BASE OLENEKIAN AND BASE ANISIAN SEQUENCE BOUNDARIES PRODUCED BY TRIASSIC CIRCUMPOLAR 'SYNCHRONOUS' TRANSGRESSIONS

Atle Mørk, IKU Petroleum Research, N-7034 Trondheim, Norway
Alexander Y. Egorov, Aerogeologiya-3, 5 block 3, Krjijanovsky St. Moscow, 117292, Russia
Ashton F. Embry, ISPG Geological Survey of Canada, 3303 -33rd St. N.W., Calgary, Alberta, T2L 2A7, Canada

ABSTRACT

Close similarity in geological development of the Triassic succession of different Arctic areas is clearly demonstrated in correlatable transgressive-regressive (T-R) cycles. Base Olenekian (Smithian) and base Anisian transgressive beds are correlated from the Sverdrup Basin of the Canadian Arctic to Svalbard and the Barents Sea area and farther east to East Siberia. In these areas, beds above the transgressive surfaces have been dated by ammonoids, within one or two ammonoid zones, and may thus be regarded as synchronous within the biostratigraphic resolution.

The base Anisian sequence boundary is interpreted as a second-order sequence boundary throughout the Arctic. The base Olenekian boundary shows characteristics of a third-order sequence boundary over much of the Arctic, except that it is classed as a second-order boundary in East Siberia. The characteristics of these second- and third-order boundaries indicate that each had a tectonic influence that resulted in a rapid relative sea-level fall (uplift) followed by a rapid rise (subsidence). Thus, these boundaries likely were generated by both eustatic and tectonic effects and are interpreted to reflect significant plate-tectonic reorganizations.

INTRODUCTION

General similarities in the development of the geological succession in widely separated arctic areas (Fig.1) have been known since early in this century, but the establishment of international cooperative projects during the last decade has made it possible to perform correlations on a more detailed level. These correlations have been greatly improved by mutual visits of the involved scientists to one another's field areas. During this same period, integration of geological disciplines (stratigraphy, sedimentology, biostratigraphy, and geophysics) led to new approaches in seismic stratigraphy and sequence stratigraphy. The similarities observed between different areas were the basis for the seismic stratigraphy concept of Vail et al. (1977), who interpreted that eustasy controlled the development of sequences. This concept has been further elaborated into "sequence stratigraphy" within the Exxon school (Haq et al., 1988; Posamentier et al., 1988; Van Wagoner et al., 1988), and the referenced authors have produced charts showing several levels of sequences on which they based the theory of eustatic control.

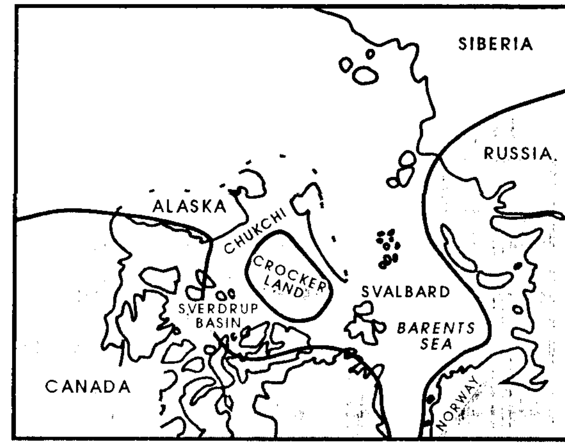

Fig.1. Map of the study area in Triassic time. Dark areas represent land areas during Early Triassic time.

Transgressive-regressive (T-R) cycles were used by Embry (1988) to delineate the Triassic succession of the Sverdrup Basin in Arctic Canada. These T-R cycles were further extended to Svalbard and the Barents Sea area by Mørk et al. (1989) and from Svalbard to East Siberia by Mørk (in press) and Mørk and Egorov (in press). Recently Embry (1992) redefined T-R cycles as T-R sequences, and he defined a hierarchic system recognizing five orders of T-R sequences based on the nature of the sequence boundaries.

Embry (1992) describes the different sequence orders in detail; only some key criteria for each order are summarized here: A first-order sequence boundary is represented by a basinwide subaerial unconformity that overlies deformed strata. A second-order boundary is characterized by a subaerial unconformity at many localities in the basin and by a significant shift in sedimentary regime across the boundary. A third-order boundary also has a significant unconformity at the basin margin, and the boundary can be correlated throughout the basin. In contrast to first- and second-order boundaries, there is only a minor shift in sedimentary regime across a third-order boundary. A fourth-order sequence boundary cannot be traced throughout the basin and is most often represented by a transgressive surface. A fifth-order sequence boundary occurs only locally in the basin. Sequence orders are best assigned only after a basinwide study.

In this paper, we present an example of a second- and a third-order sequence boundary that also can be correlated between different basins in the Arctic. These boundaries occur within and at the top of the Lower Triassic succession. The Early and Middle Triassic correlations are based on ammonoids; the reader is referred to the review papers by Mørk et al. (1989, 1992) and Mørk and Egorov (in press) for age documentation.

SVALBARD

The Svalbard Archipelago forms the exposed northwestern corner of the Barents Shelf. Basin-flank sediments occur along the western coast of the main island, and the basin margin during the Early and Middle Triassic was situated farther west, close to Greenland. In the Nordkapp Basin of the central Barents Sea, IKU has drilled Middle Triassic coastal sediment by continuous cores, showing the presence of the southeastern basin margin. Triassic T-R cycles have been described from Svalbard by Mørk et al. (1989), who noted that the base Anisian and base Olenekian were represented by transgressive surfaces (Fig.2) that were biostratigraphically well constrained. The stratigraphy is summarized by Mørk et al. (1982, 1992).

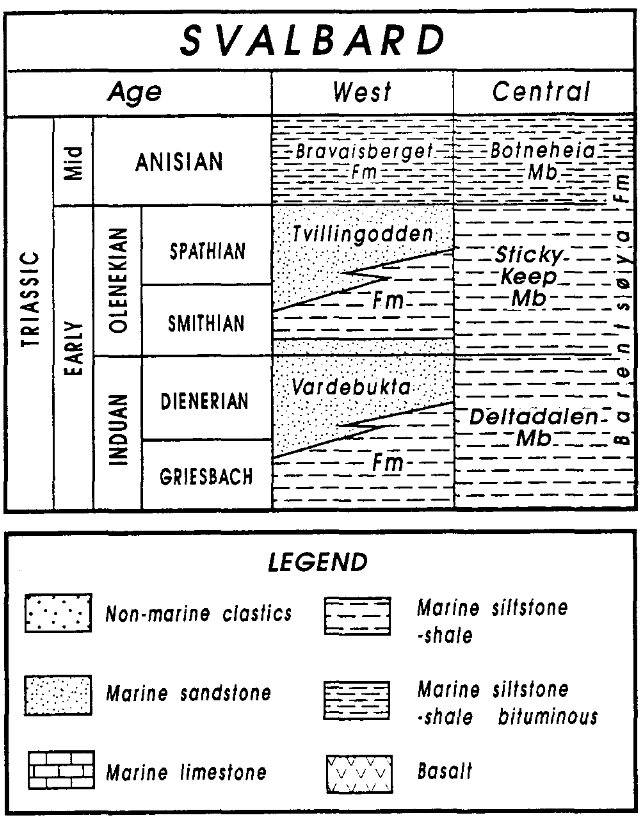

Fig.2. Svalbard Early and Middle Triassic sequence boundaries and legend for Figs.2-5.

Base Olenekian

A prominent transgressive surface marks this boundary along the basin flank (western Spitsbergen) with horizontally laminated silty shale resting conformably on top of silt or sandstone (Mørk et al., 1982). In the central and eastern areas, the contact occurs as irregularly laminated, silty shale overlain by finely laminated shale. There is no significant lithological change across the boundary, and overall the Olenekian strata closely resemble those of the Induan.

The lowest beds overlying the transgressive surface lack fossils, with the lowest specimen of *Euflemingites romunderi* occurring 5 m above the surface (Wolfgang Weitschat, pers. commun., 1992). The boundary can be traced across the basin and has the characteristics of a third-order sequence boundary.

Base Anisian

The base Anisian is one of the most obvious boundaries throughout the archipelago (Mørk et al., 1982). On the basin flank (i.e., along western Spitsbergen), soft, dark, organic-rich shale with small phosphate nodules overlies well-cemented, fine-grained sandstone. At one locality (Festningen), a thin, sandy bed with brachiopods and bivalves occurs directly above the transgressive surface. Farther south, there is a thin, parallel-laminated, bioturbated unit on top of a series of coarsening-upward units. In the central and eastern areas of Svalbard, the boundary is marked by grey, silty, locally sandy, shale overlain by black, soft, organic-rich shale with abundant small phosphate nodules. A carbonate-cemented siltstone or sandstone bed, often with abundant fossils, occurs directly above the boundary.

In all areas, there is a significant shift in sedimentary regime across the boundary. Lithological changes are marked by the sudden occurrence of phosphate nodules and organic enrichments and an overall decrease in sedimentation rate. The change in sedimentary regime and the boundary's widespread occurrence allow it to be classed as a second-order sequence boundary.

SIBERIA

Triassic rocks occur in many parts of East Siberia, including the Taymyr Peninsula, the northern portion of the Siberian Platform, the Verkhoyansk foldbelt (Fig.3) and the New Siberian Islands (Kotelney Island). In this area, more than 100 sections have been studied in detail (Egorov, 1983, 1992; Egorov and Kulikova, 1989; Egorov et al., 1987); and a detailed biostratigraphic zonation, mainly based on ammonoids (Dagys, 1981, in press; Dagys et al., 1989) has been established. A comparison of T-R sequence development in East Siberia and Svalbard is provided by Mørk and Egorov (in press), and a comparison of ammonoid zonations is given in Weitschat and Dagys (1989).

Base Olenekian

In the most marginal sections of the basin, multicoloured siltstone or light-grey sandstone with plant detritus or littoral bivalves is overlain by black shales or bituminous limestones at the Induan-Olenekian boundary (Fig.3). At some localities, a weathering crust or conglomerate bed occurs at this boundary. At some syn-sedimentary uplifts, lower Olenekian sediments occur at the base of the Triassic succession. Basinward, this boundary is recognized where light-grey clays are succeeded by black shales and by changes in fauna and mineral assemblages. Far out in the basin, at Kotelny Island, finely interbedded limestone and dark clay overlie light-grey clay at the boundary. The ammonoid *Hedenstroemia hedenstroemi* occurs in the basal beds above the boundary. At the boundary, all 8 species of 3 genera that occur in the latest Induan disappear, and 21 species of 15 genera evolve in the earliest Olenekian (A.S. Dagys, pers. commun., 1992). Also, there is a significant change in other faunal components, and mineralogical changes are pronounced. In the central part of the basin, montmorillonite in the claystones is replaced by hydromicas or kaolinite, and there are marked changes in the heavy-mineral fraction.

The boundary in this area is classified as a second-order sequence boundary owing to the marked changes in lithological development and in faunal distribution.

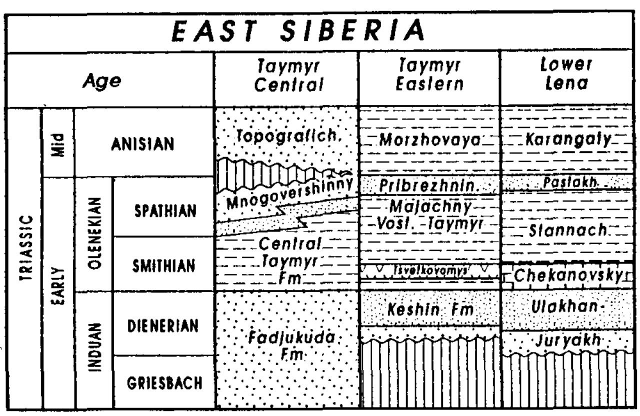

Fig.3. East Siberia Early and Middle Triassic sequence boundaries and stratigraphy (legend in Fig.2).

Base Anisian

Throughout major parts of the study area, there is an unconformity that corresponds to the lowest ammonoid subzone of the Anisian (Karangatites archipovi, Dagys and Ermakova, 1984), although in some areas the upper part of the Olenekian may also be missing (Fig.3). Erosion is observed at this boundary at several localities, and conglomerates commonly occur directly above the boundary. At most localities of the shore zone, light-grey, cross-bedded sandstones with plant detritus are overlain by siltstones and shales with numerous ammonoids above the sequence boundary. Basinward, the boundary is marked only by a thin bed of light-grey clay, which is overlain by dark-grey claystone. At many places, a carbonate cemented sandstone occurs at the top of the Olenekian succession.

At the Olenekian-Anisian boundary, 42 ammonoid species and 16 genera vanish and 13 species of 9 genera appear (Dagys, pers. commun., 1992). No genera span the boundary. There also is a significant change in other faunal groups as well as a significant change in heavy minerals, with an ilmenite-magnetite-epidote assemblage replaced by magnetite enrichments. The abrupt changes in sediment type, fauna, and mineralogy across this boundary and the clear regional hiatus indicate that this boundary represents a second-order sequence boundary (Fig.3).

SVERDRUP BASIN

Triassic strata are widespread in the Sverdrup Basin of Arctic Canada, and the stratigraphy and depositional history have been described by Embry (1991). Deltaic to shallow-marine sandstones dominate the basin flank, with thick successions of shale and siltstone in the central portion of the basin. Five second-order sequence boundaries and five third-order boundaries have been recognized in the Triassic succession (Embry, 1988, 1993). The base Olenekian boundary is a good example of a third-order boundary; the base Anisian boundary exhibits all the characteristics of a second-order boundary.

Base Olenekian

The base Olenekian sequence boundary occurs in the Bjorne Formation on the basin margin and in the Blind Fiord Formation farther basinward (Fig.4). The boundary is placed at a very prominent transgressive

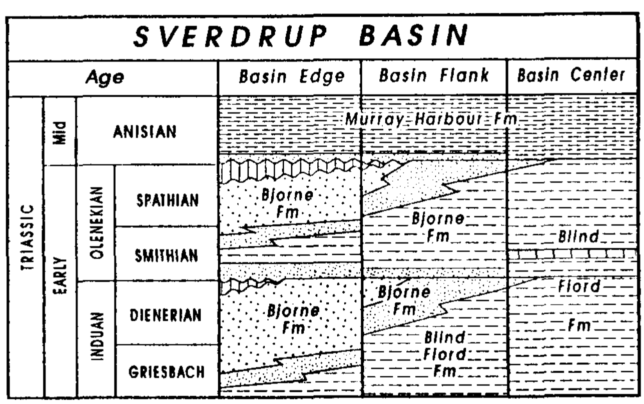

Fig.4. Sverdrup Basin Early and Middle Triassic sequence boundaries and stratigraphy (legend in Fig.2).

surface that can be correlated throughout most of the basin. Only in the Tanquary High region, located in the northeastern portion of the basin, is the boundary a subaerial unconformity.

In basin-margin sections, the transgressive surface is represented by a ravinement surface that has shoreface sandstones overlying fluvial-deltaic strata. In some areas, the ravinement surface may have cut down through a subaerial unconformity. Farther basinward, the boundary is placed at the conformable contact of medium-grey silty shales that overlie siltstones or very fine-grained sandstones of midshelf origin. Although the boundary is very widespread, there is no shift in depositional regime across it, and the regressive strata of the Olenekian sequence are very similar to those of the underlying Induan sequence (Embry, 1991). These characteristics lead to the classification of this boundary as third order.

Base Anisian

The base Anisian boundary is very prominent throughout the Sverdrup Basin and occurs at or just below the base of the Murray Harbour Formation (Fig.4). On the basin margins, the boundary is a subaerial unconformity that has been modified by shoreface erosion. Conglomerates and pebbly sandstones with clasts up to 0.5 m across directly overlie the boundary in most basin-flank localities.

The boundary becomes a conformable transgressive surface farther basinward with burrowed sandstones overlying massive to rippled shoreface deposits at the contact. In the basin center, the contact is placed at the base of phosphatic black shales that overlie medium-grey, silty shales or siltstones. There is a very major shift in the depositional regime across the boundary with thick deltaic strata below and thin, phosphatic marine shelf deposits above. This change, in conjunction with the occurrence of a widespread unconformity on the basin margins, allows the boundary to be classed as a second-order sequence boundary.

EUSTASY *VERSUS* TECTONICS

Our study shows that significant transgressions in the earliest Olenekian and earliest Anisian can be correlated throughout the Arctic areas (Fig.5) and regarded as "synchronous" within the ammonoid resolution of that area (c.f. Mørk et al., 1989). These transgressions also coincide with the classical definition of the Smithian and Anisian stages as applied in North America (c.f. Silberling and Tozer, 1968) and in the Tethys area. Different faunas, however, make correlation to Tethys and southern localities dubious, at present, and further biostratigraphical work is needed to verify the accuracy of the correlations between more remote areas.

Although the Sverdrup Basin, the Barents Shelf with Svalbard, and East Siberia all face the proto-Polar ocean and are located on the northern margin of the Pangea supercontinent, all represent *different* depositional basins. Correlative transgressions between these basins thus indicate a eustatic process. The variation in development across the sequence boundaries within each basin, however, shows that local tectonics modified the deposition.

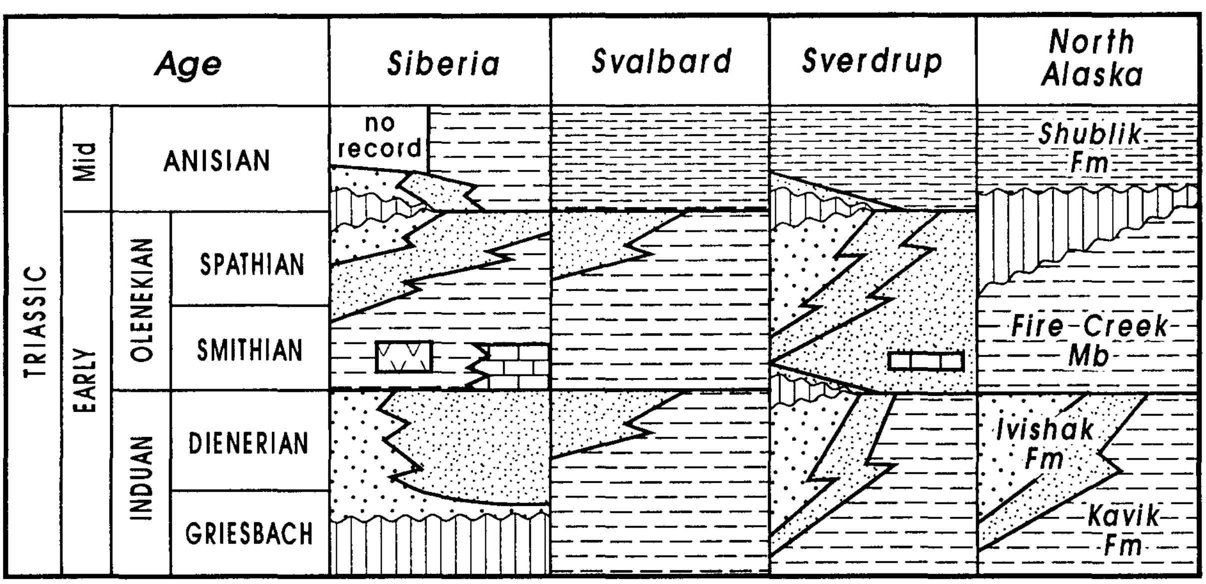

Fig.5. Summary chart and comparison with North Slope stratigraphy (legend in Fig.2).

The correlation potential of these sequence boundaries is dependent on their global nature, i.e., whether they represent real eustasy. This can only be investigated by studying areas outside the Arctic and by improved correlation between these areas. We feel that the variations seen in the development of the sequence boundaries *within* the basins can be explained by variations in lithospheric stress (c.f. Cloetingh, 1986). The impact on sea levels of such variations in lithospheric stress, both within and between plates, needs to be further investigated.

REFERENCES

Cloetingh, S. 1986. Intraplate stresses: a new tectonic mechanism for fluctuations of relative sea-level. Geology, 14: 617-621.

Dagys, A.S., 1981. Probllemy biostratigraphy triasa Sibiri i Dalnego Vostoka (in Russian) - Problems of biostratigraphy of the Triassic of the Siberia and Far East. In: 'Biostratigraphy MZ Sibiri i Dalnego Vostoka' I - Biostratigraphy of Mesozoic of the Siberia and Far East. Novosibirsk, pp. 9-16.

Dagys, A.S., in press. Lower Triassic Stage, substage and zonal scheme of North-East of Asia. Memore De Geologie, Lausanne.

Dagys, A.S., Egorov, A.Y., Kazakov, A.M. and Kurushin, N.I., 1989. Stratigraphiya triasovykh otlozheniy Yugo-Vostochnogo Taymyra (in Russian) - Stratigraphy of Triassic sediments of south-eastern Taymyr. In: 'Verkhniy Paleozoy i trias Sibiri' - Upper Paleozoic and Triassic of the Siberia, Trudy inst. geolog. i geofiziki, vyp. 732, Novosibirsk, pp. 71-174.

Dagys, A.S. and Ermakova, S.P., 1984. Zona Prohungarites similis kularskogo khrebta (in Russian) - Prohungarites sililis zone of Kular Ridge. In: 'Stratigraphy, fauna i flora triasa Sibiri' - Stratigraphy, fauna and flora of Siberian Triassic, Moscow, pp. 41-45.

Egorov, A.Y., 1983. Etapnost formirovania i facii triasovykh otlozheniy Severa Sredney Sibiri (in Russian) - Epochs of forming and facies of Triassic sediments at Siberian North. In: 'Osvestia Vuzov.' Geologia i Razvedka. pp. 20-31.

Egorov, A.Y., 1992. Stratigraphiya srednego triasa Leno-Olenekskogo rauona (in Russian) - Middle Triassic stratigraphy of the Lena-Olenek area. In: 'Regionalneya geodinamica i stratigraphia Asiatsky chasty SSSR' - Regional Plate-Tectonics and Stratigraphy of the Asian Portion of the USSR. Leningrad, pp. 5-15.

Egorov, A.Y., Bogomolov, Y.A., Konstantinov, A.G. and Sobolev, E.S., 1987. Stratigraphiya triasovykh otlozheniy ostrova Kotelny (in Russian) - Stratigraphy of Triassic at the Kotelny Island (New Siberian Islands). In: 'Borealny Trias' - Boreal Triassic. Moscow, pp. 66-80.

Egorov, A.Y. and Kulikova, L., 1989. Stratigraphicheckoe poloshgenie rannetriaasovykh trappov Taymyra (in Russian) - Stratigraphic position of early Triassic trappean basaltic of the Taymyr. In: 'Verkhniy Paleozoy i trias Sibiri' - Upper Paleozoic and Triassic of the Siberia. Novosibirsk, pp. 91-103.

Embry, A.F. 1988. Triassic sea-level changes: evidence from the Canadian Arctic Archipelago. In: C.K. Wilgus, B.S. Hastings, C.A. Ross, H. Posamentier, H. Van Wagoner, and C.G.S.C. Kendall (Editors), Sea Level Changes - An Integrated Approach. Society of Economic Paleontologists and Mineralogists, Special Publication, 42: 249-259.

Embry, A.F. 1991. Mesozoic history of the Arctic Islands. In: H.P. Trettin (Editor), Innuitian Orogen and Arctic Platform: Canada and Greenland. Geological Survey of Canada, Geology of Canada No. 3., pp. 369-433. (Also, The Geology of North America, Geological Society of America, v. E.)

Embry, A.F., 1992. Transgressive-Regressive (T-R) Sequence Analysis of the Jurassic Succession of the Sverdrup Basin, Canadian Arctic Archipelago. Canadian Journal of Earth Sciences, 30, pp. 301-320.

Embry, A.F., 1993. Triassic T-R Sequence Analysis, Sverdrup Basin, Canadian Arctic Archipelago. Program and Abstracts, Carboniferous to Jurassic Pangea, Canadian Society of Petroleum Geologists, p. 89.

Haq, B.U., Hardenbol, J., Vail, P.R., Stover, L.E., Colin, J.P., Ioannides, N.S., Wright, R.C., Baum, G.R., Gombos, A.M., Pflum, C.E. Jr., Loutit, T.S., du Chene, R.J., Romine, K.K., Sarg, J.F., Posamentier, H.W. and Morgan, B.E. 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change. In: C.K. Wilgus et al. (Editors), Sea Level Changes: An Integrated Approach, SEPM Spec. publ. 42: 71-108.

Mørk, A., in press. Triassic transgressive - regressive cycles of Svalbard and other Arctic areas; - a mirror of stage subdivision. Memore De Geologie, Lausanne.

Mørk, A. and Egorov, A.Y., in press. Svalbard and East Siberia Triassic Sequences.

Mørk, A., Embry, A.F. and Weitschat, W., 1989. Triassic transgressive-regressive cycles in the Sverdrup Basin, Svalbard and the Barents Shelf. In: J.D. Collinson (Editor): Correlation in Hydrocarbon Exploration. Norwegian Petroleum Society. Graham & Trotman Ltd., pp. 113-130.

Mørk, A., Knarud, R. and Worsley, D., 1982. Depositional and diagenetic environments of the Triassic and Lower Jurassic succession of Svalbard. In: A.F. Embry and H.R. Balkwill (Editors), Arctic Geology and Geophysics, Canadian Society Petroleum Geology, Memoir, 8, pp. 371-398.

Mørk, A., Vigran, J.O, Korchinskaya, M.V., Pchelina, T.M, Fefilova, L.A., Vavilov, M.N. and Weitschat, W., 1992. Triassic rocks in Svalbard, the Arctic Soviet Islands and the Barents Shelf; Bearing on their correlations. In: T.O. Vorren et al. (Editors), Arctic

Geology and Petroleum Potential. NPF Special Publication 2, pp. 457-479, Elsevier, Amsterdam.
Posamentier, H.W., Jervey, M.T. and Vail, P.R., 1988. Eustatic controls on clastic deposition I - conceptual framework. In: C.K. Wilgus, B.S. Hastings, and C.G. Kendall (Editors), Sea Level Changes: An Integrated Approach. Society of Economic Paleontologists and Mineralogists, Special Publication 42, pp. 109-124.
Silberling, N.J. and Tozer, E.T., 1968. Biostratigraphic classification of the marine Triassic in North America. Geological Society of America Special Paper, 110: 1-63.
Vail, P.R., Mitchum, R.M. and Todd, R.G., 1977. Seismic stratigraphy and global changes of sea level. In: C.E. Payton (Editor), Seismic Stratigraphy - Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists, Memoir 26, pp. 49-212.
Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S. and Hardenbol, J., 1988. An overview of sequence stratigraphy and key definitions. In: C.W. Wilgus et al. (Editors), Sea Level Changes: An Intergrated Approach. Society of Economic Paleontologists and Mineralogists Special Publication 42, pp. 39-45.
Weitschat, W. and Dagys, A.S., 1989. Triassic biostratigraphy of Svalbard and a comparison with NE-Siberia. Mitt. Geol.-Paläont. Inst. Univ. Hamburg, 68: 179-213