E. Halvorsen (1977)

SUBJECT GUIDE (cont'd)

PETROLOGY

Bergstøl, S. (1972)
Bjørlykke, K. (1966)
Bjørlykke, K. (1974)
Bjørlykke, K., A. Elvsborg and T. Høy (1976)
Bockelie, J.F. (1977)
Dons, J.A. and E. Gyory (1967)
Czamanske, G.K. (1965)
Czamanske, G.K. and P. Mihalik (1972)
Czamanske, G.K. and D.R. Wones (1973)
Doig, R. (1970)
Griffin, W.L. (1973)
Ihlen, P.M. and F.M. Vokes (1978)
Morton, R.D., R. Batey and R.K. O'Nions (1970)
Neumann, E.-R. (1976)
Neumann, E.-R. (1978)
Neumann, E.-R., A.O. Brunfelt and K.G. Finstad (1977)
Neumann, E.-R. and I.B. Ramberg (1977)
Nystuen, J.P. (1975)
Oftedahl, C. (1976)
Oftedahl, C. (1977)
Petersen, J.S. (1977)
Raade, G. (1969)
Raade, G. (1972)
Ramberg, I.B. (1972a)
Ramberg, I.B. (1973)
Ramberg, I.B. and B.T. Larsen (1978)
Ramberg, I.B. and E.-R. Neumann (1978)
Ramberg, I.B. and N. Spjeldnaes (1978)
Rohr-Torp, E. (1973)
Sørensen, R. (1975)
Sundvoll, B. (1978)
Turner, P. (1974)
Whitaker, J.H. (1977)
Widenfalk, L. and R. Gorbatschev (1971)

SEISMICS

Aki, K. (1977)
Berteussen, K.-A. (1975)
Berteussen, K.-A. (1977)
Berteussen, K.-A., A. Christoffersson, E.S. Husebye and A. Dahle (1975)
Bungum, H. and J. Fyen (1979)
Crampin, S. (1964)
Husebye, E.S., H. Bungum, J. Fyen and H. Gjøystdal (1978)
Husebye, E.S., P.C. England and I.B. Ramberg (1977)
Husebye, E.S., R. Kanestrøm and R. Rud (1971)
Husebye, E.S. and I.B. Ramberg (1978)
Husebye, E.S. and F. Ringdal (1977)
Kanestrøm, R. (1972)
Kanestrøm, R. (1973)
Sellevoll, M.A. and I. Aalstad (1971)
Sellevoll, M.A. and E. Sundvor (1974)
Sellevoll, M.A. and R.E. Warrick (1971)
Weigel, W.J. Hjelme and M.A. Sellevoll (1970)

SUBJECT GUIDE (cont'd)

STRUCTURE AND TECTONICS

Aki, K. (1977)
Berteussen, K.-A. (1975)
Berteussen, K.-A. (1977)
Bjørlykke, K. (1974)
Bjørlykke, K., A. Elvsborg and T. Høy (1976)
Bockelie, J.F. (1977)
Dons, J.A. and E. Gyory (1967)
Gabrielsen, R.H. and I.B. Ramberg (1979)
Gee, D.G. and M.R. Wilson (1974)
Henningsmoen, G. (1978)
Husebye, E.S. and I.B. Ramberg (1978)
Husebye, E.S. and F. Ringdal (1977)
Kanestrøm, R. (1973)
Morton, R.D., R. Batey and R.K. O'Nions (1970)
Oftedahl, C. (1976)
Oftedahl, C. (1977)
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Ramberg, I.B. (1972)
Ramberg, I.B. (1976)
Ramberg, I.B., R.H. Gabrielsen, B.T. Larsen and A. Solli (1978)
Ramberg, I.B. and B.T. Larsen (1978)
Ramberg, I.B. and S.B. Smithson (1975a)
Ramberg, I.B. and S.B. Smithson (1975b)
Ramberg, I.B. and N. Spjeldnaes (1978)
Rohr-Torp, E. (1973)
Segalstad, T.V. (1976)
Sellevoll, M.A. (1973)
Sellevoll, M.A. and E. Sundvor (1974)
Sellevoll, M.A. and R.E. Warrick (1971)
Skjernaa, L. (1972)
Sørensen, R. (1975)
Torsk, T. (1975)
Turner, P. (1974)
Weigel, W., J. Hjelme and M.A. Sellevoll (1970)
Whitaker, J.H. (1977)

VOLCANIC ACTIVITY

Barth, T.F.W. (1970)
Dons, J.A. and E. Gyory (1967)
Henningsmoen, G. (1978)
Nystuen, J.P. (1975)
Pedersen, A.K., J. Engell and J.G. Ronsbo (1975)
Ramberg, I.B. and T.F.W. Barth (1966)

VARIA

Dons, J.A. (1978)
Oslo Region Research Group (1977)

PUBLISHED MAPS OF THE OSLO REGION

Holtedahl, O. and J.A. Dons (1953) Berggrunnskart over Norge (Geologic Map of Norway), Scale 1:1,000,000. Norges Geol. Unders.

Husebye, E.S. and I.B. Ramberg (1978) The Oslo Region, Bouguer Anomaly Map. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, Norges Geol. Unders. nr. 337, plate 3.

Ihlen, P.M. and F.M. Vokes (1978) Mineral Deposit Map of the Oslo Region. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, Norges Geol. Unders., nr. 337, plate 4.

Ramberg, I.B. (1971) The Oslo Region, Bouguer Anomaly Map. In Gravity Interpretation of the Oslo Graben and Associated Igneous Rocks. Norges Geol. Unders., nr. 325, 194 p., 1976.

Ramberg, I.B. (1971) The Oslo Region, Regional Anomaly Maps I and II. In Gravity Interpretation of the Oslo Graben and Associated Igneous Rocks. Norges Geol. Unders., nr. 325, 194 p., 1976.

Ramberg, I.B. (1971) Residual Anomaly Map. In Gravity Interpretation of the Oslo Graben and Associated Igneous Rocks. Norges Geol. Unders., nr. 325, 194 p., 1976.

Ramberg, I.B. (1971) Southern Norway Bouguer Anomaly Map and Bedrock Geology. In Gravity Interpretation of the Oslo Graben and Associated Rocks. Norges Geol. Unders., nr. 325, 194 p., 1976.

Ramberg, I.B., R.H. Gabrielsen, B.T. Larsen and A. Solli (1977) Fracture Map. Geol. Mijnbouw, v. 56, n. 4, encl. 1.

Ramberg, I.B., R.H. Gabrielsen, B.T. Larsen and A. Solli (1977) Fracture Map, Southern Norway, Including Moho Contours and Main Gravity Fractures. Geol. Mijnbouw, v. 56, n. 4, encl. 5.

Ramberg, I.B. and B.T. Larsen (1978) The Oslo Region and Adjoining Areas. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, Norges Geol. Unders., nr. 337, plate 1.

Ramberg, I.B. and B.T. Larson (1978) Tectonic Map, Oslo Graben. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, Norges Geol. Unders., nr. 337, plate 2.

SELECTED BIBLIOGRAPHY ON THE OSLO RIFT (1960-1980)

Aki, K. (1977) Determination of the Three-Dimensional Seismic Structure of the Lithosphere. J. Geophys. Res., v. 82, n. 2, 277-296.

Åm, K. (1973) Geophysical Indications of Permian and Tertiary Igneous Activity in the Skagerrak. Norges Geol. Unders., nr. 287, 1-25.

Barth, T.F.W. (1970) Deep-Seated Volcanism along the Major Precambrian Breccia in South Norway. II. Svarten at Ny Hellesund. Norsk Geol. Tidsskr., v. 50, 253-256.

Bergstøl, S. (1972) The Jacupirangite at Kodal, Vestfold, Norway. A Potential Magnetite, Ilmenite and Apatite Ore. Mineral. Deposita. v. 7, 233-246.

Berteussen, K.-A. (1975) Crustal Structure and P-Wave Travel Time Analysis at NORSAR. Zeitschr. Geophysik, v. 41, 71-84.

Berteussen, K.-A. (1977) Moho Depth Determinations Based on Spectral Ratio Analysis of NORSAR Long Period P-Waves. Phys. Earth Planet. Interiors, v. 15, 13-27.

Berteussen, K.-A., A. Christoffersson, E.S. Husebye and A. Dahle (1975) Wave Scattering Theory in Analysis of P-Wave Anomalies at NORSAR and LASA. Geophys. Jour. R. Astron. Soc., v. 42, 403-417.

Berthelsen, A. (1980) Towards a Palinspastic Tectonic Analysis of the Baltic Shield. International Geological Congress, 26th, Colloquium C6: Geology of Europe from Precambrian to Post-Hercynian Sedimentary Basins, 5-21.

Bjørlykke, K. (1966) Sedimentary Petrology of the Sparagmites of the Rena District, S. Norway. Norges Geol. Unders., nr. 238, 5-53.

Bjørlykke, K. (1974) Depositional History and Geochemical Compositions of Lower Paleozoic Epicontinental Sediments from the Oslo Region. Norges Geol. Unders., nr. 305, 1-81.

Bjørlykke, K., A. Elvsborg and T. Høy (1976) Late Precambrian Central Sparagmite Basin of South Norway. Norsk Geol. Tidsskr., v. 56, 233-290.

Bockelie, J.F. (1977) The Oslo Region During the Early Paleozoic. In Tectonics and Geophysics of Continental Rifts, ed. by I.B. Ramberg and E.-R. Neumann, 195-202, D. Reidel Publ. Company, Holland.

Bungum, H. and J. Fyen (1979) Hypocentral Distribution, Focal Mechanisms, and Tectonic Implications of Fennoscandian Earthquakes, 1954-1978. Geologiska Foereningens i Stockholm Foerhandlingar, v. 101, pt. 4, 261-271.

Crampin, S. (1964) Higher Modes of Seismic Surface Waves; Phase Velocities Across Scandinavia. J. Geophys. Res., v. 69, 4801-4811.

Czamanske, G.K. (1965) Petrologic Aspects of the Finnmarka Igneous Complex, Oslo Area, Norway. J. Geol., v. 73, 293-322.

Czamanske, G.K. and P. Mihalik (1972) Oxidation During Magmatic Differentiation, Finnmarka Complex, Oslo Area, Norway: Part I, The Opaque Oxides. Jour. Petrology, v. 13, 493-509.

Czamanske, G.K. and D.R. Wones (1973) Oxidation During Magmatic Differentiation, Finnmarka Complex, Oslo Area, Norway: Part II, The Mafic Silicates. Jour. Petrology, v. 14, 349-380.

Doig, R. (1970) An Alkaline Rock Province Linking Europe and North America. Can. J. Earth Sci., v. 7, n. 22, 22-28.

Dons, J.A. (1978) Terminology and History of Investigations. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 9-16, Norges Geol. Unders., nr. 337.

Dons, J.A. and E. Gyory (1967) Permian Sediments, Lavas and Faults in the Kolsås Area west of Oslo. Norsk Geol. Tidsskr., v. 47, 57-77.

Gabrielsen, R.H. and I.B. Ramberg (1979) Fracture Patterns in Norway from Landsat Imagery: Results and Potential Uses. Norwegian Sea Symposium, Tromsø, Proceedings, 24 p.

Gee, D.G. and M.R. Wilson (1974) The Age of Orogenic Deformation in the Swedish Caledonides. Am. J. of Science, v. 274, 1-9.

Griffin, W.L. (1973) Lherzolite Nodules from the Fen Alkaline Province, Norway. Contr. Mineral. Petrol., v. 38, 135-146.

Grønlie, G. (1971) Gravity Studies of the Larvikite Massif SW of the Lake Gjerdingen, Nordmarka. Norsk Geol. Tidsskr, v. 51, 317-322.

Grønlie, G. and I.B. Ramberg (1973) A System for Determining Gravimetric Terrain Corrections in Norway. Norges Geol. Unders., nr. 294, 1-7.

Grønlie, G., K.S. Heier and C.A. Swanberg (1977) Terrestrial Heat Flow Determinations from Norway. Norsk Geol. Tidsskr., v. 57, 153-162.

Haines, G.V., W. Hannaford and P.H. Serson (1970) Magnetic Anomaly Maps of the Nordic Countries and the Greenland and Norwegian Sea. Publ. Dom. Obs., v. 34, n. 5, 123-149.

Halvorsen, E. (1972) On the Paleomagnetism of the Arendal Diabases. Norsk Geol. Tidsskr., v. 52, 217-228.

Hannaford, W. and G.V. Haines (1969) A Three-Component Aero-Magnetic Survey of the Nordic Countries and the Greenland Sea. Publ. Dom. Obs., v. 37, 113-149.

Heier, K.S. and W. Compston (1969) Rb-Sr Isotopic Studies of the Plutonic Rocks of the Oslo Region. Lithos, v. 2, 133-145.

Henningsmoen, G. (1978) Sedimentary Rocks Associated with the Lava Series. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 17-24, Norges Geol. Unders., nr. 337.

Husebye, E.S., H. Bungum, J. Fyen and H. Gjøystdal (1978) Earthquake Activity in Fennoscandia Between 1497 and 1975 and Intraplate Tectonics. Norsk. Geol. Tidsskr., v. 58, 51-68.

Husebye, E.S., P.C. England and I.B. Ramberg (1977) The Ideal-Body Concept in Interpretation of the Oslo Rift Gravity Data and Their Correlation with Seismic Observations. In Tectonics and Geophysics of Continental Rifts, ed. by I.B. Ramberg and E.-R. Neumann, 313-328, D. Reidel Publ. Company, Holland.

Husebye, E.S., R. Kanestrøm and R. Rud (1971) Observations of Vertical and Lateral P-Velocity Anomalies in the Earth's Mantle Using the Fennoscandian Continental Array. Geophys. Jour. R. Astron. Soc., v. 25, 3-16.

Husebye, E.S. and I.B. Ramberg (1978) Geophysical Investigations. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 41-54, Norges Geol. Unders., nr. 337.

Husebye, E.S. and F. Ringdal (1977) Seismic Mapping of the Fennoscandian Lithosphere and Asthenosphere with Special Reference to the Oslo Graben Region. In Tectonics and Geophysics of Continental Rifts, ed. by I.B. Ramberg and E.-R. Neumann, 297-312, D. Reidel Publ. Company, Holland.

Ihlen, P.M. and F.M. Vokes (1978) Metallogeny. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 75-90, Norges Geol. Unders., nr. 337.

Ineson, P.R., I.G. Mitchell and F.M. Vokes (1975) K-Ar Dating of Epigenetic Mineral Deposits: An Investigation of the Permian Metallogenic Province of the Oslo Region, Southern Norway. Econ. Geol., v. 70, 1426-1436.

Jacobsen, S.B. and G. Raade (1975) Rb-Sr Whole Rock Dating of the Nordagutu Granite, Oslo Region, Norway. Norsk Geol. Tidsskr., v. 55, 171-178.

Kanestrøm R. (1972) On Seismic Phases P_n and S_n as recorded in Fennoscandia. Pure and Applied Geophys., v. 97, 37-43.

Kanestrøm, R. (1973) A Crust-Mantle Model for the NORSAR Area. Pure and Applied Geophys., v. 105, 729-740.

Kristoffersen, Y. (1973) A Magnetic Investigation of the Larvikite Complex SW of Gjerdingen, Nordmarka. Norsk Geol. Tidsskr., v. 53, 267-281.

Lind, G. and S. Saxov (1970) Some Geophysical Profiles in Ostfold. Norges Geol. Unders., nr. 266, 37-48.

Morton, R.D., R. Batey and R.K. O'Nions (1970) Geological Investigations in the Bamble Sector of the Fennoscandian Shield, South Norway. Norges Geol. Unders., nr. 263, 72 p.

Neumann, E.-R. (1976) Compositional Relations Among Pyroxenes, Amphiboles and Other Mafic Phases in the Oslo Region Plutonic Rocks. Lithos, v. 9, 85-109.

Neumann, E.-R., (1978) Petrology of the Plutonic Rocks. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 25-34, Norges Geol. Unders., nr. 337.

Neumann, E.-R., A.O. Brunfelt and K.G. Finstad (1977) Rare Earth Elements in Some Igneous Rocks in the Oslo Rift, Norway. Lithos, v. 10, 311-319.

Neumann, E.-R. and I.B. Ramberg (1977) Petrology and Geochemistry of Continental Rifts, D. Reidel Publ. Company, Holland, 296 p.

Nystuen, J.P. (1975) Plutonic and Subvolcanic Intrusions in the Hurdal Area, Oslo Region. Norges Geol. Unders., nr. 317, 1-21.

Oftedahl, C. (1976) Northern End of European Continental Permian. The Oslo region. In The Continental Permian in Central, West and South Europe, ed. by H. Falke, 2-13, D. Reidel Publ. Company, Holland.

Oftedahl, C. (1977) Main Geologic Features of the Oslo Graben. In Tectonics and Geophysics of Continental Rifts, ed. by I.B. Ramberg and E.-R. Neumann, 167-194, D. Reidel Publ. Company, Holland.

O'Nions, R.K., R.D. Morton and H. Baadsgaard (1969) Potassium Argon Ages from the Bamble Sector of the Fennoscandian Shield in South Norway. Norsk Geol. Tidsskr., v. 49, 171-190.

Oslo Region Research Group (1977) News from the Oslo Region Research Group, Program with Abstract, Paleorift Systems with Emphasis on the Permian Oslo Rift, 68 p.

Pedersen, A.K., J. Engell and J.G. Rønsbo (1975) Early Tertiary Volcanism in the Skaggerak: New Chemical Evidence from Ash-Layers in the Mo-Clay of Northern Denmark. Lithos, v. 8, 255-268.

Petersen, J.S. (1977) Structure of the Larvikite-Lardalite Complex, Oslo Region, Norway, and its Evolution. Geol. Rundschau, v. 67, 330-342.

Raade, G. (1969) Cavity Minerals from the Permian Biotite Granite at Nedre Eiker Church. Contribution to the Mineralogy of Norway, no. 40, Norsk Geol. Tidsskr., v. 49, 227-239.

Raade, G. (1972) Mineralogy of the Miarolitic Cavities in the Plutonic Rocks of the Oslo Region, Norway. Mineral. Record, v. 3, 7-11.

Ramberg, I.B. (1972a) Braid Perthite in Nepheline Syenite Pegmatite, Langesundfjorden, Oslo Region (Norway). Lithos, v. 5, 281-306.

Ramberg, I.B. (1972b) Crustal Structure across the Permian Oslo Graben from Gravity Measurements. Nature (Physical Science), v. 240, 149-153.

Ramberg, I.B. (1973) Gravity Studies of the Fen Complex, Norway, and their Petrological Significance. Contr. Mineral. Petrol., v. 38, 115-134.

Ramberg, I.B. (1976) Gravity Interpretation of the Oslo Graben and Associated Igneous Rocks. Norges Geol. Unders., nr. 325, 194 p.

Ramberg, I.B. and T.F.W. Barth (1966) Ecocambrian Volcanism in Southern Norway. Norsk. Geol. Tidsskr., v. 46, 219-236.

Ramberg, I.B., R.H. Gabrielsen, B.T. Larsen and A. Solli (1977) Analysis of Fracture Pattern in Southern Norway. Geol. Mijnbouw, v. 56, 295-310.

Ramberg, I.B. and B.T. Larsen (1978) Tectonomagmatic Evolution. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 55-74, Norges Geol. Unders., nr. 337.

Ramberg, I.B. and E.-R. Neumann (1978) Paleorift Systems--Introduction. In Petrology and Geochemistry of Continental Rifts, ed. by E.-R. Neumann and I.B. Ramberg, XIX-XXVII. D. Reidel Publ. Company, Holland.

Ramberg, I.B. and S.B. Smithson (1971) Gravity Interpretation of the Southern Oslo Graben and Adjacent Precambrian Rocks, Norway. Tectonophysics, v. 11, 419-431.

Ramberg, I.B. and S.B. Smithson (1975a) Geophysical Interpretation of Crustal Structure along the Southeastern Coast of Norway and Skagerrak. Geol. Soc. America Bull., v. 86, 769-774.

Ramberg, I.B. and S.B. Smithson (1975b) Gridded Fault Patterns in a Late Cenozoic and a Paleozoic Continental Rift. Geology, v. 3, 201-205.

Ramberg, I.B. and N. Spjeldnaes (1978) The Tectonic History of the Oslo Region. In Tectonics and Geophysics of Continental Rifts, ed. by I.B. Ramberg and E.-R. Neumann, 167-194, D. Reidel Publ. Company, Holland.

Rohr-Torp, E. (1973) Permian Rocks and Faulting in Sandsvaer at the Western Margin of the Oslo Region. Norges Geol. Unders., nr. 300, 53-71.

Segalstad, T.V. (1976) Cauldron Subsidences, Ring-Structures, and Major Faults in the Skien District, Norway. Norsk Geol. Tidsskr., v. 55, 321-337.

Sellevoll, M.A. (1973) Mohorovicic Discontinuity Beneath Fennoscandia and Adjacent Parts of the Norwegian Sea and the North Sea. Tectonophysics, v. 20, 359-366.

Sellevoll, M.A. and I. Aalstad (1971) Magnetic Measurements and Seismic Profiling in the Skagerrak. Marine Geophys. Res., v. 1, 284-302.

Sellevoll, M.A. and E. Sundvor (1974) The Origin of the Norwegian Channel--A Discussion Based on Seismic Measurements. Can. J. Earth Sci., v. 11, 224-231.

Sellevoll, M.A. and R.E. Warrick (1971) A Refraction Study of the Crustal Structure in Southern Norway. Bull. Seism. Soc. America, v. 61, 457-571.

Skjernaa, L. (1972) The Discovery of a Regional Crush Belt in the Orje Area, Southeast Norway. Norsk Geol. Tidsskr., v. 52, 459-461.

Sørensen, R. (1975) The Ramnes Cauldron in the Permian of the Oslo Region, Southern Norway. Norges Geol. Unders., nr. 321, 67-86.

Storetvedt, K.M., S. Pedersen, R. Løvlie and E. Halvorsen (1977) Paleomagnetism in the Oslo Rift Zone. In Tectonics and Geophysics of Continental Rifts, ed. by I.B. Ramberg and E.-R. Neumann, 289-296, D. Reidel Publ. Company, Holland.

Sundvoll, B. (1978) Isotope- and Trace-Element Chemistry, Geochronology. In The Oslo Paleorift, ed. by J.A. Dons and B.T. Larsen, 35-40, Norges Geol. Unders., nr. 337.

Swanberg, C.A., M.D. Cjessman, G. Simmons, S.B. Smithson, G. Grønlie and K.S. Heier (1974) Heat Flow-Heat Generation Studies in Norway. Tectonophysics, v. 23, 31-48.

Torsk, T. (1975) Possible Mesozoic Mantle Plume Activity Beneath the Continental Margin of Norway. Norges Geol. Unders., nr. 322, 73-90.

Turner, P. (1974) Lithostratigraphy and Facies Analysis of the Ringerike Group of the Oslo Region. Norges Geol. Unders., nr. 314, 101-131.

Vokes, F.M. (1960) Mines in South and Central Norway. Guide to Excursion, Intern. Geol. Congress, Norden, 1960. Norges Geol. Unders., nr. 212m, 73 p.

Vokes, F.M. (1973) Metallogeny Possibly Related to Continental Break-up in Southwest Scandinavia. In Implications of Continental Drift to the Earth Sciences, ed. by D.H. Tarling and S.K. Runcorn, 573-579, Academic Press, London.

Vokes, F.M. and G.H. Gale (1976) Metallogeny Relatable to Global Tectonics in Southern Scandinavia. Geol. Assoc. Canada, Spec. Paper, n. 14, 413-441.

Weigel, W., J. Hjelme and M.A. Sellevoll (1970) A Refraction Profile Through the Skagerrak from Northern Jutland to Southern Norway. Geodaet. Inst. Medd., v. 45, Copenhagen, 1-28.

Whitaker, J.H. (1977) A Guide to the Geology Around Steinsfjord, Ringerike. Universitetsforlaget, Oslo, 56 p.

Widenfalk, L. and R. Gorbatschev (1971) Contributions to the Mineralogy of Norway, No. 43. A Note on a New Occurrence of Baddeleyite in Larvikite from Larvik, Norway. Norsk Geol. Tidsskr., v. 51, 193-194.