

Subsidence and Tectonics in Late Precambrian and Palaeozoic Sedimentary Basins of Southern Norway

KNUT BJØRLYKKE

Bjørlykke, K. 1983: Subsidence and tectonics in Late Precambrian sedimentary basins of southern Norway. *Norges geol. Unders.* 380, 159-172.

The assumption that sedimentary basins approach isostatic equilibrium provides a good foundation for modelling basin subsidence based on variables such as cooling rates (thermal contraction), crustal thinning, eustatic sea-level changes and sedimentation. The Sparagmite basin of Central Southern Norway was probably formed by crustal extension during rifting. During Cambrian and Ordovician times the Oslo Region was rather stable part of the Baltic Shield, reflected in slow epicontinental sedimentation. The Bruflat Sandstone (Uppermost Llandovery) represents the first occurrence of a rapid clastic influx, reflecting a pronounced basin subsidence. This change in sedimentation is believed to be related to the emplacement of the first Caledonian nappes in the northern part of the Oslo Region, providing a nearby source for the sediments and resulting in subsidence due to nappe loading. The underlying Palaeozoic sequence was detached along the Cambrian Alum Shale in front of the Osen Nappe. Devonian sedimentation was characterised by vertical tectonics and some of the Devonian basins, such as the Hornelen Basin, may be related to listric faulting rather than strike-slip fractures. The Permian sediments of the Oslo Graben were probably overlain by Triassic and possibly also by Jurassic sediments during post-rift subsidence.

K. Bjørlykke, *Geologisk Institutt, Avd. A, Allégt. 41, N-5014 Bergen-Univ. Norway.*

Introduction

Sedimentary basins are very sensitive recorders of contemporaneous tectonic movements. Their potential as a key to the understanding of the tectonic history of a region has, however, not always been fully utilized. The present paper will examine some of the Late Precambrian and Palaeozoic sequences in Southern Norway and attempt to relate sedimentation to tectonic movements. The principle of crustal isostasy is old and well established in geological and geophysical literature. It is, however, only recently that Airy's isostatic model has been widely applied to recalculate primary tectonic movements or sea level changes in sedimentary basins (e.g. Kinsman 1975, Watt & Stecker 1979, Watt & Ryan 1976, Watt 1981, 1982).

We may assume that most sedimentary basins are in approximate isostatic equilibrium. This implies that basin subsidence must be due to changes in the isostatic equilibrium (Kinsman 1975). However, at basin margins or along hinge lines in passive margins, flexural rigidity of the crust may play an important role (Watts & Ryan 1976). The requirements that isostatic equilibrium should be maintained, allows us to model the relationship between

tectonics and sedimentation and to place important constraints on sedimentological and stratigraphical interpretations. Since several factors influence isostatic equilibrium, this principle rarely gives unique solutions but forces us to consider different mechanisms by which isostatic equilibrium can be maintained.

Primary subsidence of the crust underlying a sedimentary basin may be due to four principal phenomena:

1. Extension and thinning of the continental crust.
2. Cooling, causing thermal contraction and isostatic subsidence due to the increased density.
3. Increased loading, due to the ice or emplacement of tectonic nappes.
4. Eustatic rises in sea level will also cause subsidence in order that isostatic equilibrium can be maintained. Secondary subsidence will result from increased load due to deeper water and to the sediments filling the basin.

Isostatic uplift following the melting of glaciers has shown that the crust responds rather quickly to changes in loading in the perspective of the geological time-scale. Nansen (1928) also pointed out the significance of water and sediment loading for isostatic equilibrium.

Stratigraphic information may be used to calculate primary crustal subsidence by removing the effects of loading by sediments and water using a back-stripped technique (Stecker & Watts, 1978):

$$Y = S \frac{P_m - P_s}{P_m - P_w} - SL \frac{P_w}{P_m - P_w} + Wd - SL \quad (1)$$

Sediment
Water
Water
loading
loading
depth

where Y is the primary basement response, S is the stratigraphic thickness compensated for compaction, P_m is the density of the mantle, P_s is the density of the sediments, P_w is the density of water, SL is the change in sea level and Wd is the water depth.

Late Precambrian and Lower Palaeozoic sedimentation in the Sparagmite Basin and the Oslo Region

In Late Precambrian times the Baltic Shield was a mature craton and erosion reached deep into the roots of older orogenic belts (Ofte Dahl 1980). The Late Precambrian Sparagmite Basin formed as a result of continental rifting (Bjørlykke et al. 1976, Roberts & Gale 1978, Nystuen 1982). Isostatically, the subsidence was probably due to thinning of the continental crust. Contemporaneous faulting and volcanism suggest that rifting was active up to the time of deposition of the Ring Formation (Fig. 1) (Sæther & Nystuen 1981). The Ringsaker Quartzite (Fig. 1) represents an important stratigraphic reference horizon since this extensive, thin, transgressive orthoquartzite suggests a very stable tectonic environment.

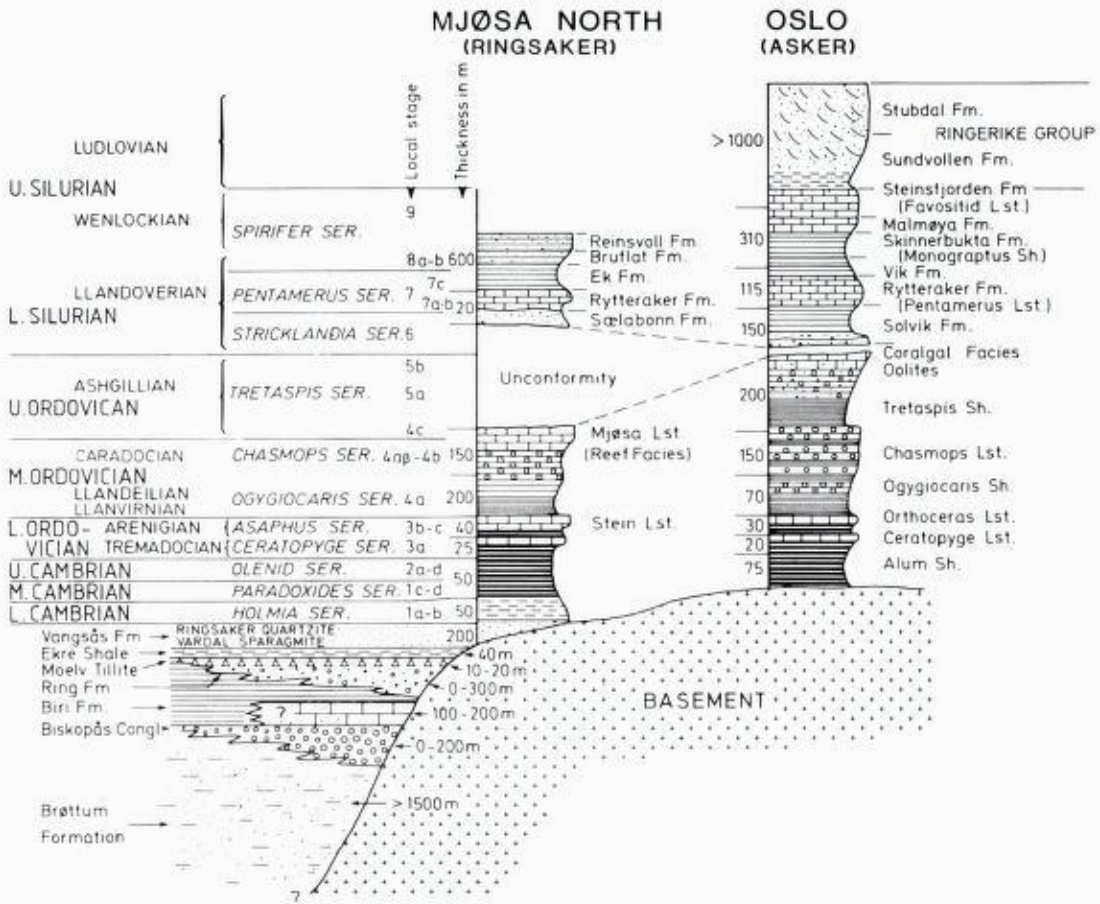


Fig. 1. Stratigraphy and Late Precambrian and Lower Palaeozoic sedimentary sequences in the Lake Mjøsa and Oslo districts. Silurian stratigraphy from Worsley et al. (1982). In the Mjøsa Region the name Helgøy Quartzite is used for the basal quartzite above the Ordovician–Silurian unconformity and Limovnstangen Formation for the Pentamerus Limestone (Høy & Bjørlykke, 1980).

The Vangsås Formation is only 150–200 m thick and the Ekre Shale and the Moelv Tillite are rarely more than 40 and 30 m thick, respectively. The Ekre Shale, however, may locally be thicker and is 150 m thick in Osdalen (Nystuen 1982). These sediments, which may be interpreted as deposited after the cessation of active rifting, are thus only 200–300 m thick in total. Using the back-stripping technique (equation 1), we find that the corresponding primary crustal subsidence due to thermal contraction in the Sparagmite basin was less than 100 m. Assuming that the Moelv Tillite was deposited at 650 Ma (Bjørlykke & Nystuen 1981) and the Ringsaker Quartzite at 580 Ma (lowermost Cambrian) the sequence was deposited over a period of 70 Ma at a low sedimentation rate. By Ringsaker Quartzite times most of the thermal contraction should have been completed, and the Ringsaker Quartzite thus suggests very slow sedimentation in a shallow water marine envi-

ronment. 100 m is a very modest primary subsidence and it may be pertinent to ask why thermal contraction due to post-rift cooling did not cause more subsidence. One possible explanation is that most of the rifting and crustal heating occurred during the deposition of the Brøttum and Biri Formations, and the Ring Formation may then also have been deposited during the cooling phase. Evidence of contemporaneous volcanicity, however, is found below the Moelv Tillite in Østerdalen (Sæther & Nystuen, 1981). These are the only areas where there is clear evidence of contemporaneous volcanicity, although basaltic clasts are common in the Biskopåsen Conglomerate (Sæther & Nystuen, 1981). The Sparagmite rift basin would therefore seem to have been characterised by limited volcanic activity and may have had a lower geothermal gradient than other rift basins. This would have resulted in modest post-rift subsidence due to cooling.

The Ringsaker Quartzite is succeeded by Lower Cambrian (Holmia) shales which are transgressive southwards, lapping on to basement in the Mjøsa District. These beds are found not only in other parts of the Baltic Shield (Martinson 1974) but also on several continents (Brasier 1982) suggesting that the transgression was eustatic. Back-stripping this part of the sequence we find that the Lower Cambrian transgression could have been caused by a eustatic sea level rise or a primary basin subsidence of as little as 30–40 m which is considerably less than that suggested by Vail et al. (1977). This may have been related to cambrian sea-floor spreading.

A conglomerate of lower Middle Cambrian age (Paradoxides oelandicus zone) indicates a period of regression and erosion (Skjeseth 1963, Bjørlykke 1974b). The subsequent Middle Cambrian transgression gradually covered most of the Baltic Shield. This transgression occurred at the same time in Norway and southern Sweden and probably represents a new eustatic rise in sea-level. The transgression initiated a cycle of black shale sedimentation which continued, interrupted only by episodes of carbonate sedimentation, to Late Tremadocian times when reworking of the upper part of the Ceratopyge limestones developed. Correcting for later compaction and using equation (1), we find that the deposition of the 120 m-thick Middle Cambrian to Late Tremadocian sequence in the Oslo Region could have been caused by a 40 m eustatic change in sea-level.

The Ordovician sequence in the Oslo Region indicates an accelerating rate of subsidence (Fig. 2). Carbonate sediments constitute a shallow-water facies, shales occurring essentially when rates of subsidence or eustatic rises in sea level exceeded the rate of sedimentation. We can recognise the following cycles of deepening and subsequent shallowing:

1. L. Arenig → U. Arenig (L. Didymograptus Shale (3b) → Orthoceras Limestone (3L).
2. Llanvirn → Caradoc (U. Didymograptus Shale (4a) → Chasmops Limestone (4b).
3. U. Caradoc → U. Ashgill (Tretapis Shale (4c) → Limestone (5b).

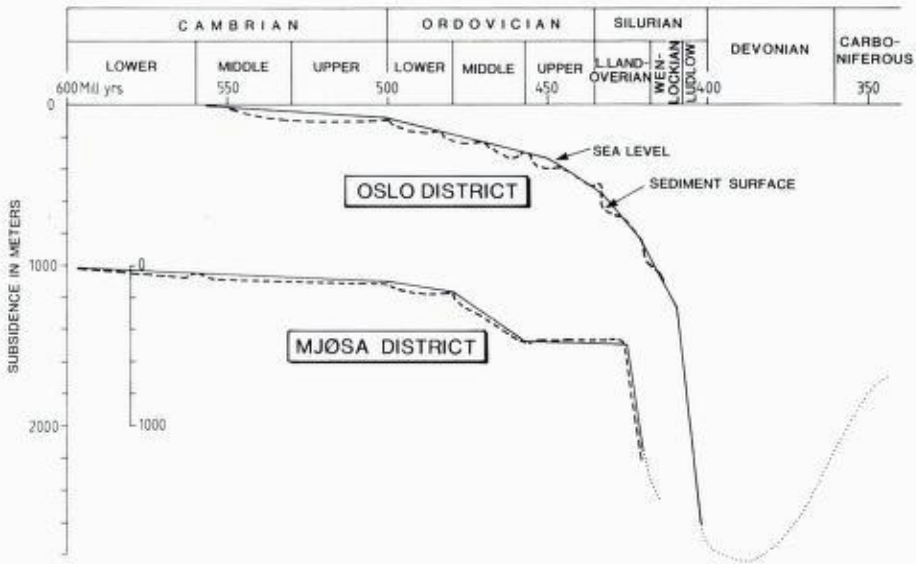


Fig. 2. Basin subsidence curves for the Oslo and Mjøsa districts during Lower Palaeozoic sedimentation.

Within these cycles several minor sea-level oscillations can be recognized. Particularly in the Llanvirn–Caradoc cycle minor oscillations resulted in the alternation of shale and limestone in the Ampyx and the Chasmops series.

The Tretaspis Shale (Uppermost Caradoc to Lowermost Ashgill) is a black shale with a thin phosphate conglomerate near the base, and represents a very significant transgression from the shallow-water environment of the Chasmops limestone. The Tretaspis Shale passes into a shallower water sequence with impure carbonates and corallgal facies at the top. It is difficult to evaluate the effect of eustatic changes in sea level in the Ordovician sequence. The Upper Ordovician glaciation in W. Africa and S. America (Crowell et al. 1981, Biju-Duval et al. 1981, Deynoux & Trompette 1981) should be expected to have caused eustatic sea-level changes that might be detectable in the Oslo Region (Bjørlykke, 1974a, p. 18, Brenchley & Newall 1980).

It has proven difficult to establish the age of this glaciation precisely within the time range from Caradoc to Llandovery. Tillites in the Anti-Atlas are, however, better dated and suggested an uppermost Ashgillian (Hirnantian) age (Destombes 1981). The W. African and S. American glaciations of Late Ordovician age may not have been synchronous, but if they were, their extent would suggest a rather significant change in sea-level. Even a much smaller sea-level change than that associated with the Pleistocene glaciation, i.e. 30–50 m, would be expected to have had a quite profound influence on sedimentation in a shallow-marine environment like that in the Oslo Region. It is therefore tempting to correlate the unconformity along the Ordovician/Silurian boundary with the Late Ordovician glaciation, even though the glaciation cannot be dated very precisely. However, the somewhat variable rates of relative subsidence associated with the Lower Silurian transgression in the

Oslo Region suggest a strong tectonic influence (Bjørlykke 1974a). Spjeldnæs (1957) has also suggested that a significant angular unconformity exists at the Ordovician/Silurian boundary in the Oslo Region but it is difficult to find conclusive evidence of this. If the Lower Silurian transgression was only due to a post-glacial eustatic rise in sea-level, it should have been more synchronous and uniform. The U. Ordovician/l. Silurian unconformity in the Oslo Region represents, however, only an episode of relative uplift in a period of accelerating subsidence (Fig. 2), and the unconformity is probably, at least partly, also controlled by tectonic movement. If the erosional relief in the Ordovician sediments at the base of the Silurian sequence (up to 100 m) (Bjørlykke 1974a, p. 21) was entirely due to glacio-eustatic regression, it is surprising that well developed karst structure are rare or absent below the unconformity. On the other hand we might assume that if we had a significant glacio-eustatic sea-level drop in Upper Ordovician time, it could only be placed at the top of the Caradoc or in the Hirnatian, based on the stratigraphic record of the Oslo region.

Relationships between Silurian thrusting and sedimentation (nappe loading)

Sedimentation rates in the Llandovery and Wenlock require significant crustal subsidence, in marked contrast to the stable situation in Middle Cambrian to Middle Ordovician times. A distinct cause of this crustal subsidence should be sought as its magnitude is too large to be explained in terms of eustatic sea-level changes. The Oslo Region must also have been thermally mature and subsidence due to cooling is therefore highly unlikely. The possibility of thinning of the continental crust cannot be ruled out, but it might be expected to have affected the whole of the Oslo Region at the same time. In the author's opinion the cause of the increased rates of subsidence in Late Ordovician and Silurian times may be due to isostatic loading by nappes which were thrust towards the E and SE during Caledonian deformation. A similar relationship is found in the Silurian of North Greenland (Hurst et al. 1983).

There were probably several phases of thrusting, the earliest of which was of Lower to Middle Ordovician age and involved the obduction of ophiolites (Sturt & Thon 1978). The ophiolites were obducted on to Precambrian basement representing a westward extension of the Baltic Shield. Despite the considerable distance to the obduction sites the clastic sediments of the Oslo Region are strongly influenced by debris from basic igneous rocks and distinctive minerals such as chromite can be traced back to ophiolitic source rocks (Bjørlykke 1974a, b, Bjørlykke & Englund 1979). The geochemical influence of ophiolite debris is first felt in the Oslo Region in Arenigian times and reaches a peak in Middle Ordovician (Caradocian) times. Thus the inflow of clastic materials derived from the ophiolites helps to date their

emplacement and uplift prior to erosion. A similar pattern of clastic chromite distribution is also found to date the obduction of ophiolites in Newfoundland (Church & Stevens 1971). Early Ordovician thrusting (Sturt & Thon 1976) caused major nappe loading and basin subsidence in regions in proximal positions relative to the nappes, but they were probably too distant to cause major loading effects in the Oslo Region. Middle to Upper Ordovician flysch in Gausdal may however reflect subsidence and sediment supply from advancing Ordovician nappes (e.g. the Jotun Nappe: Nystuen (1981)). The fact that the Upper Ordovician subsidence in the Oslo Region is synchronous with uplift and exposure in the Lake Mjøsa district indicates that relative subsidence at that time was not caused by eustatic sea-level changes or nappe loading but was probably the result of slight adjustments in the part of the craton related to subduction further west.

The Bruflat Sandstone (Fig. 1 & 2) provides the first evidence of relatively rapid subsidence, and the formation of turbidites and deltaic sediments is good evidence of a proximal exposure of a major land mass (Bjørlykke 1974a). This may have been caused by the emplacement of the Osen Nappe or Quartz Sandstone Nappe (Schiötz 1902, Nystuen 1981) towards the Oslo Region. Emplacement was probably the result of gravity sliding producing an imbricate structure (Price 1977) which could cause isostatic subsidence in front of the nappe and at the same time constitute an uplifted source area to the north-west. The Bruflat Sandstone, which is now considered to be of uppermost Llandovery age (Worsley et al. 1982), may thus date the advancement of the Osen Nappe into the Lake Mjøsa Region.

Since the Bruflat Formation and in some areas the Reinsvoll Formation (Worsley et al. 1982) are overlain unconformably by Permian lava and sediments in the Mjøsa district, we are not in a position to detect continued subsidence and sedimentation in the Lake Mjøsa Region through the Upper Silurian. In the Ringerike district carbonate sedimentation was predominant in Wenlockian times, showing that this region was still unaffected by the clastic influx (Worsley et al. 1982). Sedimentation rates however, were relatively high (Fig. 2).

The Ringerike Sandstone (Sundvollen Fm.) of upper Wenlock and Ludlow age (Worsley et al. 1982) represents progradation of fluvial sediments over marine sediments in the Ringerike and Bærum-Asker districts and requires a land area to the north or north-west. The depocentre was displaced to the south in the Upper Llandovery although it appears that the Bruflat Sandstone represents a separate and earlier episode of subsidence. If the Bruflat Sandstone dates the emplacement of the Osen Nappe in the northern part of the Oslo Region, some folding of the Cambro-Silurian sequence might be expected to have occurred in front of the nappe (Fig. 3). The thrusting of the Osen Nappe over the Cambrian Alum Shale requires that the Ordovician and Lower Silurian sequences were detached from the Alum Shale ahead of the Osen Nappe (Fig. 3). Strong deformation of the Alum Shale in the Lake Mjøsa district, due to the movement of the Ordovician-Silurian sequence over the basement, has been documented by Skjeseth (1963). The impor-

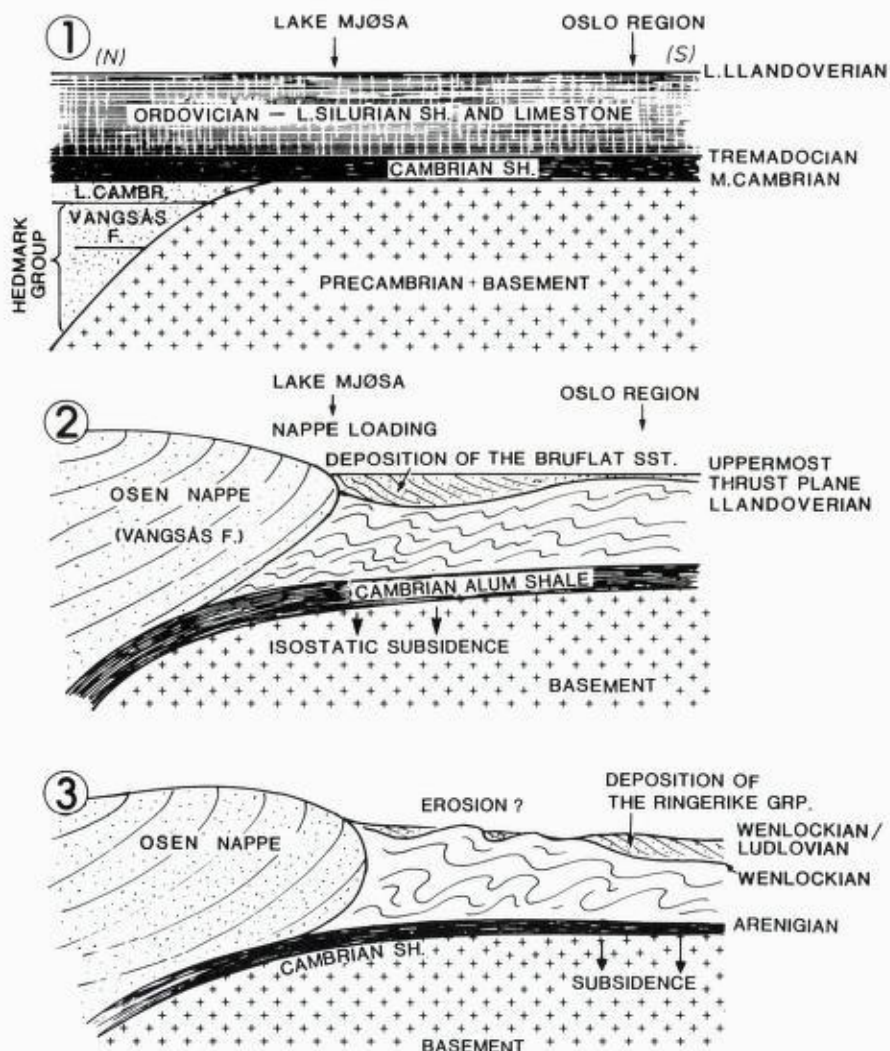


Fig. 3. Hypothetical model for Silurian sedimentation and thrusting in the Oslo Region.

tance of the Alum Shale as a major décollement horizon was first recognised by Brøgger (1882). Nansen (1928, p. 105) stated:

«Along this slope from the mountain range the sedimentary formations gradually slid downwards towards the Oslo Region, this sliding being facilitated by the loose, and slippery Alum-schist which formed the lowest sedimentary layer and acted as a lubricating material reducing the friction against the underlying surface of Archæan rocks. Thus a lateral pressure arose in the sliding Cambrian and Silurian strata, and they were gradually compressed, folded and crumpled».

The gravity sliding is likely to have been associated with some folding which would then have taken place before the deposition of the Ringerike Sand-

stone. As pointed out by Worsley et al. (1982) relatively stable areas of carbonate sedimentation existed in the Asker and Ringerike districts through most of Wenlock time. However, the Lower Wenlockian (Sheinwoodian) NW-SE trending facies belt shown on 'time slice' maps (Worsley et al. 1982) may represent surface expressions of gentle early folding.

Before the deposition of the Ringerike Group the underlying Lower Palaeozoic sediments probably consisted of well-cemented limestone interbedded with rather soft muds due to very limited degrees of compaction by the overburden. This sequence could have been folded in a rather ductile manner by differential sliding between the limestone beds.

The Ringerike Sandstone has a more open fold style representing less shortening than for the folds in the underlying sediments. This may possibly be the result of differences in competence but may also be partly explained by some pre-Ringerike Sandstone folding. Further to the south-east the highest rates of subsidence occurred in a basin extending into Scania, Denmark and N. Poland (Størmer 1967). This depression is nearly parallel to the direction of Caledonian thrusting and may be related to extension perpendicular to Caledonian compression along a zone of weakness in the Baltic Shield.

If the Lower Palaeozoic rocks were not deformed prior to the deposition of the Ringerike Sandstone, then the thrusting of the Osen Nappe must have been accomplished during the Silurian. Since the Osen Nappe was emplaced over Cambrian shales, the total shortening of the Ordovician/Silurian sequence must correspond to the magnitude of the Osen Nappe overthrust (Fig. 3).

In the Oslo Region and the Southern part of the Sparagmite Basin the Precambrian basement was not significantly deformed during nappe emplacement. In the southernmost part of the Oslo Region (Skien-Langesund district) there is little evidence of folding or thrusting of the Lower Palaeozoic sequence in relation to the basement. This implies that the shortening of the Ordovician/Silurian sequence related to the emplacement of the Osen Nappe must be represented by folding within the Oslo Region. Based on the occurrence of outliers of the Nappe (Schjötz 1902, Holtedahl 1915) the minimum distance of translation is 25-40 km. Oftedahl (1943) and Nystuen (1981) have, on various lines of evidence; interpreted the remaining part of the Sparagmite Basin north of Lake Mjøsa to be highly allochthonous (200-400 km). If the 'Sparagmite nappe' had also been sliding on Cambrian shales the shortening of the underlying Cambro-Silurian sequence must have been correspondingly larger. In the present author's opinion the style of the folding in the Cambro-Silurian sequence in the Oslo Region does not suggest shortening of this magnitude.

Late Palaeozoic sedimentation

Subsidence and thrusting during Late Silurian and Early Devonian times resulted in a very significant crustal thickening in the Central Norwegian Caledonides. This resulted in isostatic uplift and the formation of a topo-

graphic mountain chain. Since conglomerates and sandstones of Lower to Middle Devonian age in Western Norway (Steel 1978) and in Trøndelag (Siedlecka 1975, Roberts 1974) rest on Lower Palaeozoic sediments or basement, there must have been considerable erosion prior to the formation of the basins. The Devonian basins represent areas of very strong subsidence in the Central Norwegian Caledonides. Such large-scale subsidence requires a thinning of the continental crust, and Steel (1976) suggests for the Hornelen basin that crustal extension and thinning was related to a transcurrent fault system. It is, however, difficult to explain how a major E-W trending strike-slip fault extends and dissipates into the central part of the Baltic Shield.

Bryhni (1964) suggested that the eastward tilting in the Hornelen basin was due to a basin progressively migrating eastwards by successive faulting. Another mode of formation of the sedimentary basin is by detachment faulting between a basement complex and a cover terrain similar to those described from the Cordilleran metamorphic core complexes (Coney 1980). Extensional tectonics related to uplift may produce sedimentary basins by listric faulting (Fig. 4). The sedimentary basins open by movement on a listric gravity fault, producing a basin by extension of the crust in much the same way as one opens a drawer. Sliding of the Hornelen basin with its underlying basement to the west explains the continuous infilling of the basin from the

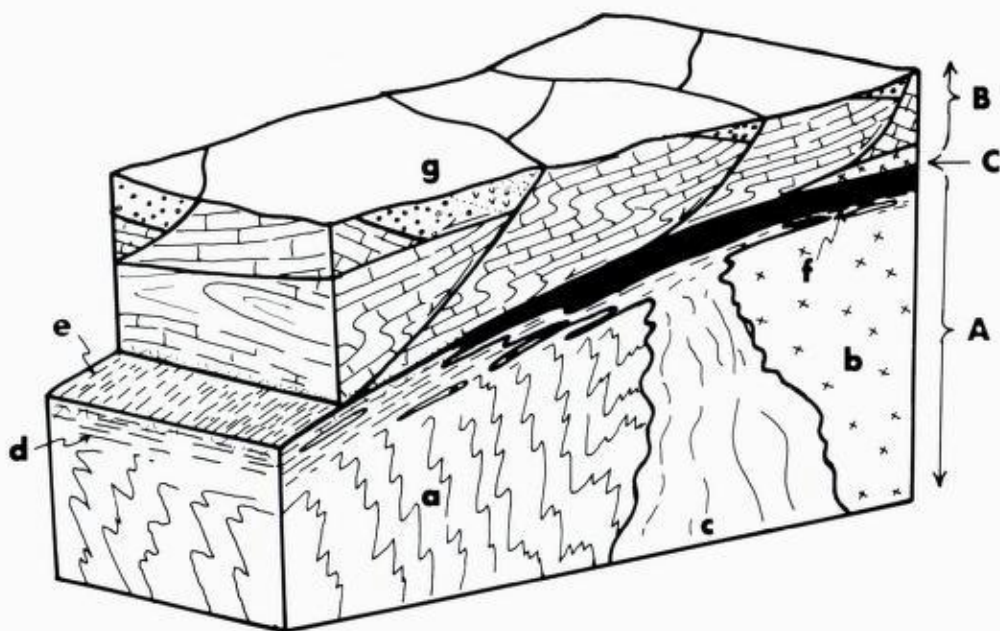


Fig. 4. Formation of sedimentary basins due to listric extensional faulting (from Coney 1980). Note that this model predicts that sedimentary infill occurs asymmetrically as the basin is extended and that the sedimentary sequence will be younging away from the direction of the relative tectonic movement of the fault blocks. The dip of the beds will decrease up section as rotation along the fault-plane takes place during sedimentation.

east, as well as the decrease in dip to the east due to rotation during sedimentation. Detailed tectonic studies are, however, needed before such a model can be substantiated. Basin subsidence related to listric structures and crustal extension has also been suggested by Roberts (1983).

Upper Palaeozoic rifting in the Oslo Region was associated with the production of rather large volumes of igneous rocks (Ramberg & Spjeldnæs 1976) and a sequence of Upper Carboniferous and Permian sediments only a few hundred metres thick was deposited (Olaussen 1981). We would expect that the Upper Palaeozoic rifting was followed by a later phase of subsidence. Post-rifting cooling could theoretically result in a thermal subsidence of 2–3 km, depending upon the degree of thinning of the continental crust and additional subsidence due to sediment loading (Kinsman 1975). It is therefore probable that the Brumunddal Sandstone of the Lake Mjøsa district is only a small part of a once much more extensive and thicker sequence of Post-Permian sediments in the Oslo Region. This assumption is supported by the fact that in the continuation of the Oslo Rift in Skagerak and N. Jylland we find 3–4 km of Triassic sediments (Ziegler 1981, 1982).

In the Oslo Graben, thermal subsidence with the deposition of a 2–3 km thick sequence of sediments would be expected to have followed the Permian igneous activity. It is therefore likely that the Carboniferous–Permian sequence in the Oslo Region was succeeded by approximately 2 km of younger sediments and that sedimentation continued into the Triassic and possibly also the Jurassic.

Conclusions

1. The post-rift subsidence in the Sparagmite Basin is considerably smaller than theoretically expected. This may be explained in two ways:
 - a) The rift was characterised by relatively low geothermal gradients.
 - b) The main rifting took place during the deposition of the Brøttum Formation and the overlying sequence may be regarded as part of the cooling phase despite the fact that small volumes of volcanic rocks have been found in this overlying sequence.
2. Lower Palaeozoic epicontinental sedimentation indicates a high degree of tectonic stability in Cambrian and Ordovician times. Allowing for basin subsidence due to water loading and sedimentation, the Lower and Middle Cambrian transgression can be explained in terms of much smaller eustatic sea-level changes than those proposed by Vail et al. (1977).
3. The increased rate of subsidence in mid-Silurian times (Late Llandovery and Wenlock) in the Oslo Region may be due to nappe loading, a model which also provides a source for upper Silurian sandstones. If this model is correct it provides a powerful tool for dating thrusting in the Scandinavian Caledonides, as also shown from the Cretaceous of the western United States (Jordan 1983).

4. Devonian sedimentation is characterised by large-scale vertical tectonics and the possibility that Devonian basins in Western Norway may be related to gravity-generated listric faulting rather than strike-slip faulting deserves further attention.
5. In the Oslo Graben, thermal subsidence with the deposition of 2–3 km of sediment would be expected to have followed the Permian magmatism. It is therefore likely that the Carboniferous–Permian sequence in the Oslo Region was succeeded by approximately 2 km of younger sediments and that sedimentation continued into the Triassic and possibly also into the Jurassic.

Acknowledgements. – The author would like to thank Dr. D. Worsley, Dr. J. P. Nystuen, and Professor N. Spjeldnæs for valuable comments. Professor B. A. Sturt, Dr. B. Robins and Dr. M. R. Talbot have kindly critically read and improved the manuscript.

REFERENCES

- Bjørlykke, K., 1974a: Depositional history and geochemical composition of Lower Paleozoic epicontinental sediments from the Oslo Region. *Norges geol. Unders.*, 305, 81 p.
- Bjørlykke, K., 1974b: Geochemical and mineralogical influence of Ordovician island areas on epicontinental sediments from the Oslo Region. *Sedimentology*, v. 21, 251–272.
- Bjørlykke, K. and Englund, J. O., 1979: Geochemical response to Upper Precambrian rift basin sedimentation and Lower Paleozoic epicontinental sedimentation in South Norway. *Chemical Geology*, v. 27, 271–295.
- Bjørlykke, A., 1979: Gjøvik og Dokka. Beskrivelse til de berggrunnsgeologiske kart 1816 I og 1816 IV M 1:50.000. *Norges geol. Unders.* 344, 48 p.
- Bjørlykke, K., Elvsborg, A. and Høy, T., 1976: Late Precambrian sedimentation in the central Sparagmite basin of South Norway. *Norsk geol. Tidsskr.* 56, 233–240.
- Bjørlykke, K. and Nystuen, J. P., 1981: Late Precambrian Tillites of South Norway. In: Hambrey, M. J. and Harland, W. B. (eds.): *Earth's pre-Pleistocene glacial Record*. Cambridge Univ. Press, p. 624–628.
- Biju-Duval, B., Deynoux, M. and Rognon, P., 1981: Late Ordovician Tillites of Sentral Sahara. In: Hambrey, M. J. and Harland, W. B. (eds.): *Earth's pre-Pleistocene Record*. Cambridge Univ. Press, p. 99–107.
- Brasier, M. D., 1982: Sea-level changes, facies changes and the late Pre-Cambrian – early Cambrian evolutionary explosion. *Precambrian Research* 17, p. 105–123.
- Brenchley, P. J. and Newall, G., 1980: A Facies Analysis of Upper Ordovician Regressive Sequences in the Oslo Region, Norway – A record of glacioeustatic changes. *Palaeogeogr. Palaeoclim. Palaeoecol.*, 31, p. 1–38.
- Bryhni, I., 1964: Migration basins on the Old Red Continent. *Nature*, Lond. 202, No. 4930, p. 384–384.
- Brogger, W. C., 1982: Die Silurischen Etagen 2 und 3 in Kristiania Gebiet und auf Eker. Universitätsprogramm für 2. Sem. 1982, 326 p.
- Church, W. R. and Stevens, R. K., 1971: Early Paleozoic Ophiolite Complexes of the Newfoundland Appalachian as Mantle–Oceanic Crust Sequences. *Journ. Geophys. Res.* 76, p. 1460–1460.
- Coney, P. J., 1980: Cordilleran metamorphic core complexes: An overview. In: Crittenden, M. D. (ed.): *Cordilleran Metamorphic Core Complexes*. *Geol. Soc. Am. Memoir* 153, p. 7–34.
- Crowell, J. C., Suarez-Sorucor and Rocha-Campos, A. C., 1981: The Silurian Cancianiri (Zapla) Formation of Bolivia, Argentina and Peru. In: Hambrey, M. J. and Harland, W. B. (eds.): *Earth's pre-Pleistocene Record*. Cambridge Univ. Press, p. 902–907.
- Destombes, J., 1981: Hirnantian (Upper Ordovician) Tillites on the North Flank of the Tindout Anti-Atlas Morocco. In: Hambrey, M. J. and Harland, W. B. (eds.): *Earth's pre-Pleistocene Record*. Cambridge Univ. Press, p. 87–88.

- Deynoux, M. and Trompette, R., 1981: Late Ordovician Tillites of the Taodeni Basin of West Africa. *In*: Hambrey, M. J. and Harland, W. B. (eds.): *Earth's pre-Pleistocene Record*. Cambridge Univ. Press, p. 89-96.
- Holtedahl, O., 1915: Iagttagelser over fjeldbygningen omkring Randfjordens nordende. *Norges Geol. Unders.*, No. 75 - Årbok 1915, p. 1-32.
- Hurst, J. M., McKerrow, W. S., Soper, N. J. and Surlyk, F., 1983: The relationship between nappe tectonics and Silurian Turbidite deposition in north Greenland. *J. Geol. Soc., Lond.*
- Høy, T. and Bjørlykke, A., 1980: Hamar, Berggrunnskart 1961 IV, m 1:50.000, *Norges geol. Unders.*
- Jordan, T. E., 1981: Thrust Loads and Foreland Basin Evolution, Cretaceous, Western United States. *Am. Ass. Petr. Geol.* 65, 2506-2520.
- Kinsman, D. J. J., 1975: Rift Valley Sedimentation and Sedimentary History of Trailing Continental Margins. *In*: Fischer, G. and Sheldin, J. (eds.): *Petroleum and Global Tectonics*, p. 83-129. Princeton Univ. Press, 322 p.
- Martinsson, A., 1974: The Cambrian of Norden. *In*: Holland, C. H. (ed.): *Cambrian of the British Isles, Norden and Spitsbergen*. John Wiley & Son, p. 185-284.
- Nansen, F., 1928: The earth's crust, its surface forms and isostatic adjustment. *Det Norske Vitenskaps Skrifter, Mat.-Nat. klasse* 1927, nr. 12, 121 p.
- Nystuen, J. P., 1981: The Late Precambrian «Sparagmites» of southern Norway: A major Caledonian allochthon - the Osen-Roa Nappe Complex, *Am. J. Sci.*, v. 281, p. 69-94.
- Nystuen, J. P., 1982: Late Proterozoic basin evolution on the Baltoscandian craton: The Hedmark Group, Southern Norway. *Norges geol. Unders.*, 375, p. 1-74.
- Oftedahl, C., 1943: Om sparagmitter og deres skyvning innen kartbladet Øvre Rendal. *Norges geol. Unders.*, No. 161, 65 p.
- Oftedahl, C., 1980: Geology of Norway. *Norges geol. Unders.*, No. 356.
- Olaussen, S., 1981: Marine incursion in the Upper Palaeozoic Sedimentary rocks of the Oslo Region, southern Norway. *Geol. Mag.* v. 118, p. 281-288.
- Price, N. J., 1977: Aspects of Gravity Tectonics and the Development of Listric Faults. *J. Geol. Soc. Lond.*, 133, p. 311-327.
- Ramberg, I. B. and Spjeldnæs, N., 1978: The tectonic history of the Oslo Region. *In*: Ramberg, I. B. and Neuman, E. R. (eds.): *Tectonics and Geophysics of Continental Rifts*. Reidel Publ. Co., Dordrecht, p. 167-197.
- Roberts, D., 1974: Sedimentary Tectonics and Metamorphic Features of the Devonian of Roragen, Sør-Trøndelag. *Norges geol. Unders.* 311, p. 88-108.
- Roberts, D. and Gale, G. H., 1978: The Caledonian - Appalachian Iapetus Ocean. *In*: Tarling, D. H. (ed.): *The Evolution of the Earth Crust*, p. 255-342.
- Roberts, D., 1983: Devonian tectonic deformation in the Norwegian Caledonides and its regional perspectives. *Norges geol. Unders.* 380.
- Schiotz, O. E., 1902: Den syd-østlige del av Sparagmitt-kvartsfjellet i Norge. *Norges geol. Unders.*, 35, p. 135, Map.
- Siedlecka, A., 1975: Old Red Sandstone Lithostratigraphy and Sedimentation of the Outer Fosen Area, Trondheim Region. *Norges geol. Unders.*, 321, p. 1-36.
- Skjeseth, S., 1963: Contributions to Geology of the Mjøsa District and the classical Sparagmite area in Southern Norway. *Norges geol. Unders.*, 220, 126 p.
- Spjeldnæs, N., 1957: The Silurian/Ordovician Border of the Oslo Area. *Norsk geol. Tidsskr.*, 37, p. 355-371.
- Steckler, M. S. and Watts, H. B., 1978: Subsidence of the Atlantic-type continental margin off New York. *Earth Planet Sc. Lett.*, 41, p. 1-13.
- Steel, R. J., 1976: Devonian Basins of Western Norway - Sedimentary Response to Tectonism and to Varying Tectonic Context. *Tectonophysics* 36, p. 207-224.
- Stormer, L., 1967: Some aspects of the Caledonian Geosyncline and foreland west of the Baltic Shield. *Quart. Journ. Geol. Soc.*, v. 123, p. 183-214.
- Sturt, B. A. and Thon, A., 1978: An ophiolite complex of probable Early Caledonian age discovered on Karmøy. *Nature, Lond.* 275, p. 538-539.
- Sæther, T. and Nystuen, J. P., 1981: Tectonic Framework, Stratigraphy, Sedimentation and Vulcanism of the Late Precambrian Hedmark Group, Østerdalen, S. Norway. *Norsk geol. Tidsskr.* 61, p. 193-211.

- Vail, P. R., Mitchum, R. M., Todd, R. C., Widmer, J. M., Thompson, S., Sangree, J. B., Bubbs, J. N., and Hatlelid, W. G.: Seismic stratigraphy and Global changes of Sea Level, 1977. In Payton, C. E. (Ed.). Seismic Stratigraphy application to hydrocarbon exploration. AAGP Memoir 26. Tulsa, U.S.A., p.49-204.
- Watts, A. B., 1981: The U.S. Atlantic Continental margin subsidence history, crustal structure and thermal evolution. In: Bally et al. (ed.): Geology of Passive Continental Margins. AAPG Education Course Note Series 19, 2-1 - 2-7-5.
- Watts, A. B., 1982: Tectonic subsidence, flexure and global changes at sea level. *Nature*, 297, p. 469-474.
- Watts, A. B. and Ryan, W. B. F., 1976: Flexure of the lithosphere and continental margin basins. *Tectonophysics*, 34, p. 25-44.
- Watts, A. B. and Steckler, M. S., 1979: Subsidence and eustasy at the continental margin of eastern North America. In: Marine Ewine Series, vol. 3. Deep Drilling Results in the Atlantic Ocean; Continental Margins and Paleo-environments, p. 218-239. American Geophysical Union. Washington D.C. 218-234.
- Worsley, D., Aarhus, N., Basset, M. G., Howe, P. A., Mørk, A. and Olaussen, S., 1982: The Silurian succession of the Oslo Region. Paleontological contribution from the University of Oslo, No. 276.
- Ziegler, P. A., 1981: Evolution of Sedimentary Basins in North-West Europe. In: Illing, L. V. and Hobson, G. D. (eds.): Petroleum Geology of the Continental Shelf of North-West Europe. Proceedings of the Second Conference on petroleum Geology of the Continental Shelf of North-West Europe, organised by the Institute of petroleum, London, March 1980, p. 3-42.
- Zigler, P. A., 1982: Geological Atlas of Western and Central Europe. Shell Internationale Maatschappij, B. v., 130 p. Elsevier, Holland.