Lithostratigraphic nomenclature of the UK North Sea

6. PERMIAN AND TRIASSIC OF THE SOUTHERN NORTH SEA

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FOREWORD

This publication is one of a series of seven volumes that provide comprehensive and up-to-date information on North Sea lithostratigraphic nomenclature, together with details of all nomenclature revisions. Such information is vital to anyone concerned with the geology of the North Sea, especially those involved in the search for oil and gas, and the volumes have been designed to serve as practical desk-top or well-site reference manuals for operational geologists. The British Geological Survey has always played a major role in studies related to the petroleum geology of the North Sea. Indeed its pioneering work in the North Sea in the early 1960s provided the basis for early exploration and the licensing of the region for exploration. The BGS has been pleased to work with the United Kingdom Offshore Operators Association (UKOOA) to compile and jointly fund the first five volumes in the series, which together covered the Central and Northern North Sea plus the Carboniferous of the Southern North Sea. However, this project did not cover the post-Carboniferous sequences of the Southern North Sea and therefore the BGS decided on its own initiative to fund two extra volumes (Volumes 6 and 7) in order to extend the post-Carboniferous nomenclatural scheme to the entire UK sector of the North Sea. The comprehensive and systematic descriptions, coupled with the copious illustration of individual well sections, should form the basis for extending the lithostratigraphic scheme used here to other sectors of the North Sea. No doubt North Sea lithostratigraphic nomenclature will continue to evolve in the years ahead as oil and gas exploration proceeds, but I believe that this volume, together with its six companion volumes, will serve as the standard reference work for many years to come.

One of the essential elements in the successful compilation and publication of this vast amount of lithostratigraphic data has been the close co-operation between the BGS and the member companies of UKOOA who provided data and allowed their staff to serve on steering committees for the volumes.

In the recent Government White Paper on the future of science and technology in Britain, stress was placed on the role that science has to play in the creation of wealth. In no area of science is this more apparent than the geosciences in general, and petroleum science in particular, for it is geology that provides the data and the knowledge that together produce the new ideas on where to search for oil and gas. The British Geological Survey in partnership with industry looks forward to contributing to the future success of one of Britain's most important industrial endeavours this century — the UK offshore oil and gas industry.

Peter J Cook, Director, BGS

September 1994
The first comprehensive lithostratigraphic schemes for the North Sea Basin were established by Deegan & Scull (1977) for the UK and Norwegian Central and Northern North Sea, and by Rhys (1974) for the UK Southern North Sea. The subsequent acquisition of an increasing body of new stratigraphic data has led to piecemeal additions to these formal nomenclature schemes and also to a proliferation of informal names, some of which are now widely used by oil companies. This, together with increasing divergence in the application of existing formal names, has led to considerable uncertainty as to the meaning of many lithostratigraphic terms. This work aims to rationalize stratigraphic usage and to provide a nomenclature that will have the widest acceptance within the oil industry as a whole. It does not attempt to review the genesis or economic importance of the North Sea rock successions.

The original UKOOA plan was to publish the revision in five volumes, concentrating on prospective parts of the succession that were considered to be most in need of lithostratigraphic revision. However, coverage of the UK North Sea succession has been completed by the addition, by BGGS, of two further volumes on the post-Carboniferous of the UK Southern North Sea Basin.

The review of each of the stratigraphic intervals was carried out with the assistance of a steering committee, drawn from UKOOA member companies. The primary role of these committees was to critically assess the proposals presented by BGGS and to agree the final nomenclature schemes.

The area of study was defined at the outset by UKOOA as the UK sector of the North Sea. As a consequence, there has been no comprehensive comparison with lithostratigraphic schemes used in the adjacent sectors of, for example, Norway and the Netherlands. However, each volume includes a summary of schemes used in adjacent sectors. The primary source of data for the review has been the several hundred completion reports of wells released by the Department of Energy and, more recently, by the Department of Trade and Industry. These reports provide wellsite lithology logs (mud logs), wireline logs, and biostratigraphic reports. Additional information has been obtained from published papers and unpublished sources, including BGGS reports, consultants' reports, and unreleased post-completion reports made available by UKOOA member companies.

One of the primary objectives of the study has been to review the lithostratigraphic terms currently in use, whether formal or informal, and to establish a comprehensive nomenclature scheme for the entire UK North Sea area. This provides a lithostratigraphic framework that will facilitate stratigraphic communication and the assimilation of stratigraphic information obtained through the exchange of well data.

Emphasis has been placed on developing a scheme that, while satisfying the requirements of lithostratigraphic procedure, is of practical value to the diverse group of professionals needing to use it (e.g. exploration/development geologists, drillers, mud loggers, petroleum engineers, and members of the academic community). To this end, the aim has been to ensure that all lithostratigraphic units included within the scheme will be readily identifiable with the minimum of information, i.e., through the routine study of cuttings and wireline logs.

The format of these volumes differs significantly from the customary style of presentation. The new format aims to satisfy two requirements: (i) for an updated stratigraphic lexicon, and (ii) for a practical manual that meets the needs of operational activities. Consequently, each lithostratigraphic unit is illustrated by at least two key well sections, showing the lithological succession and corresponding gamma-ray and sonic log signatures. Lateral variation within units is displayed in a series of correlation panels at the end of the relevant section.

The lithostratigraphic procedures adopted in this revision follow the recommendations of the North American Commission on Stratigraphic Nomenclature (1983) and the Geological Society's recent guide to stratigraphical procedure (Whittaker et al. 1991).

The underlying principle followed is that the fundamental lithostratigraphic unit is the Formation. A formation must be mappable and must possess lithological characteristics that distinguish it from adjacent formations. Since this study is concerned exclusively with the subsurface, the definition of lithostratigraphic units depends on well data, primarily cuttings, but also side-wall cores and, to a lesser extent, continuous cores. Together, these provide the only direct information on the lithological succession. Wireline logs provide further essential control in characterizing more precisely the lithological succession, especially where they have been calibrated with lithological samples. The continuous nature of information from wireline logs ensures that they play a vital role in providing a consistent definition of lithological boundaries in the subsurface. As a consequence, wireline-log signatures constitute a significant element in the definition, description, and correlation of lithostratigraphic units. Furthermore, wireline log signatures often provide lithological information of a more subtle nature than can be obtained from cuttings alone, for example, grain-size trends and variations in bed thickness. Such information plays an important role in the differentiation of lithostratigraphic units.

While the primary aim of the study has been to establish a formal lithostratigraphic nomenclature, informal lithostratigraphic units have been used for units that are of practical value but that do not justify formal status. This category includes, for example, reservoir rock units that are restricted to individual fields and rock units that cannot be identified with certainty without the acquisition of biostratigraphic data. The principal consideration has therefore been to limit the use of formal names to units of significant geographic extent that can be routinely defined on lithological and wireline-log character alone, and to apply informal names where these criteria cannot be met, but where a clear practical purpose is served by doing so.

The authors are aware of many informal lithostratigraphic schemes that have been devised by oil companies for their own internal use. These are often extremely detailed, having evolved as a result of exploration success and consequent appraisal and development activities. These are generally of limited value outside the specific areas for which their use was primarily intended, in which case they have not been included within the mainstream formal nomenclature. Other schemes have been devised by consultancy groups. Some of the lithostratigraphic terms proposed in these schemes have wide usage, but, because their incorporation is restricted to exclusive reports, their incorporation into the current scheme has been possible in only a limited number of cases.

Biostratigraphic data should not constitute an essential element in the definition of a lithostratigraphic unit. Rock units whose identification depends wholly on biostratigraphic data do not warrant formal status. However, it is common practice for biostratigraphic data to be used as an aid to the identification and correlation of lithostratigraphic units. For this reason, a review of the various biostratigraphic schemes in common use has been included in this study and a selection of the most widely recognized biostratigraphic markers presented in an appendix to each part. These biostratigraphic markers are restricted to downhole occurrences and first downhole acme occurrences, since these alone are identifiable in routine cuttings analysis.

It should be stressed that the biostratigraphic markers identified in this review are already in regular use, many of them in published form. They are not discussed in detail, although their selection has involved analysis of a large amount of data. The sole purpose of the review of the biostratigraphic markers is to provide a basic biostratigraphic framework for each of the lithostratigraphic schemes and to provide a common link between the several published and unpublished schemes that will continue to be used within the oil industry.

The relationship of lithostratigraphy to seismic stratigraphy and sequence stratigraphy has been briefly discussed by Whittaker et al. (1991), and it is beyond the scope of this study to include any in-depth discussion of either discipline. It should be stressed, however, that sequence stratigraphy and lithostratigraphy are two quite separate methods which, to some extent, are complimentary. Lithostratigraphy is essentially objective. It provides a means of describing the spatial relationships of rock units and thus acts as the 'lingua franca' for stratigraphic analysis, whether by sequence stratigraphy or by other methods. Although sequence stratigraphy has introduced a fresh approach to basin studies, therefore, lithostratigraphy remains an essential and continuing element in any stratigraphic analysis.

Structural elements referred to in the following text are shown on the accompanying map. This is based on the map entitled 'Structural framework of the North Sea area', issued by the Petroleum Exploration Society of Great Britain (revised edition, March 1992), but includes the additional terms 'Outer Moray Firth', 'UK Central North Sea' and 'UK Northern North Sea'. As used here, the UK Central North Sea encompasses the Central Graben, Outer Moray Firth and Inner Moray Firth basins, together with adjacent parts of the Western Shelf and the East Shetland Platform. The UK Northern North Sea encompasses the Viking Graben, Beryl Embayment and East Shetland Basin, together with adjacent parts of the East Shetland Platform.
KEY TO GRAPHICS

KEY WELLS
These illustrate the principal variations in lithology and wireline-log signature. All depths are quoted below KB.

48/30-4

DISTRIBUTION MAPS
These are based primarily on well data. However, some up-dip limits are based on shallow seismic data. Colour boundaries without lines indicate minimum extent, corresponding to the limit of well data.

STRATIGRAPHIC SYNOPSES
These summarize the lithostratigraphic relationships within each group.

STRUCTURAL NOMENCLATURE
Structural terms in this study are shown on the accompanying map, which is taken from the map ‘Structural framework of the North Sea area’, issued by the Petroleum Exploration Society of Great Britain (1994 edition).
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INTRODUCTION

The first formal lithostratigraphic scheme for the Permian and Triassic of the UK Southern North Sea was proposed by Rhys (1974), as part of a general account of the lithostratigraphy of that area. German stratigraphic terms had already been widely applied by oil companies to the UK succession, and Rhys formalized their usage with only minor anglicizations. The Rhys nomenclature (see tables, pp. 4, 57 and 113) is well established in the UK sector of the Southern North Sea Basin and only minor modifications are proposed here (see pp. 3 and 53).

In the Rhys scheme, the boundaries of the Permian and Triassic succession were equated with lithostratigraphic boundaries. This approach has been followed in this study because biostratigraphic data are insufficient to relate the North Sea successions with the standard marine successions of other areas. We follow Rhys in placing the base of the Permian at the base of the Rotliegend Group, the base of the Triassic at the base of the Bunter Shale Formation, and the base of the Jurassic at the base of the Lias Group. The base of the Triassic thus corresponds to the top of the Zechstein facies as developed in the UK Southern North Sea. Recent stratigraphic studies on the German succession also equate the base of the Trias with the top of Zechstein, but it should be noted that the Zechstein facies extends to a higher stratigraphic level in Germany than in the UK, and includes beds equivalent to the basal part of the UK Bunter Shale Formation (see discussion on p. 33).

Biostratigraphic control for the Triassic and Permian of the UK Southern North Sea is extremely limited. The few regionally identifiable biostratigraphic markers are described in the Appendix.

Reference

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TRIASSIC
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TRIASSIC

The first formal lithostratigraphic scheme for the Triassic of the Southern North Sea was proposed by Rhys (1974), as part of a general account of the lithostratigraphy of that area. Prior to that study, the nomenclature adopted had been an extension of those used onshore in Germany and the Netherlands. In the scheme compiled by Rhys (see table, p.4), the boundaries of the Triassic succession were equated with lithostratigraphic boundaries and the constituent strata assigned to six formations. The lower two formations (Bunter Shale and Bunter Sandstone) constituted the Bacton Group; the overlying Haisborough Group comprised, in ascending order, the Dowsing Dolomitic, Dudgeon Saliferous, and Triton Anhydritic formations. Beds above the Haisborough Group were designated the Winterton Formation. With the exception of the Bunter Sandstone, all the formations contained named members.

The Rhys nomenclature has been applied widely in the UK sector of the Southern North Sea Basin; only minor modifications have been made, largely as a result of the introduction of informal lithostratigraphic names for units subsequently recognized within those created by Rhys. Several of these units, such as those recognized in the Dowsing Formation by Southworth (1987, cited in Cameron et al. 1992), are widely developed; they have not, however, been named or consistently adopted in many well records and are not formally adopted or defined in this volume. The main modification to the Rhys nomenclature has resulted from the abandonment of the Winterton Formation, following the redefinition by Lott & Warrington (1988) of the top of the Haisborough Group and their identification of the succeeding beds as the correlatives and the lithostratigraphical equivalents of the Penarth Group recognized onshore in England.

Proposed scheme

The proposed nomenclature is illustrated in Figure 1 (p.5). In addition to the units recognized in the Bunter Shale Formation by Rhys, the Amerykast Member (Cameron et al. 1992) is adopted for a proximal arenaceous facies that is largely equivalent to the Rogenstein Member. The use of the term ‘Bacton Sandstone Member’ (Rhys 1974), within which is now the Penarth Group, is discontinued. In addition, the bases of the Dudgeon and Bunter Sandstone formations have been slightly revised to the levels of more regionally consistent log-markers. Correlations of the proposed scheme with those adopted in eastern England, the southern part of the Central North Sea, and in the Netherlands and Germany, are illustrated in the table (p.4).

Biostratigraphy

Biostratigraphic data for the UK Southern North Sea are sparse, but are supplemented by data from correlative strata in adjacent onshore and offshore areas (see Appendix).

References


Figure 1. Lithostratigraphic nomenclature scheme for the Triassic of the Southern North Sea

Figure 2. Areal distribution of the Triassic groups
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PENARTH GROUP
The term Penarth Group was introduced by Warrington et al. (1980) for the sequence, formerly termed 'Rhaetic', which is present between the Mercia Mudstone and Lias groups onshore in the UK. There, it comprises the Westbury Formation overlain by the Lilstock Formation, the latter comprising lower (Coatham) and upper (Langport) members. The group was recognized in UK Southern North Sea sections by Lott & Warrington (1988), in a study which resulted in the revision of the top of the Triton Formation, at the top of the Halstock Group, and the abandonment of the Winterton Formation of Rhys (1974).

The constituent formations of the Penarth Group onshore cannot be consistently recognized offshore, but a shallow cored borehole in block 41/25 (Lott & Warrington 1988) revealed a succession comparable to that of eastern England. There, the Westbury Formation consists of dark grey to black shales with some thin limestones and grey sandstones, and the Lilstock Formation is represented largely by grey, green-grey and brown, laminated, silty shales and mudstones of the Coatham Member. The calcareous Langport Member, which is well developed above the Coatham Member in central and southern England, appears to be absent or represented only by thin micritic limestones in eastern England. Diversity of foraminifers, including dinoflagellate cysts, occurs in both formations (Lott & Warrington 1988; Warrington in Gaunt et al. 1992, fig.11, in Powell et al. 1992, fig.7, in Frost in press).

In the shallow offshore borehole, pale grey-green, dolomitic mudstones (Blue Anchor Formation equivalent, uppermost Mercia Mudstone Group) are overlain by grey to black pyritic mudstones, with siltstone and sandstone interbeds (Westbury Formation equivalent), followed by green-grey, dolomitic mudstones (lower Lilstock Formation equivalent). This comparison, supported by palynological evidence, allowed Lott & Warrington (1988) to extend recognition of the Penarth Group eastwards into the UK offshore area and to abandon the use of Winterton Formation, which is believed to have included equivalents of the Blue Anchor Formation (Mercia Mudstone Group), now assigned to the underlying Triton Formation (Halstock Group).

The upper boundary of the group offshore is placed at a downward change from grey calcareous mudstones with interbedded limestones of the Lias Group, to grey-green mudstones and silty mudstones. This boundary corresponds to an abrupt downhole increase in gamma-ray values and a decrease in velocities. The lower boundary of the group offshore is defined by a sharp downward change from dark grey shales, and white to grey, fine to medium grained sandstones, to grey-green dolomitic mudstones overlying red-brown mudstones with some grey-green beds and thin dolomites. This boundary typically corresponds to an abrupt downhole increase in gamma-ray values and a sharp decrease in velocity which reflects a downward change from sandstone to mudstone (Lott & Warrington 1988). Where sandstone is not present at the base of the Penarth Group (e.g. 43/25-1, p.29) the log profile of the boundary, with a downward decrease in gamma-ray values and an increase in velocity, is similar to that recorded from boreholes onshore (see Lott & Warrington 1988, fig. 2).

The Penarth Group offshore is divided informally into a lower division and an upper division. These correspond closely to the Westbury and Lilstock formations recognized onshore, but a definite correlation is not proposed because of the differences in log character between the two areas, resulting from the presence of thicker and more numerous sandstone beds in the lower part of the group offshore. The boundary between the upper and lower divisions is placed at an abrupt and usually pronounced downward decrease in gamma-ray values and an increase in velocity, corresponding to a change from mudstone to sandstone or interbedded sandstone and mudstone. The Penarth Group comprises deposits which accumulated during a marine transgression, and represents aqueous environments ranging from brackish to marine in character (Warrington & Ivimey-Cook 1992).

The Penarth Group, though less extensive than the Haisborough Group (Fig. 2, p.5), is present throughout large areas of quadrants 41, 42, 43, 47 and 48, and parts of quadrants 44, 49, 52 and 53. The offshore outcrop is in continuity with that of the group onshore to the west. The Penarth Group is more than 25m thick in the Sole Pit Basin and has a maximum thickness of 75m in the southern part of that basin (Cameron et al. 1992). Thicknesses decrease rapidly across the Dowsing Fault Zone to the west of the Sole Pit Basin, indicating syndepositional movement in that zone (Lott & Warrington 1988).

The greatest degree of thickening within the Sole Pit Basin occurs in the lower division of the group. The Penarth Group offshore has yielded palynomorph associations indicative of a Rhaetian (Late Triassic) age and comparable with those known from the group onshore (Lott & Warrington 1988). In UK onshore successions, the base of the Jura isic is placed at the level of the lowest occurrence of ammonites of the genus Palaeoceras: this typically occurs a few metres above the base of the Lias Group, the lowest beds of which are, therefore, assigned a latest Triassic age (Cope et al. 1980; Warrington et al. 1980). Independent evidence of the latest Triassic age of these beds is provided by records of conodonts from the basal beds of the Lias Group near Nottingham (Swift 1989). The criterion adopted for the recognition of the base of the Jurassic onshore is not applicable in the offshore sequences, where the top of the Penarth Group is arbitrarily taken as the top of the Triassic succession. The boundary offshore is thus placed slightly lower than that defined biostratigraphically in onshore sections, and the succeeding Lias Group is assigned wholly to the Jurassic.

References


Name. From UK onshore lithostratigraphic nomenclature (Warrington et al. 1980).

Age. Late Triassic (Rhaetian).
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HAISBOROUGH GROUP
HAISBOROUGH GROUP

The term Haisborough Group was introduced by Rhys (1974) for the sequence of formations lying between the top of the Bacton Group and the base of the Winterton Formation in the Triassic succession in the UK Southern North Sea. Lot & Warrington (1988) abandoned the Winterton Formation, on the basis that it was largely correlative with the Penarth Group established onshore (Warrington et al. 1980), and incorporated the lowest beds of that formation into the Triton Formation, at the top of the Haisborough Group. This approach, which also results in lithostratigraphic correspondence of the Haisborough Group with the Mercia Mudstone Group of the contiguous UK onshore succession, is adopted in this account. The Haisborough Group comprises the Dowson Formation, incorporating the Rot and Muschelkalk halite members, in the Dowson Formation, and the Keuper Halite Member, in the Dudgeon Formation. The Triton Formation is relatively anhydritic in character, and a concentration of anhydrite in the middle of the formation constitutes the Keuper Anhydrite Member. The boundary of the group is marked by a downward change from dark grey shales and white to grey sandstones of the Penarth Group, to grey-green and red-brown mudstones of the Triton Formation. The lower boundary is an unconformity equivalent to the Hardegse unconformity ("H-Diskordanz", Trusheim 1961) of Germany and is marked by an abrupt downward change from mudstones of the basal Dowson Formation to the arenaceous Bunter Sandstone Formation (Bacton Group).

The formations which constitute the Haisborough Group comprise fine-grained clastic and evaporite deposits which accumulated under both subaerial and subaqueous conditions in environments ranging from distal floodplains and playas, to hypersaline bodies of water of marine origin fringed by sabkhas (Warrington & Ivimey-Cook 1992). Transgressive and regressive phases have been recognized, particularly in the Dowson Formation (Southworth 1987, cited in Cameron et al. 1992).

The Haisborough Group, though less extensive than the Bacton Group, is present throughout most of the UK Southern North Sea south of 55°N (Fig. 2, p. 5). The outcrop is in continuity with that of the Mercia Mudstone Group onshore to the west. The Dowson Formation shows a general thickening towards an area northwest of the Cleaver Bank High, where thicknesses exceed 400m; elsewhere, thickness is commonly in the order of 200m. The succeeding Dudgeon and Triton formations have thickness maxima in the Sole Pit Basin and thin abruptly westwards from that basin, across the Dowson Fault Zone, indicating syndepositional movement there during the Late Triassic. Outside the Sole Pit Basin the Dudgeon Formation is generally less than 100m thick and the Triton Formation less than 200m. The Haisborough Group has a maximum thickness of some 900m in the south Sole Pit Basin area.

References


Name. From Haisborough Sand (Rhys 1974, p. 12).

Constituent formations

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Age

Middle and Late Triassic (Anisian to Norian).
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DOWSING FORMATION

The name derives from the term 'Dowsing Dolomitic Formation' introduced by Rhys (1974) for an argillaceous unit which contains beds of dolomite, in addition to some anhydrite and two main units of bedded halite. The formation rests unconformably upon the Bunter Sandstone Formation of the Bacton Group, and is overlain conformably by an argillaceous, halite-bearing unit, the Dudgeon Formation (Dudgeon Saliferous Formation of Rhys 1974), in which dolomite beds are less significant.

Reference


Name. Derived from 'Dowsing Dolomitic Formation' (Rhys 1974) which was named for the Outer Dowsing Buoy and the higher dolomite content of the unit, relative to that of the overlying Dudgeon Formation. Dolomite is, however, a minor component and the term 'dolomitic' is deleted from the formation name.

Type section

49/21-2 (Rhys 1974): 1161.5-1375.5 m (3810-4512 ft) below KB (metric conversion revised; revised top).

Rhys (1974) regarded this section as possibly faulted at the level of the base of the Muschelkalk Halite Member and illustrated potentially missing beds with a section from well 49/22-1. The characters of this part of the succession, and the lateral variations within the formation, are better illustrated in the reference sections.

Reference sections

42/15b-1: 862-1025 m (2828-3362 ft)
47/5a-2: 1438-1773.5 m (4718-5818 ft)
49/21-3: 994.5-1324 m (3262-4344 ft)
53/2-3: 829-1082 m (2720-3550 ft)

Formal lithostratigraphic subdivisions

Muschelkalk Halite Member p. 17
Röt Halite Member p. 19
Lithology

The Dowsing Formation consists largely of mudstones but a significant amount of bedded halite is present, mostly concentrated in the widespread Rot Halite Member, near the base of the formation, and in the less extensive Muschelkalk Halite Member in the higher part of the formation. The mudstones are red, red-brown, orange-red and green, and silty in part; thin beds of anhydrite occur and beds of grey to buff coloured dolomite are more prominent than in the overlying Dudgeon Formation. The log profile of the formation is complex and varies regionally, mainly as a consequence of the number of bedded halite units present. In parts of quadrants 42, 43, 44, 48 and 49, and small areas of 41 and 47, the presence of both the Muschelkalk and the Rot halite members results in log profiles with two parallel-sided, low gamma-ray and high velocity sections, representing halite, separated by a slightly ‘waisted’ section with more variable, higher gamma-ray and lower velocity values representing a predominantly mudstone interval with dolomite interbeds, thin anhydrite beds and, in parts of quadrants 41, 42, 43, 44, 47 and 48, a thin halite bed. In these areas, mudstones with dolomites and some anhydrites occur above the Muschelkalk Halite Member, and a relatively thin basal mudstone occurs below the Rot Halite Member. The upper mudstone unit shows an asymmetric ‘waisted’ log profile in which velocities are usually more variable than the gamma-ray values; this unit is also recognizable in blocks in the south of quadrants 48 and 49 and the north of quadrant 53, where only the Muschelkalk Halite Member is present in the formation (e.g. 53/2-3). The basal mudstone shows gamma-ray values which typically decrease up-section, and variable velocities. Where only the Muschelkalk Halite Member is present, the underlying mudstones show a generally ‘waisted’ log profile overlying a thin, high gamma-ray and low velocity unit equivalent to the basal mudstone (e.g. 53/2-2, p.49); low gamma-ray and high velocity values immediately above this may represent beds laterally equivalent to the Rot Halite Member. Where only the Rot Halite Member is present, the overlying mudstone succession shows a ‘waisted’ log profile (e.g. 42/15b-1) or a completely traceless log profile with relatively low gamma-ray and high velocity values around the level of beds which are probably laterally equivalent to the Muschelkalk Halite Member (e.g. 43/12-1, p.49).

Upper boundary

The top of the Dowsing Formation is placed at a downward change from Dudgeon Formation mudstones, with silty interbeds, thin anhydrites, dolomites and traces of halite, to a sequence in which rather similar mudstones are distinguished by more numerous and prominent beds of grey and buff coloured dolomite. The boundary corresponds to a downhole decrease in gamma-ray values and an increase in velocity at a regionally consistent log-marker that is slightly below the level selected by Rhys (1974) in the type section (49/21-2).

Lower boundary

The base of the Dowsing Formation is defined by a sharp downward change from red-brown mudstones, with dolomite and evaporite interbeds, to the sandstone-dominated sequence of the underlying Bunter Sandstone Formation. This boundary corresponds to an abrupt decrease in gamma-ray values and an increase in velocity. The boundary is an angular unconformity at which the Dowsing Formation overlies beds within the Bunter Sandstone Formation (see pp.36, 51).

Lithostratigraphic subdivision

The Dowsing Formation includes the Rot and Muschelkalk halite members. Additional units and divisions of the mudstones recognized by Southworth (1987, cited in Cameron et al. 1992, pp.59-63) are widely developed but have not been named or adopted consistently in many well records; none of these units are formally adopted in this account.

Distribution and thickness

The Dowsing Formation is more than 200m thick over a large part of the UK Southern North Sea and has a maximum thickness of 420m in the southeastern part of Quadrant 43. The formation is partially eroded around the basin margins (Cameron 1993).

Regional correlation

The Dowsing Formation correlates with the Muschelkalk Halite Member in the lower part of the Upper Germanic Trias Group in the northern North Sea and the Netherlands, and with the upper Rot Halite Member and the Rot-salinar of north German sequences; the Muschelkalk Halite Member correlates with the Muschelkalk Salt Member and the Rot Halite Member of the Netherlands and with the Unterer Rot-salinar of German sequences. The Muschelkalk Halite Member correlates with the Muschelkalk Salt Member and the Unterer Rot-salinar of those areas (see table, p.4). Mudstones underlying the Rot Halite Member in the UK sector correlate with the Soiling Claystone Member at the base of the Rot Formation (basal Upper Germanic Trias Group) in the Netherlands, and with the Soiling Fuge, at the top of the Mittlerer Buntsandstein in northern Germany. A thin halite, the Oberes Rot-salinar of German sequences and the Upper Rot Halite Member of the Netherlands, extends into the UK sector, where it occurs slightly above the Rot Halite Member in southern parts of quadrants 41, 42, 43 and 44, and northern areas of quadrants 47 and 48; it comprises the ‘Upper Rot Halite Member’ of Southworth (1987, cited in Cameron et al. 1992, pp.60-63) but is not formally defined here.

Genetic interpretation

The Dowsing Formation comprises three sedimentary cycles in which fine-grained clastics deposited during a marine transgressive phase are succeeded by a regressive sequence of halite overlain by anhydrites, dolomites and dolomitic mudstones (Southworth 1987, cited in Cameron et al. 1992).

Age

Middle Triassic (Anisian to Ladinian), based upon palynological evidence from the UK sector (Geiger & Hopping 1968); the top of the formation occurs below the FDO of Retisulcites perforatus and above that of Parerialites minor. Moisopore assemblages from the Rot and lower Muschelkalk formations in the Netherlands (Visscher 1966; Visscher & Commensarius 1968) and from the Oberer Buntsandstein to Mittlerer Muschelkalk sequence in Germany (Reitz 1985) include Stellapollenites thiergartii, indicating an Anisian age for the correlatives of those units in the UK sector.

References


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The term Muschelkalk Halite Member was introduced by Rhys (1974) for the higher of the two principal units within the Dowsing Formation (Dowsing Dolomitic Formation: Rhys 1974) that consist largely of halite.

**Name.** From the dominant halite content of the member and its position within a formation correlatable with part of the German Muschelkalk.

**Type section**  
49/21-2 (Rhys 1974): 1210.5-1250.5m (3972-4103ft) below KB (metric conversion revised)  
Rhys (1974) regarded the member as possibly faulted against underlying Dowsing Formation mudstones and illustrated potentially missing beds with a section from well 49/22-2; the characters of the lower part of the member are better represented in the reference sections.

**Reference sections**  
43/26-7: 1116-1177m (3662-3862ft) drilled depths  
49/21-3: 1063-1126m (3488-3695ft)

**Lithology**  
The Muschelkalk Halite Member comprises halite with thin interbeds of red-brown mudstone and anhydrite. The member typically shows low gamma-ray values and high velocities and a mainly parallel-sided log signature representative of halite; narrow peaks of high gamma-ray and lower velocity values correspond to mudstone interbeds.

**Upper boundary**  
The top of the Muschelkalk Halite Member is placed at the downward change from halite to red-brown mudstones, with beds of dolomite and some anhydrite, to halite in the upper part of the Dowsing Formation. The boundary is marked by an abrupt downward decrease in gamma-ray values and a slight increase in velocity.

**Lower boundary**  
The base of the Muschelkalk Halite Member is placed at the downward change from halite to red-brown mudstones, with beds of dolomite and some anhydrite, in the upper part of the Dowsing Formation. The boundary is marked by an abrupt downward increase in gamma-ray values and a decrease in velocity.

**Distribution and thickness**  
The Muschelkalk Halite Member is recognized over about half the area occupied by the Dowsing Formation; it is less extensive than the Rot Halite Member, lower in the Dowsing Formation, but occurs over a greater area than the Keuper Halite Member in the succeeding Dudgeon Formation. The member is present from the Cleaver Bank High westwards to the Sole Pit Basin, from where it extends northwards and northeastwards into the North Dogger Shelf and Silver Pit Basin areas. The member is commonly between 30 and 60m in thickness but exceeds 60m in the southern part of the Sole Pit Basin and several other areas, principally adjacent to the Cleaver Bank High (Cameron et al. 1992).

**Regional correlation**  
The Muschelkalk Halite Member is eroded along the eastern margin of its occurrence, along the Cleaver Bank High. The member correlates eastwards with the Muschelkalk Salt Member of the Netherlands, and with the Mittlerer Muschelkalk Salinar of north German sequences. To the south and west of the Sole Pit Basin, and to the north, in quadrants 41, 42 and 43, it passes laterally into non-halite bearing beds within the upper part of the Dowsing Formation; these comprise part of the ’Muschelkalk Evaporite Member’ of Southworth (1987, cited in Cameron et al. 1992, pp.60-62). Warrington et al. (1980) correlated the Muschelkalk Halite Member and equivalent beds with units low in the Mercia Mudstone Group of the eastern UK onshore succession (see table, p.4).

**Genetic interpretation**  
The Muschelkalk Halite Member was precipitated from bodies of hypersaline water connected to a marine source.

**Age**  
Mid-Triassic, Anisian, on palynological evidence (Geiger & Hopping 1968; van der Zwan & Spaak 1992).

**References**  
The term Röt Halite Member was introduced by Rhys (1974) for the lower of the two main units in the Dowsing Formation (Dowsing Dolomitic Formation; Rhys 1974) which consist largely of halite. It corresponds to the ‘Main Röt Halite Member’ of Southworth (1987, cited in Cameron et al. 1992).

**Name.** From the dominant halite content of the member which is correlatable with the Lower Röt Evaporite Member of the Netherlands and the Uiterses Röt-Salinar of Germany.

**Type section** 49/21-2 (Rhys 1974): 1348.13-1367m (4423-4485ft) below KB

The type well does not show the relationship of the Röt Halite Member to the thinner, less extensive, ‘Upper Röt Halite Member’ of Southworth (1987, cited in Cameron et al. 1992, pp.60-65) (see p.14). The contrasting characters of the succession overlying the Rot Halite Member where the ‘Upper Röt Halite Member’ is present and where it is absent are illustrated in the reference sections.

**Reference sections**

43/26-7: 1339.1-1411.5m (4391-4610ft) true vertical depths 1338.5-1410.5m (4391-4628ft) true vertical depths 49/21-3: 1287.5-1316m (4224-4317ft)

**Lithology**

The Röt Halite Member comprises halite with thin interbeds of red, green and grey mudstone and some anhydrite. The member shows low gamma-ray values and high velocities and a mainly parallel-sided log signature representative of halite; narrow peaks of high gamma-ray and low velocity values correspond to mudstone interbeds.

**Upper boundary**

The top of the Röt Halite Member is placed at a downward change, in the lower part of the Dowsing Formation, from red-brown mudstones, with beds of dolomite and some anhydrite, to halite. The boundary is marked by an abrupt downward change from very variable gamma-ray values and velocities, to lower gamma-ray and slightly higher velocity values. In southern parts of quadrants 42, 43 and 44, and northern parts of quadrants 47 and 48, the boundary is 25 to 30m below the base of the less extensive ‘Upper Röt Halite Member’ of Southworth (1987, cited in Cameron et al. 1992, pp.60-65) (see reference section will 43/26-7, and p.49).

**Lower boundary**

The base of the Röt Halite Member is placed at the downward change from halite to red-brown mudstones in the lowest part of the Dowsing Formation. The boundary is marked by an abrupt downward increase in gamma-ray values and a decrease in velocity.

**Lithostratigraphic subdivision**

No formal subdivision proposed; five evaporite cycles, each comprising a thin mudstone overlain by a thin dolomite or anhydrite succeeded by a thick halite, were recognized by Southworth (1987, cited in Cameron et al. 1992).

**Distribution and thickness**

The Röt Halite Member is the most extensive of the three halite members recognized in formations of the Haighborough Group and is the only one to extend westwards into the eastern UK onshore. It is more extensive than the Muschelkalk Halite Member (p.17), which is present higher in the Dowsing Formation, and is recognized over about 60% of the offshore area occupied by that formation (p.15). Thicknesses are commonly over 30m and exceed 60m in parts of quadrants 42, 43, 44 and 48 (Cameron et al. 1992).

**Regional correlation**

The Röt Halite Member correlates with the Lower Röt Evaporite Member of sequences in the Netherlands, and with the Uiterses Röt-Salinar in north Germany. The member extends into the eastern UK onshore area where it occurs within the Eek Evaporite Formation in the lower part of the Mucrola Mudstone Group (see table, p.4). To the south of the Sole Pit Basin, westwards, onto the East Midlands Shelf, and to the north, in quadrants 34, 35, 41 and 42, the member passes laterally into non-halite bearing beds, comprising part of the ‘Main Röt Evaporite Member’ of Southworth (1987, cited in Cameron et al. 1992, pp.60-62), within the lower part of the Dowsing Formation.

**Genetic interpretation**

The Röt Halite Member was precipitated from bodies of hypersaline water connected to a marine source. Southworth (1987, cited in Cameron et al. 1992, p.60) recognized five evaporite cycles in the member; the halite phase is more restricted in extent in the first cycle than in subsequent ones. A marine connection is indicated by the bromide content of the correlative halite in the Netherlands (Holser & Wilgus 1981).

**Age**

Mid-Triassic, Anisian, on palynological evidence (Geiger & Hopping 1968; van der Zwan & Spaak 1992).

**References**


**Age**

Mid-Triassic, Anisian, on palynological evidence (Geiger & Hopping 1968; van der Zwan & Spaak 1992).
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DUDGEON FORMATION

The name derives from the term 'Dudgeon Saliferous Formation' introduced by Rhys (1974) for a dominantly argillaceous unit with minor anhydrite and dolomite beds; in parts of the Southern North Sea Basin, a thick halite-bearing unit, the Keuper Halite Member, forms the upper part of the formation. The formation rests conformably upon the argillaceous, dolomitic and halite-bearing Dowsing Formation (Dowsing Dolomitic Formation of Rhys, 1974) and is overlain by the argillaceous, anhydrite-bearing Triton Formation (Triton Anhydritic Formation of Rhys 1974).

Reference


Name. Derived from 'Dudgeon Saliferous Formation' (Rhys 1974) which was named for the Dudgeon Light-Vessel and the locally significant halite content of the unit. The term ‘saliferous’ applies to only part of the formation, distinguished as the Keuper Halite Member, and is therefore deleted from the formation name.

Type section

49/21-2 (Rhys 1974): 882-1161.5 m (2893-3810ft) below KB (revised base). The base of the formation in this section has been revised from 1158.5 m (3800ft) (metric conversion revised) (Rhys 1974) to the level of a regionally consistent log-marker.

Reference sections

42/29-3: 1555-1659.5 m (5102-5444ft)
47/5a-2: 1262.5-1438 m (4142-4718ft)
53/2-2: 610-932.5 m (2001-3059ft) below KB, drilled depths 605.5-892.5 m (1987-2928ft) true vertical depths

Formal lithostratigraphic subdivision

Keuper Halite Member p.25
Lithology
The Dudgeon Formation consists largely of mudstones but a concentration of halite in the upper part of the sequence, mainly in parts of quadrants 47, 48, 49, 52 and 53, constitutes the Keuper Halite Member; thin halite beds also occur lower in the formation. The mudstones are red, red-brown, orange-red, and green; some silty interbeds and thin beds of anhydrite, and grey to buff dolomite occur. The log profile of the formation varies regionally. Where the Keuper Halite Member is present, the lower part of the formation shows generally moderate gamma-ray and velocity values; some wide variations in amplitude occur, especially on the velocity trace, and the gamma-ray and velocity profiles may show a slight decrease and increase up-section respectively. The higher part of the section in these areas shows low gamma-ray and high velocity values and the generally parallel-sided profile representative of halite, with some high gamma-ray and corresponding low velocity peaks marking mudstone interbeds. Where the Keuper Halite Member is absent, the log-profile is commonly slightly ‘waisted’; here, gamma-ray and velocity values may be slightly lower and higher respectively at the top of the formation, in beds laterally equivalent to the Keuper Halite Member, than at the base (e.g. 42/29-3).

Upper boundary
Where the Keuper Halite Member occurs, the top of that unit, at the downward change from Triton Formation mudstones to halite, marks the top of the Dudgeon Formation. This boundary corresponds with an abrupt downward decrease in gamma-ray values and a slight increase in velocity. Elsewhere, the boundary is marked by a downward change from rather uniform, red-brown mudstones, with thin anhydrites, of the Triton Formation, to the more varied red, red-brown, orange-red, and green mudstones, with some silty beds, thin anhydrites and dolomites, of the Dudgeon Formation. Here, the boundary corresponds to a downhole change to gamma-ray and velocity values that are generally lower and higher respectively than in the overlying Triton Formation and which form the top of a slightly ‘waisted’ log profile (pp.23, 49).

Lower boundary
The base of the Dudgeon Formation is marked by a downward change from a mudstone sequence with some silty interbeds, thin anhydrites, dolomites and traces of halite, to a sequence in which rather similar mudstones are distinguished by the presence of more numerous and more prominent beds of grey and buff coloured dolomite. The boundary corresponds to a downhole decrease in gamma-ray values and an increase in velocity at a regionally consistent log-marker that is slightly below the level selected by Rhys (1974) in the type section (49/21-2).

Lithostratigraphic subdivision
The Keuper Halite Member (p.25) forms the upper part of the Dudgeon Formation, mainly in parts of quadrants 47, 48, 49, 52 and 53, but also in small areas in quadrants 42, 43 and 44; its extent is less than one third that of the formation.

Distribution and thickness
The Dudgeon Formation is present throughout quadrants 47 and 48, much of quadrants 41, 42, 43 and 44, and parts of 49, 52 and 53. The formation is thickest in the Sole Pit Basin, with a maximum of 350m present at the southern end of that basin. The formation thins abruptly westwards across the Dowsing Fault Zone, indicating syndepositional movement in that fault zone, and is less than 100m thick on the South Hewett Shelf and the East Midlands Shelf. To the north of quadrants 47, 48 and 49 thicknesses are also less than 100m (Cameron 1993). The formation is partially eroded on the western margin of the Cleaver Bank High and farther north, on the southern flank of the Mid North Sea High.

Regional correlation
The Dudgeon Formation is equivalent to the Edwalton Formation and upper part of the underlying Gunthorpe Formation in the Mercia Mudstone Group of the eastern UK onshore succession. To the east, the formation correlates with the Lower Keuper Claystone Member and Main Keuper Evaporite Member succession in the Netherlands, and with the Lettenkeuper and Unterer Gipskeuper in sequences in north Germany (see table, p.4).

Genetic interpretation
The Dudgeon Formation comprises fine-grained distal floodplain sediments and evaporites that formed in hypersaline water bodies and surrounding sabkhas.

Age
Late Mid-Triassic (Ladinian) to early Late Triassic (Carnian), based upon the occurrence of the highest beds (Geiger & Hopping 1968) below the FDO of Retisulcites perforatus and above that of Perotrilites minor.

References
DUDGEON FORMATION

DISTRIBUTION MAP

LITHOLOGY
- Mudstone and argil, marlstone
- Dolomitic dolomitic mudstone/shale
- Anhydrite/gypsum

See also Dowsing Fm., p.15

Notes:
- Deviated section, corrected to true vertical depth

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The term Keuper Halite Member was introduced by Rhys (1974) for a unit within the Dudgeon Formation (Dudgeon Saliferous Formation; Rhys 1974) that consists largely of halite.

**Name.** From the dominant halite content of the member and its position within a formation correlatable with part of the German Keuper.

**Type section**
49/21-2 (Rhys 1974): 882-1036.5m (2893-3401ft) below KB (metric conversion revised)

**Reference section**
48/6.22: 914-1035.5m (2998-3397ft) drilled depths
805.5-895m (2643-2937ft) true vertical depths

**Lithology**
The Keuper Halite Member comprises halite, in beds up to 20m thick, with interbeds of red-brown mudstone and anhydritic mudstone; halite constitutes up to 80% of the member in the Sole Pit Basin (Cameron et al. 1992). The member typically shows predominantly low gamma-ray values and high velocities, and the mainly parallel-sided log signature representative of halite; narrow peaks of high gamma-ray and lower velocity values correspond to mudstone interbeds.

**Upper boundary**
The top of the Keuper Halite Member corresponds to the top of the Dudgeon Formation and is placed at a downward change from red-brown mudstones, with thin dolomite and anhydrite beds, of the Triton Formation, to halite. The boundary is marked by an abrupt downward decrease in gamma-ray values and a slight increase in velocity.

**Lower boundary**
The base of the Keuper Halite Member is placed at the base of the main concentration of bedded halite within the Dudgeon Formation. It is characterized by an abrupt downward increase in gamma-ray values and a decrease in velocity.

**Distribution and thickness**
The Keuper Halite Member is recognized in a relatively small part of the area occupied by the Dudgeon Formation; it is the least extensive of the three halite members recognized in formations of the Haisborough Group but is considerably thicker than those present in the underlying Dowson Formation. The principal occurrence, in quadrants 47, 48, 49 and 53, is centred on the Sole Pit Basin; small isolated occurrences are present further north in quadrants 41, 42 and 45. The member exceeds 150m in the southern part of the Sole Pit Basin (Cameron et al. 1992), with over 200m present in Block 49/26, but elsewhere varies mostly between 30 and 100m in thickness.

**Regional correlation**
The member is eroded along the eastern margin of its occurrence in quadrants 44, 49 and 53, but may have been in continuity with evaporite deposits in the Dutch sector via the area south of the Cleaver Bank High (Cameron et al. 1992). The member correlates eastwards with the Main Keuper Evaporite Member of the Netherlands, and with the Unterer Gipskeuper of sequences in northern Germany (see table, p.4). To the south and west of the Sole Pit Basin and to the north, in quadrants 41, 42, 43 and 44, the member passes laterally into non-halite bearing beds which form the upper part of the Dudgeon Formation (see pp.23, 49). Geiger & Hopping (1968) recorded the FDO of Retisulcites perforatus in beds below the member in the Leman Field. In the eastern UK onshore succession, this misssipe is recorded (as Retisulcites perforatus) from the lowest beds of the Edwalton Formation of the Mercia Mudstone Group (unpublished BGS records), indicating that beds equivalent to the Keuper Halite Member occur higher in that sequence than suggested by Warrington et al. (1980).

**Genetic interpretation**
The Keuper Halite Member was precipitated in the most rapidly subsiding parts of the basin, from bodies of hypersaline water connected to a marine source (Fisher & Dudge 1990; Cameron et al. 1992).

**Age**
Late Triassic, Carnian, based upon its occurrence (Geiger & Hopping 1968) below the FDO of Comerosporites secatus and above that of Retisulcites perforatus (Monosulcites perforatus; Geiger & Hopping 1968) (see Appendix).

**References**
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TRITON FORMATION

The name derives from the term ‘Triton Anhydritic Formation’ introduced by Rhys (1974) for a dominantly argillaceous unit, with a significant anhydrite content, which rests conformably upon the argillaceous, halite-bearing Dudgeon Formation (Dudgeon Saliferous Formation of Rhys 1974) and is succeeded by mudstones, shales and sandstones which formed part of the ‘Winterton Formation’ of Rhys (1974), but which are now assigned to the Penarth Group (Warrington et al 1980; Lott & Warrington 1988).

References

Name. Derived from ‘Triton Anhydritic Formation’ (Rhys 1974) which was named for Triton Knoll and the significant anhydrite content of the unit. The term ‘anhydritic’ applies to only part of the formation, distinguished as the Keuper Anhydrite Member, and is therefore deleted from the formation name.

Type section
49/21-2 (Rhys 1974): 660.5-882m (2167-2893ft) below KB (metric conversion revised; revised top).
The top of the formation in this section is here revised from 668m (2287ft) (Rhys 1974) to the level of a regionally consistent log-marker (Lott & Warrington 1988); the upper boundary is poorly characterized on the velocity log of this section and is better represented in the reference sections.

Reference sections
43/25-1: 1680-1880m (5512-6168ft)
47/5a-3: 1123-1294m (3685-4246ft)
49/21-5: 567-744.5m (1861-2442ft) below KB, drilled depths
53/2-4: 652.5-817.5m (2140-2682ft)

Formal lithostratigraphic subdivision
Keuper Anhydrite Member p.31
Lithology
The Triton Formation consists largely of mudstones but a significant amount of anhydrite is present in the lower and middle parts, and some thin beds of buff or green dolomite occur in the upper part. The mudstones are mainly red and red-brown, but some grey-green beds are present and the top of the formation is predominantly grey-green. The anhydrite is white, grey or colourless and occurs in thin beds, a concentration of which occurs in the middle of the formation and is distinguished as the Keuper Anhydrite Member (p.31). The log profile of the formation is complex. Beds below the Keuper Anhydrite Member typically show an asymmetric ‘waisted’ log profile in which there is greater variation in the gamma-ray values than in velocities. The Keuper Anhydrite Member has a more variable log profile; the lowest beds in the member typically have lower gamma-ray and higher velocity values than those of the underlying beds. In some wells a general up-hole increase in gamma-ray values is seen in this member; this may be paralleled by a general decrease in velocity values, as in wells 47/5a-3 and 53/2-4, but in others, such as 49/21-5, this feature is not apparent. The upper part of the formation, above the Keuper Anhydrite Member, typically has higher, but very variable, gamma-ray values, which decline up-section, and slightly lower, less variable, velocity values which may show a small decrease up-section or remain relatively constant.

Upper boundary
The top of the Triton Formation is defined by a sharp downward change from dark grey shales, and white to grey, fine to medium grained sandstones of the Penarth Group (p.9), to grey-green, dolomitic mudstones overlying red-brown mudstones with some grey-green beds and thin dolomites. This boundary typically corresponds to an abrupt downhole increase in gamma-ray values and a sharp decrease in velocity which reflects a downward change from sandstone to mudstone (Lott & Warrington 1988); where sandstone is not present at the base of the Penarth Group (e.g. 43/25-1) the boundary corresponds to a decrease in gamma-ray values and a marked increase in velocity.

Lower boundary
Where the Keuper Halite Member marks the top of the underlying Dudgeon Formation, the base of the Triton Formation is defined by a downward change from red-brown mudstones, with some grey-green beds and thin anhydrites, to halite. This boundary corresponds to an abrupt downhole decrease in gamma-ray values and a marked increase in velocity. Where the Keuper Halite Member is absent, as in much of quadrants 41, 42, 43, 44 and 47 and parts of quadrants 48, 49, 52 and 53, the boundary is marked by a downward change from rather uniform, red-brown mudstones, with thin anhydrites, of the Triton Formation, to more varied red, red-brown, orange-red, and green mudstones, with some silty beds, thin anhydrites and dolomites, of the Dudgeon Formation; this boundary corresponds to a downhole change in the gamma-ray and velocity values to levels that are generally lower and higher respectively than in the overlying Triton Formation and which form the top of a ‘waisted’ log profile (pp.23,49).

Subdivision
The Triton Formation includes the Keuper Anhydrite Member (p.31) which separates un-named lower and upper mudstone units.

Distribution and thickness
The Triton Formation is present throughout much of quadrants 41, 42, 43, 44, 47 and 48 and parts of quadrants 44, 49, 52 and 53. The formation is thickest in the Sole Pit Basin where it exceeds 200m; 250m occur at the southern end of that basin. Westwards from the Sole Pit Basin the thickness decreases abruptly across the Dowsing Fault Zone to less than 100m, indicating that syndepositional movement occurred in that zone. Northwards from the Sole Pit Basin the thickness decreases less abruptly (Cameron et al. 1992).

Regional correlation
The Triton Formation is equivalent to the Cropwell Bishop Formation and the overlying Blue Anchor Formation in the Mercia Mudstone Group of the eastern UK offshore succession; grey-green beds which occur widely at the top of the formation may represent the Blue Anchor Formation (Warrington et al. 1988) of the UK offshore succession (see table, p.4). To the east the formation correlates with beds above the Main Keuper Evaporite Member in the Keuper Formation of sequences in the Dutch sector and the Netherlands, and with those above the Schilfsandstein in the Mittlerer Keuper of northern Germany (see table, p.4).

Genetic interpretation
The fine-grained clastic sediments of the Triton Formation accumulated largely under continental conditions; anhydrite beds, principally concentrated in the Keuper Anhydrite Member, were precipitated from brines of mixed continental and marine origin (Taylor 1983) in sabkha environments (Warrington & Ivimey-Cook 1992). The highest, mainly grey-green, beds of the formation comprise a transitional facies deposited during the initial phase of a transgression which resulted in the establishment of marine environments throughout the Southern North Sea Basin by the end of the Triassic.

Age
Late Triassic, Norian to early Rhaetian (?), on palynological evidence (Geiger & Hoping 1968; Morbey 1978; Lott & Warrington 1988); the formation occurs above the FDO of Camerosporites secundus and is overlain by the Penarth Group which has yielded Rhaetian palynomorph assemblages.

References


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The term Keuper Anhydrite Member was introduced, as ‘Keuper Anhydritic Member’, by Rhys (1974) for a unit within the Triton Formation (Triton Anhydritic Formation; Rhys 1974) characterized by a significant concentration of beds of anhydrite.

**Name.** From the anhydritic character and position of the member within a formation correctable with part of the German Keuper.

**Type section**
49/21-2 (Rhys 1974): 697-808.5m (2287-2653ft) below KB (metric conversion revised)

The upper boundary of the Triton Formation, close above the top of the Keuper Anhydrite Member, is poorly characterized on the velocity log of this well; the characters of this part of the sequence are better represented in the reference sections.

**Reference sections**
47/5a-3: 1158.5-1235m (3800-4051ft)
49/21-5: 594-702.5m (1948-2303ft) true vertical depths

**Lithology**
The Keuper Anhydrite Member comprises red, red-brown and grey-green mudstones with numerous beds of white to grey, transparent, crystalline anhydrite and some interbedded dolomite and siltstone. The member typically shows lower gamma-ray values and higher velocities than the overlying and underlying Triton Formation mudstones. The gamma-ray and velocity logs also display greater ranges in value and are more spiky in character.

**Upper boundary**
The top of the Keuper Anhydrite Member is defined by a downward change from red-brown mudstones with some grey-green interbeds to a unit of similar mudstones with numerous interbeds of anhydrite and some thin dolomites and siltstones. The boundary corresponds to a downward decrease in gamma-ray values, compared with the overlying mudstones; an increase in velocity may be apparent at the same level.

**Lower boundary**
The base of the Keuper Anhydrite Member is placed at the base of the main concentration of anhydrite interbeds in the Triton Formation. It is characterized by a marked downhole increase in gamma-ray values and a decrease in velocity.

**Distribution and thickness**
The Keuper Anhydrite Member is widely recognized within the UK sector where its extent is only slightly less than that of the Triton Formation. The member varies in thickness from about 30m, to the north of the Sole Pit Basin, to over 115m in that basin.

**Regional correlation**
The Keuper Anhydrite Member is represented in the onshore successions by concentrations of sulphate evaporites that occur in the upper part of the Mercia Mudstone Group, in beds now assigned to the lower part of the Cropwell Bishop Formation. The member correlates eastwards with the Red Keuper Evaporite Member of the Netherlands, and the lower part (Rote Wand) of the Oberer Gipskeuper of north German sequences (see table, p.4).

**Genetic interpretation**
The Keuper Anhydrite Member represents deposition from brines of mixed continental and marine origin (Taylor 1983) in sabkha environments (Warrington & Ivimey-Cook 1992).

**Age**
No direct evidence but constrained, by palynological evidence from underlying and overlying beds, to a Late Triassic, probably Norian, age.

**References**
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Southern North Sea

**AGE**
- TRIASSIC
  - RHAETIAN
  - NORIAN
  - CARNIAN
  - LADINIAN
  - ANISIAN
  - OLENKIAN
  - INDUAN

**GROUP**
- PENARTH GROUP
  - Upper division
  - Lower division
- TRITON FORMATION
- DUDGEON FORMATION

**BACTON GROUP**
- BUNTER SANDSTONE FORMATION
  - Amethyst Member
  - Regenatien Member
  - BUNTER SHALE FORMATION

**HAISBOROUGH GROUP**
- BUNTER SHALE FORMATION
  - Muschelkalk Halite Member

**SMITH BANK FORMATION NORTH OF THIS LATITUDE**

100 km

100 km

100 km
The term Bacton Group was introduced by Rhys (1974) for the lower part of the succession assigned to the Triassic in the UK Southern North Sea, comprising beds lying between the top of the Zechstein (Permian) and the base of the Haisborough Group. The group comprises the Bunter Shale Formation overlain by the Bunter Sandstone Formation; the former includes the Brückelschiefer, Amethyst and Rogenstein members, but the Bunter Sandstone Formation is undivided.

The dominantly argillaceous lower part of the Bacton Group comprises the Bunter Shale Formation. Siltstones and sandstones are present locally in the upper part of the formation (Amethyst Member), and more extensively in the lowermost part (Brückelschiefer Member), which also includes the thick but localized Hewett Sandstone. The upper part of the group, comprising the Bunter Sandstone, is predominantly arenaceous. The upper boundary of the group is an unconformity equivalent to the Hardegsen Unconformity (‘1-Diskordanz’; Trushheim 1961) of Germany, and is marked by an abrupt downward change from mudstones of the basal Dowson Formation (Haisborough Group) to the arenaceous Bunter Sandstone Formation. The lower boundary is placed at the downward change from clastic sediments assigned to the Brückelschiefer, to evaporites assigned to the underlying Zechstein Group.

The formations that constitute the Bacton Group are components of a clastic succession which prograded eastwards and north-eastwards into the Southern North Sea Basin as the area in which evaporites and carbonates of the Zechstein Group accumulated decreased significantly in size after the deposition of the Z5 cycle. Thus, the boundaries between lithostratigraphic units within the group, and the base of the group itself, are likely to be diachronous and to young eastwards, though this is not yet substantiated by biostratigraphic or other evidence. The Brückelschiefer Member, at the base of the group, overlies the Grenzanhdydrit of the Z5 cycle, a correlate of the Littlebeck Anthydrite Formation of the EZ5 cycle (Eskdale Group) of eastern UK onshore successions (Smith et al. 1986). Further east, where two higher Zechstein cycles are recognized (Kading 1978; Best 1989), ‘grenzanhdydrit’ units are recognized at several levels (Best 1989). The Brückelschiefer in these eastern areas is considered to be stratigraphically equivalent to the higher part of the UK Brückelschiefer Member plus the basal mudstones of the overlying undifferentiated Bunter Shale Formation. Thus, the Brückelschiefer facies is diachronous, with time-equivalents of the UK Brückelschiefer Member occurring within the ‘Upper Zechstein’ and Basal Buntsandstein Member sequence of the Netherlands, and within the Zechstein Übergangsfolge in northern Germany (see table, p.4).

The Zechstein Übergangsfolge in Germany is assigned a Permian age (Rohling 1991), and a Late Permian age has been proposed for the correlative sequence in the Netherlands (van der Zwan & Spaak 1992). There is, however, no biostratigraphic evidence for this age assignment and for the implied pre-Triassic age for the Brückelschiefer Member of the UK sector. Therefore, though the base of the Bacton Group may not be isochronous, its established use as an arbitrary base for the Triassic succession in the UK Southern North Sea is retained.

The Bacton Group is extensively developed in the UK Southern North Sea sector (Fig. 2, p.5). The outcrop, which extends northwards from Hartlepool, through quadrants 40 and 34, into the Central North Sea province, is continuous with that of the Eskdale and Sherwood Sandstone groups, and extends southwest to the southwestern part of the Bacton Group.

References


Name. From Bacton village, on the Norfolk coast (Rhys 1974, p.12).

Constituent formations

BUNTER SANDSTONE FORMATION p.37
BUNTER SHALE FORMATION p.41

Age
Conventionally regarded as Early Triassic; no direct evidence from the Bunter Shale Formation but some indication of a later Early Triassic age for the Bunter Sandstone Formation.
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BUNTER SANDSTONE FORMATION

Rhys (1974) introduced the term Bunter Sandstone Formation for the dominantly arenaceous unit which rests conformably upon the argillaceous Bunter Shale Formation and is succeeded by mudstones, evaporites and carbonates of the Dowsoning Formation (Haisborough Group). The Bunter Sandstone Formation constitutes the upper part of the Bacton Group (Rhys 1974).

Reference

Name. From the 'Bunter Sandstein' or 'Buntsandstein' (coloured sandstone) of German lithostratigraphic nomenclature.

Type section
49/21-2 (Rhys 1974): 1375.5-1683m (4512-5522ft) below KB (metric conversion revised; revised base).
The base of the formation in this section is here revised from 1695.5m (5563ft, metric conversion revised) (Rhys 1974) to the level of a regionally consistent log-marker (see p.51).

Reference sections
41/24a-2: 504-656.5m (1654-2154ft)
48/7c-3: 1535-1885m (5036-6184ft)
53/2-3: 1082-1429.5m (3550-4690ft)
Lithology
The Bunter Sandstone Formation comprises red, orange, occasionally white or colourless, sandstones, interbedded with red, grey, rarely green, occasionally dolomitic, mudstone and silty or sandy mudstone. The sandstone varies from fine to coarse, and contains varying amounts of dolomitic or anhydritic cements.

Log characteristics indicate that sandstones in the lower part of the formation in the type section are finer and have a greater argillaceous content than those higher in the section where cleaner, coarser, more massive sandstones are separated by more discrete mudstone beds. Gamma-ray signatures indicate that a similar upward change occurs in many other wells (e.g. 48/7b-3 and 53/2-3) but is not present in all (e.g. 41/24a-2).

Upper boundary
The top of the Bunter Sandstone Formation is defined by a sharp downward change from red-brown mudstones, with dolomite and evaporite interbeds, to a thick sandstone-dominated sequence. This boundary corresponds to an abrupt downward decrease in gamma-ray values and an increase in velocity. Comparison of log profiles within the Bunter Sandstone Formation suggests that the boundary is an angular unconformity at which beds within the formation are truncated and where overstep by the overlying Dowsing Formation occurs. For example, a unit forming the upper part of the formation in the type section is absent from wells such as 48/7b-3 and 41/24a-2 (see Regional correlation and p.51).

Lower boundary
The base of the Bunter Sandstone Formation is defined by a downward change from a dominantly arenaceous sequence to the dominantly argillaceous Bunter Shale Formation. The boundary is usually clear and marked by a downward increase in gamma-ray values but may be less distinct towards the London-Brabant Platform and the eastern UK onshore area where the formation rests upon the Amethyst Member of the Bunter Shale Formation (see p.51).

Distribution and thickness
The Bunter Sandstone Formation is present throughout most of the UK sector of the Southern North Sea. The formation is thickest in the Sole Pit Basin where it locally exceeds 350m. The formation thins towards the London-Brabant Platform, the Cleaver Bank High and the Mid North Sea High (Cameron et al. 1992).

Regional correlation
The Bunter Sandstone Formation is equivalent to the Main Buntsandstein Formation of the Netherlands, and most of the Mittlerer Buntsandstein of Germany. To the west it correlates with the Sherwood Sandstone Group of the UK onshore succession (see table, p.4). The Mittlerer Buntsandstein comprises four upward-fining units (folgen; see Boigk 1959; Wolburg 1961; Herrmann 1962) that have been assigned formation status (Röhling 1991). Borehole geophysical log-correlation (Boigk 1959; Trusheim 1963) demonstrated that the highest (Soiling) folge is separated from older units by an angular unconformity, the ‘H-Diskordanz’ (Trusheim 1961), commonly referred to as the ‘Hardegsen disconformity’ (Geiger & Hopping 1968) or the ‘Hardegsen Unconformity’. The divisions of the German sequence have not been recognized in the UK sector (Cameron et al. 1992). However, the top of the Bunter Sandstone Formation is an angular unconformity at which units within the formation are truncated and overstepped in the same way that the Volpriehausen, Detfurth and Hardegsen folgen of the Mittlerer Buntsandstein are overstepped by the Soiling Folge at the ‘H-Diskordanz’ in Germany. The Bunter Sandstone Formation therefore correlates with the Volpriehausen, Detfurth and Hardegsen folgen and the Soiling Folge, the highest unit in the Mittlerer Buntsandstein, is represented in the UK sector by beds assigned to the basal part of the Dowsing Formation (see p.14).

Genetic interpretation
The Bunter Sandstone Formation comprises sands derived largely from the UK onshore area to the west and the London-Brabant Platform to the south (Cameron et al. 1992; Warrington & Ivimey-Cook 1992) and deposited in fluvial channel systems. In the Esmond, Forbes and Gordon gasfields (Quadrant 43) the sediments have been interpreted as comprising the deposits of coalescing alluvial fans which were dissected by fluvial braided channels in a semi-arid to arid climate (Bifani 1986).

Age
Early Triassic, on palynological evidence (Geiger & Hopping 1968; Fisher 1979). Reitz (1988) assessed the correlative Volpriehausen, Detfurth and Hardegsen folgen as late Induan to early Olenekian in age; van der Zwan & Spaak (1992) proposed an early Olenekian age.

References
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BUNTER SHALE FORMATION

Rhys (1974) introduced the term Bunter Shale Formation for the dominantly argillaceous unit which rests upon evaporites assigned to the Zechstein Group and is succeeded by the arenaceous Bunter Sandstone Formation. The Bunter Shale Formation constitutes the lower part of the Bacton Group (Rhys 1974).

Reference


Name. From the predominantly argillaceous character of the unit which correlates partly with the Lower Buntsandstein Formation of the Dutch sector and the Netherlands, and the Untere r Buntsandstein of north German sequences.

Type section

49/21-2 (Rhys 1974): 1683-2011m (5522-6597ft) below KB (revised top). The top of the formation in this section is here revised from 1695.5m (5563ft, metric conversion revised) (Rhys 1974) to the level of a regionally consistent log-marker (see p.51).

Reference sections

41/24a-l: 695.5-1002m (2281-3288ft)
48/7b-3: 1885-2263.5m (6184-7426ft)
53/14-1: 766-997.5m (2513-3273ft)

Formal lithostratigraphic subdivisions

Amethyst Member
Breccelschiefer Member
Rogenstein Member
Lithology
The Bunter Shale Formation consists predominantly of red, red-brown, and some grey mudstones and shales. In basin margin areas, sandstones interbedded with silty mudstones in the upper part of the formation form the Amethyst Member (p.43); this passes distally into the Rogenstein Member (p.47) which comprises mudstones with siltstone and some dolomite interbeds and traces of anhydrite, and is characterized by the presence of calcareous oolitic beds (rotenstein). The lowest beds of the formation comprise red-brown, silty, dolomitic or anhydritic mudstones interbedded with siltstones and some fine sandstones, and constitute the Brockelschiefer Member which includes the Hewett Sandstone (p.45). The log profile of the formation varies regionally. In central basin sections gamma-ray and velocity values are relatively uniform, giving rise to parallel-sided traces; sporadic low-gamma and high velocity peaks in the upper part of the formation in these areas are associated with oolitic beds in the Rogenstein Member, and lower gamma-ray and higher velocity values in the lowest part of the formation are associated with the Brockelschiefer Member (e.g. 49/21-2). Towards the western and southern margins of the basin the upper part of the formation, corresponding to the Amethyst Member, shows lower gamma-ray values and a greater range in amplitude in both the gamma-ray and velocity log profiles, than the underlying mudstones (see well 41/24a-1).

Upper boundary
The top of the Bunter Shale Formation is defined by a downward change from the dominantly arenaceous sequence of the Bunter Sandstone Formation to a predominantly argillaceous succession. The boundary is usually clear and is marked by a downward increase in gamma-ray values, but may be less distinct towards the London-Brabant Platform and the eastern UK onshore area where the Amethyst Member, which includes sandstones up to 10m thick, forms the upper part of the Bunter Shale Formation.

Lower boundary
The base of the Bunter Shale Formation is defined by a downward change from red-brown, silty, dolomitic or anhydritic mudstones, interbedded with siltstones and some fine sandstones, to anhydrites and halites or, in rare instances (e.g. 54/11-1, p.51), carbonates of the Zechstein Group. This boundary corresponds to an abrupt downhole decrease in gamma-ray values and a marked increase in velocity. Throughout most of the UK sector the Bunter Shale Formation overlies the Grenzanhdydrit of the Z5 cycle (see Regional correlation). In the southeast of the sector, however, the Bunter Shale Formation may be interpreted as resting upon Zechstein carbonates (e.g. 54/11-1), indicating the presence of an unconformity with overstep.

Lithostratigraphic subdivision
The Brockelschiefer Member is widely recognized at the base of the Bunter Shale Formation in the UK sector; within this member the Hewett Sandstone is developed adjacent to the London-Brabant Platform (see p.45). Beds in the upper part of the Bunter Shale Formation are assigned to the Amethyst Member (p.43) and its finer-grained distal equivalent, the Rogenstein Member (p.47).

Distribution and thickness
The Bunter Shale Formation is the most widely occurring of the formations assigned to the Triassic in the Southern North Sea region. It thickens progressively eastwards and northeastwards from the UK onshore area and the London-Brabant Platform. The formation is over 200m thick throughout most of the UK sector and exceeds 300m in quadrants 42, 43 and 44, and adjacent parts of quadrants 41, 47, 48 and 49; it is over 400m thick on the northwest side of the Cleaver Bank High (Cameron 1993).

Regional correlation
The Bunter Shale Formation is the offshore equivalent of the argillaceous Roxby Formation (Smith et al. 1986) which lies between Zechstein carbonates and evaporites and the Sherwood Sandstone Group in eastern UK onshore successions. The upper boundary of this formation youngs eastwards as also does its lower boundary which rises from a level in the EZ3 cycle (Teesside Group), at outcrop in Yorkshire, to one above the Littlebeck Anhydrite Formation in the EZ3 cycle (Eskdale Group), at subsurface farther east towards the UK coast. The Littlebeck Anhydrite Formation is a correlative of the Grenzanhdydrit of the Z5 sequence in the UK offshore area (Smith et al. 1986). The lower and upper boundaries of the Bunter Shale Formation, and those of its members, are therefore regarded as diachronous and younging eastwards. In consequence, the Brockelschiefer Member of the UK sector is considered to be a time correlative of deposits which, in the Netherlands and north Germany, include higher evaporite cycles in the Zechstein sequence than those present below the member in the UK sector. The base of the Amethyst Member is also likely to young away from the UK coast and towards the lateral passage of this unit eastwards into the Rogenstein Member (see table, p.4).

Genetic interpretation
The Bunter Shale Formation comprises a complex of fluvial, distal floodplain, and playa lake clastic deposits, with minor evaporites, which prograded diachronously eastwards and northeastwards into the Southern North Sea Basin from the eastern UK and London-Brabant Platform.

Age
No direct evidence; conventionally regarded as Early Triassic or Scythian (see Bacton Group, p.33); van der Zwan & Spaak (1992) proposed a Late Permian to early Scythian (Induan) age for the correlative sequence in the Netherlands.

References
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The term Amethyst Member was introduced by Cameron et al. (1992) for a dominantly argillaceous unit in the upper part of the Bunter Shale Formation that is characterized by the presence of beds of sandstone up to 10m thick; a type section was not designated.

**Name.** From the Amethyst Field (Cameron et al. 1992).

**Type section**

47/14a-3: 1780.5-1952.5m (5842-6405ft) below KB (here designated)

**Reference section**

47/18-1: 1677-1899m (5502-6230ft)

**Lithology**

Red and red-brown silty mudstones with beds of sandstone. The proportion of sandstone increases, southwestwards and westwards, towards the London-Brabant Platform and the eastern UK onshore area. Sandstone beds are commonly 5 to 10m thick but some thicker units occur towards the basin margins. The member typically displays more varied gamma-ray values and velocities than the underlying Bunter Shale Formation mudstones and the overlying Bunter Sandstone Formation.

**Upper boundary**

The top of the Amethyst Member corresponds to the top of the Bunter Shale Formation which occurs at an abrupt downward increase in the proportion of mudstone below the dominantly arenaceous Bunter Sandstone Formation. The boundary is typically marked by an abrupt downward increase in gamma-ray values and a slight decrease in velocity.

**Lower boundary**

The base of the Amethyst Member is placed at the base of the lowest significant sandstone bed in the upper part of the Bunter Shale Formation; this level is marked by a downward change to higher gamma-ray values and lower velocities, and to more even log signatures. When traced eastwards from the UK onshore area and northwards from the flank of the London-Brabant Platform the base of the member occurs at progressively higher levels within the Bunter Shale Formation.

**Distribution and thickness**

The Amethyst Member occurs on the southern and western margins of the basin, adjacent to the London-Brabant Platform and the eastern UK onshore area, and extends to between 15 and 100km from the English coast. The member thins distally, away from the coast, as a consequence of a decrease in the thickness and number of sandstone beds and the lateral passage of those in the lower part of the member into finer sediments; it is about 170m thick in the type section area but over 220m thick in the area of the more proximally situated reference section.

**Regional correlation**

The Amethyst Member passes distally, eastwards and northeastwards, into the Rogenstein Member (see pp.47, 51). Westwards, it passes, by increase in the proportion of sandstone, into the lower part of the Sherwood Sandstone Group of the eastern UK onshore succession (see table, p.4)

**Genetic interpretation**

The Amethyst Member comprises an interdigitating sequence of fluvial sandstones and floodplain and lacustrine sediments which fines distally and passes laterally into the deposits of a playa lake (the Rogenstein Member). The fluvial floodplain deposits were sourced from the west and southwest and prograded gradually into the basin, resulting in thinner sequences in the more distal areas.

**Age**

No direct evidence; conventionally regarded as Early Triassic or Scythian; van der Zwan & Spaak (1992) proposed an Induan age.

**References**


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The Bröckelschiefer unit, as recognized in the UK Southern North Sea succession by Geiger & Hopping (1968), was formalized as the Bröckelschiefer Member by Rhys (1974). It consists of interbedded silty mudstones, siltstones and fine sandstones that form the basal unit of the Bunter Shale Formation.

**Name.** From the Bröckelschiefer (brockel=crumbly, friable; schiefer=shale) of German lithostratigraphic nomenclature.

**Type section**
49/21-2 (Rhys 1974); 1983-201 m (6505-65970) below KB

**Reference sections**
42/10a-1: 1625.5-1639m (5331-53780) below KB
52/5-1: 1237-1306m (4059-1285ft)

**Lithology**
The Bröckelschiefer Member comprises red-brown to chocolate-brown, micaceous, calcareous (dolomitic) or anhydritic shales, silty mudstones and siltstones with some interbeds of very fine to fine, red-brown sandstone. The member is commonly upward-fining in character, indicated by an upward-increasing gamma-ray profile, and has a distinctly higher velocity than the overlying Bunter Shale Formation mudstones. Thicker sandstones, including the Hewett Sandstone, a reservoir unit for the Hewett Field (Cumming & Wyndham 1975), are developed overlying Bunter Shale Formation mudstones. Thicker downdip to the Hewett Field (Cumming & Wyndham 1975), are developed in the southern part of the basin, adjacent to the London-Brabant Platform.

**Upper boundary**
The top of the Bröckelschiefer Member is placed at a downward change from red silty mudstones to red-brown silty mudstones and siltstones with sandstone interbeds; this is marked by a downward decrease in gamma-ray values and an increase in velocity. Locally, the top of the Hewett Sandstone corresponds with the top of the member (see pp.41, 51).

**Lower boundary**
The base of the Bröckelschiefer Member corresponds to the base of the Bunter Shale Formation. Within the limits of the former Permian evaporite basin in the UK sector the base of the member is defined by a sharp downward change from red-brown silty mudstones and siltstones with sandstone interbeds to evaporites and evaporitic mudstones of the Zechstein Group; a marked downward decrease in gamma-ray values and an increase in velocity occur at this level. To the south of the former evaporite basin, the boundary is commonly less clear and is open to different interpretations, including the possibility that the member overlies beds of the Z4 sequence and rests unconformably upon older (Z3) beds of the Zechstein Group (see p.51).

**Lithostratigraphic subdivision**
Only one unit, the Hewett Sandstone, is distinguished within the Bröckelschiefer Member. The type section (Rhys 1974) is well 52/5-IX: 1230-1297m (4043-4264ft) below KB. The Hewett Sandstone comprises fine to coarse, red-brown, locally grey, well-sorted quartzose sandstones with scattered pebbles and thin conglomerates that incorporate angular, subrounded and rounded clasts of metamorphic rocks and grey-green siltstones. In comparison with the underlying and overlying beds of the Bröckelschiefer Member it displays substantially lower gamma-ray values and more variable, but generally slightly lower, velocities. Locally, the top of the Hewett Sandstone forms the top of the Bröckelschiefer Member (see pp.41, 51).

**Distribution and thickness**
The Bröckelschiefer Member is coextensive with the Bunter Shale Formation within the Southern North Sea region (Figure 2, p.5). The member varies from 20m up to 70m in thickness (Cameron et al. 1992). The Hewett Sandstone has a maximum thickness of over 60m and is restricted to the area of the South Hewett Shelf, adjacent to the London-Brabant Platform (Cumming & Wyndham 1975; Cameron et al. 1992).

**Regional correlation**
The Bröckelschiefer Member correlates eastwards with beds comprising the ‘Upper Zechstein’ and lower part of the Basal Buntsandstein Member of successions in the Netherlands, and with most of the Zechstein Übergangsfolge, including the Bröckelschiefer, of north German sequences (see table, p.4).

**Genetic interpretation**
The Bröckelschiefer Member comprises a generally upward-fining sequence of fine-grained clastic sediments that were deposited in distal floodplain environments which extended over and beyond the site of the former Permian evaporite basin in the UK sector. The Hewett Sandstone is interpreted as a fluvial deposit derived from the adjacent London-Brabant Platform (Fisher & Mudge 1990).

**Age**
No direct evidence; conventionally assigned an earliest Triassic age.

**References**
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The term Rogenstein Member was introduced by Rhys (1974) for a unit in the upper part of the Bunter Shale Formation characterized by the presence of thin calcareous beds containing abundant ferruginous ooliths.

**Name.** From the rogenstein (oolite) of German lithostratigraphic terminology.

**Type section**
49/21-2 (Rhys 1974): 1683-1798.5m (5522-5901ft) below KB (metric conversion revised)
The top of the member in this section is here revised from 1695.5m (5563ft) to the level of a regionally consistent log-marker (see p.51).

**Reference section**
43/20-1: 1737-1948.5m (5699-6392ft)

**Lithology**
Dominantly red and some grey mudstones with calcareous beds (rogenstein), generally less than 1m thick, which contain abundant ferruginous ooliths; thin beds of fine sandstone, siltstone and dolomite occur, and traces of anhydrite may be present. The member typically displays gamma-ray and velocity log signatures similar to those shown by the underlying Bunter Shale Formation mudstones but differentiated by the presence of low gamma-ray and high velocity peaks generated by the oolitic beds.

**Upper boundary**
The top of the Rogenstein Member corresponds to the top of the Bunter Shale Formation and is placed at an abrupt downward increase in the proportion of mudstone below the dominantly arenaceous Bunter Sandstone Formation. The boundary is marked by an abrupt downward increase in gamma-ray values and, in some logs, by a downward decrease in velocity.

**Lower boundary**
The base of the Rogenstein Member is placed at the base of the lowest occurrence of ooliths and of the associated low gamma-ray and high velocity peaks.

**Distribution and thickness**
The Rogenstein Member occurs throughout an area extending westwards from the Cleaver Bank High to the west side of the Sole Pit Trough and northwards to the Silver Pit Basin and North Dogger Shelf. Thicknesses range from about 100m to more than 210m.

**Regional correlation**
The Rogenstein Member is the distal equivalent of the Amethyst Member present to the west and south. To the east it is correlative with the Rogenstein Member of the Lower Buntsandstein Formation in the Dutch sector and the Netherlands, and with the Obere Folge of the Unterer Buntsandstein succession of Germany (see table, p.4).

**Genetic interpretation**
The Rogenstein Member was deposited in shallow brackish or hypersaline water in a playa lake environment.

**Age**
No direct evidence; conventionally regarded as Early Triassic or Scythian; van der Zwan & Spaak (1992) proposed an Induan age.

**References**

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CORRELATIONS PANELS
CORRELATION PANEL 1

LITHOLOGY

- Sandstone
- Mudstone
- Dolomitic / anhydritic

HAISBOROUGH GROUP

- TRITON FORMATION
- Muschelkalk Member
- DUDGEON FORMATION
- Muschelkalk Member
- DOWSING FORMATION
- Muschelkalk Member
- BACTON GROUP
- LIAS GROUP
- PENARTH GROUP

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PERMIAN
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PERMIAN

The first formal lithostratigraphic scheme for the Permian of the UK Southern North Sea was proposed by Rhys (1974). Because individual stratigraphic units in the Northwest European Southern Permian Basin (Glennie 1990) are very widespread, informal German stratigraphic terms had already been widely applied by oil companies to the UK succession, and Rhys formalized their usage with only minor anglicizations. The Rhys lithostratigraphic scheme has subsequently been widely adopted, and is retained in this study, with only minor modification.

Rhys designated a unit of Lower to Middle Permian desert sediments the ‘Rotliegendes Group’. Following Cameron (1993), however, this unit is here formally renamed the Rotliegend Group, as the term ‘Rotliegend’ is linguistically preferable (see Glennie 1990). The two formations (Leman Sandstone Formation and Silverpit Formation) that Rhys included within the Rotliegend Group are retained here. However, an additional unit of interbedded mudstones and halites is recognized within the Silverpit Formation, and is formally designated the Silverpit Evaporite Member, following NAM & RGD (1980). On the Mid North Sea High, red-brown sandstones of the Auk Formation (Deegan & Scull 1977) and the underlying basalts and interbedded sandstones and mudstones of the Inge Volcanics Formation (Cameron 1993) are also included in the Rotliegend Group.

Rhys recognized four major carbonate evaporite cycles within a complex Upper Permian unit designated the Zechstein Super-Group, and assigned group status to each cycle (Z1 to Z4). In this study, however, the Zechstein Super-Group and the Z1 to Z4 groups are abandoned and all Upper Permian strata are included in the Zechstein Group. The Zechstein Group now extends across the UK North Sea and into the Norwegian and Dutch sectors (e.g. Cameron 1993; Deegan & Scull 1977; NAM & RGD 1980). Most of the 17 Zechstein formations recognized by Rhys are retained in this study. However, the terms Lower Werraanhydrit Formation, Werra Halite Formation and Upper Werraanhydrit Formation are abandoned and their constituent strata are included in a revised Werraanhydrit Formation. This simplification of the nomenclature is warranted because the Werra Halite of Rhys can be recognized in only very few wells and is not sufficiently widespread to justify either formal status of its own, or formal separation of the Lower and Upper Werraanhydrit. The term Deckanhydrit Formation is also abandoned here, because this unit is now recognized as a solution residue at the base of the Z3 cycle (Taylor & Colter 1975; Cameron et al. 1992).

Two new units, the Blakeney Formation and Scotl Head Formation, are introduced for terrigenous clastic-dominated strata at the southern basin margin which are laterally equivalent, respectively, to Z1/22 and Z3-726 evaporite-dominated basinal strata. The Blakeney and Scotl Head formations are equivalent to the Edlington and Roxby formations in eastern England (Smith et al. 1986).

On the Mid North Sea High, the Halibut Carbonate, Turbot Anhydrite and Shearwater Salt formations of the Northern Permian Basin, as defined by Cameron (1993), are related to and partly interdigitate with the Southern North Sea Zechstein formations (see Zechstein Group Panel 1). Many of these formations correlate directly with formations recognized in eastern England (Smith et al. 1974; Smith et al. 1986) (see table, p.57).

Proposed scheme

The proposed lithostratigraphic nomenclature for the Permian of the UK Southern North Sea is illustrated in Figure 3 (p.55). This illustrates the interpreted relationship of Zechstein cycles to the revised lithostratigraphic nomenclature, although the Z1 to Z4 lithostratigraphic groups of Rhys (1974) are abandoned. The long-established practice of dividing the Zechstein into four cycles was modified by Jung (1968), who added a relatively minor, and less extensive, fifth cycle. This has now been recognized in northeast England, where it comprises the Littlebeck Anhydrite (formerly Top Anhydrite) (Smith 1970, 1980, 1989; Smith et al. 1986) and in the Southern North Sea, where it comprises the Grenzanhydrit Formation (Taylor & Colter 1975; Taylor 1980). Minor sixth and seventh evaporite cycles have been reported in Germany, but are regarded by Taylor (1990) as being probably of continental rather than marine origin, and possibly of Triassic age.

An alternative, sequence stratigraphic interpretation of Zechstein cycles has been proposed by Tucker (1991). The term Grenzanhydrit Formation as introduced by Rhys (1974) is retained here. It should be noted, however, that in Germany the ‘grenzanhydrit’ is now regarded as a solution residue that occurs at more than one level (Best 1989). The Z5 Grenzanhydrit Formation in the Southern North Sea is believed to equate with the Ohré Anhydrit of North Germany and the Netherlands (Smith 1989).

Biostatigraphy

As described in the Appendix, biostatigraphic control for the Permian of the UK Southern North Sea is extremely limited.

References

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Figure 3. Lithostratigraphic nomenclature scheme for the Permian of the Southern North Sea

Figure 4. Areal distribution of the Permian groups
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## SOUTHERN NORTH SEA

### Stratigraphic Column

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<tr>
<th>Formation</th>
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<th>Anglo-Dutch Basin</th>
<th>South Hewett Shelf</th>
<th>Zechstein Cycle</th>
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### Maps

- **Rotliegend Group**
- **Zechstein Group**

### Notes
- 100 km grid markers
- Various geological formations and members are labeled.
Rhys (1974 & 1975) assigned group status (Z1 to Z4 groups) to the four Upper Permian carbonate-evaporite cycles of the Southern North Sea, and Super-Group status to the Zechstein as a whole. However, in this report the Zechstein Super-Group and Z1 to Z4 groups are abandoned and the term Zechstein Group is applied to the entire Upper Permian succession. Thus, in the UK sector, the Zechstein Group becomes common to both the Southern North Sea and the Central and Northern North Sea (Deegan & Scull 1977; Cameron 1993). It can also be followed into the Norwegian sector (Deegan & Scull 1977) and Dutch sector (NAM & RGD 1980). Although the Z1-Z4 groups are now redundant, the interpreted relationship of Zechstein cycles to the revised lithostratigraphic nomenclature is indicated here. Following Jung (1968), a relatively minor fifth cycle has now been recognized in northeast England (Littlebeck Anhydrite: Smith 1989) and in the Southern North Sea Basin (Grenzanhydrite Formation: Taylor & Colter 1975; Taylor 1990). It should be noted that the Grenzanhydrite Formation of the UK Southern North Sea does not equate with the ‘grenzanhydrit’ of German sections, which is regarded as a solution residue that occurs at several levels (Best 1989). The Z5 Grenzanhydrite Formation is believed to equate with the Ohre Anhydrit of north Germany and the Netherlands. In a contrasting interpretation of cyclicity in the North Sea Zechstein, Tucker (1991) used sequence stratigraphic models to propose that each cycle begins with the deposition of lowstand evaporites followed by transgressive and highstand carbonates.

The Zechstein Group of the Anglo-Dutch Basin is here divided into fifteen formations, the majority of which were recognized by Rhys (1974). In contrast to Rhys (1974), the terms Lower Werraanhydrit, Werra Halite and Upper Werraanhydrit Formation are abandoned here and these combined strata are assigned to a revised Werraanhydrit Formation. This simplification of the nomenclature is warranted because the Werra Halite Formation of Rhys (1974) can be recognized in only very few wells and is not sufficiently widespread to justify either formal status of its own, or formal separation of the Lower and Upper Werraanhydrit formations.

The formal term Deckanhydrit Formation is also abandoned here, because this unit is now regarded as a solution residue (Taylor & Colter 1975; Cameron et al. 1992). In the Anglo-Dutch basin, thick Upper Permian salt and polyhalite dominated sections that are extensively deformed and which include deposits of the Z2, Z3 and Z4 cycles are informally designated ‘undivided Zechstein salt’ in this study.

On the Mid North Sea High, north of approximately 55°10’N, many of the Upper Permian sections are most readily divided in terms of Northern Permian Basin lithostratigraphic nomenclature (Cameron 1993). Accordingly, the Halibut Carbonate, Shearwater Salt and Turbot Anhydrite formations are recognized on the northern margin of the Anglo-Dutch Basin. Similarly, a thick sequence of undivided Zechstein salt, lying within an embayment that extends southwards across the Mid North Sea High in Quadrant 37, is included in the Shearwater Salt Formation of the Northern Permian Basin (Cameron 1993).

On the South Hewett Shelf, where clastic deposits dominate over evaporites of the Z2, Z3, Z4 and Z5 cycles, the terms Blakeney and Scott Head formations are introduced for strata believed to be equivalent in part to the offshore Edlington and Roxby formations, respectively (Smith et al. 1986).

The Zechstein Group is widely distributed over the Southern North Sea. Evaporites in the basin centre are much disturbed by halokinesis and are locally over 2500m thick. In more marginal sections, which are not much affected by halokinesis, the Zechstein Group is about 500m thick. The Zechstein Group in the Southern North Sea generally rests on desert sediments of the Rotliegend Group, or locally oversteps these onto pre-Permian strata. Its upward transition into Baeton Group clastic sediments is generally taken as the Permian/Triassic boundary.
References

Name. From the old German stratigraphic term for Upper Permian deposits.

Age
Late Permian.

Constituent formations (Southern North Sea)

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* Denotes Central North Sea formations that extend into the northernmost part of the Southern North Sea. They are described in full in Cameron (1993); summary descriptions only are given here.

Name. From the old German stratigraphic term for Upper Permian deposits.

Age
Late Permian.

Constituent formations (Southern North Sea)

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* Denotes Central North Sea formations that extend into the northernmost part of the Southern North Sea. They are described in full in Cameron (1993); summary descriptions only are given here.
ALLER HALITE FORMATION

The term Aller Halite Formation was first used in the UK Southern North Sea by Rhys (1974) for a unit of halite, K/Mg salts and thin, red-brown, saliferous mudstones lying between the Pegmatitanhydrit Formation and the Grenzanhydrit Formation. The Aller Halite Formation is here revised to include a thin unit of saliferous mudstones at its top, which was not recognized by Rhys (1974). These mudstones are interpreted as regressive deposits and are believed to correlate with the Sleights Siltstone Formation of the 'Yorkshire Province' (Smith et al. 1974). The Aller Halite Formation marks the main evaporitic phase of the Z4 cycle (Rhys 1974). In areas of intense halokinetic deformation, the Aller Halite Formation passes laterally into undifferentiated Zechstein salts.

References

Name. From the old German stratigraphic term.

UK reference sections
36/26-1: 982.5-1036.5m (3224-3400ft)
41/25-1: 1091-1168.5m (3580-3834ft)
47/13-2: 2212-2242.5m (7257-7358ft)
49/26-4 (Rhys 1974, table 2, fig. 3): 1527.5-1587m (5012-5206ft)
Lithology
The Aller Halite Formation consists of halite with subordinate interbedded and intergrown K/Mg salts and saliferous mudstones. The halite is generally colourless, locally orange, pink, yellow, white or grey, coarsely crystalline, transparent to translucent, occasionally opaque and moderately hard. The K/Mg salts mainly comprise sylvite and carnallite with rare occurrences of kieserite and are white, pink or red, transparent to opaque, and hard. Mudstones, generally occurring in the upper part of the formation, are red-brown, locally grey-green, soft, amorphous, occasionally hard and locally saliferous and/or anhydritic.

Upper boundary
The top of the Aller Halite Formation is normally marked by a sharp downward change from white or pale grey anhydrite of the Grenzanhidrit Formation to halite and local red-brown saliferous mudstones. The boundary is characterized on wireline logs by a downward decrease in velocity and density and a downward increase in gamma-ray values. It is locally less well defined where the overlying Grenzanhidrit Formation is thin (e.g. 49/26-4). Where the Grenzanhidrit Formation is locally absent and siltstones of the Bunter Shale Formation rest directly on the Aller Halite Formation, a sharp downward increase in gamma values and velocity marks the boundary (e.g. 41/25a-1).

Lower boundary
The base of the Aller Halite Formation is normally defined by a sharp downward change from colourless or pink, clear halite to white or grey anhydrite of the Pegmatiananhidrit Formation. The boundary is characterized on wireline logs by a sharp downward increase in velocity and density, and a downward increase in gamma-ray values. It is locally less well defined where the overlying Grenzanhidrit Formation is thin (e.g. 49/26-4). Where the Pegmatiananhidrit Formation is locally absent, the Aller Halite Formation rests on the Roter Salzton Formation, coinciding with a sharp downward increase in gamma values, but no significant change in velocity (e.g. 36/26-1).

Lithostratigraphic subdivision
An informal four-fold subdivision of the Aller Halite Formation is recognized here (designated as units A1, A2, A3 and A4) on the basis of relative amounts of K/Mg salts or mudstones and the associated wireline log signatures.

Unit A1: at the base of the formation, consists of relatively pure halite which locally contains thin beds of anhydrite (e.g. 49/26-4) or mudstone and/or sylvite (e.g. 41/25a-1) in its lower part. It is generally characterized by uniformly low velocity and low gamma values (e.g. 47/13-2).

Unit A2 consists of K/Mg salts (mainly sylvite, carnallite and rare kieserite) with mostly subordinate halite and local thin beds of red-brown, saliferous mudstone. It is characterized by a spiky, high-gamma signature and its base coincides with a sharp downward decrease in gamma values and an increase in velocity (e.g. 41/25a-1 and 49/26-4).

Unit A3 consists of relatively pure halite, but where thickly developed commonly contains thin beds of red-brown, silty, saliferous mudstone (e.g. 41/25a-1). In its base is defined by a sharp downward increase in gamma values and a slight decrease in velocity.

Unit A4 consists of red-brown, silty, saliferous mudstones (e.g. 47/13-2). The base of the unit is characterized by a downward decrease in gamma values and an increase in velocity. Where the Aller Halite Formation passes laterally into halokinetically disturbed and undivided Zechstein salt, mudstones equivalent to unit A4 can sometimes be distinguished immediately below the overlying Grenzanhidrit Formation (e.g. 38/24-1, Panel 1).

Distribution and thickness
The Aller Halite Formation is present throughout much of the Southern North Sea Basin. It thickens into the centre of the basin to approximately 130m, although its depositional thickness is difficult to determine because many areas have been extensively dissected by halokinensis. Unit A1 thickens from around 19m on the Yorkshire coast (Smith & Crosby 1979) to approximately 35m in the centre of the Southern North Sea. The limit of unit A2 lies 10-30km basinward of the limit of unit A1, and it thickens from 32m on the coast of Yorkshire to around 75m in the basin centre. Unit A3 also thickens basinward from 5m to approximately 20m. Unit A4 is present in a marginal belt 20-80km wide in the northern, western and southeastern parts of the basin. It is most thickly developed in the northwest where it reaches about 30m. The unit thins basinward and appears to be absent from the centre of the basin possibly due to lateral passage into halites of unit A3.

Regional correlation
Laterally equivalent strata in the 'Yorkshire' and 'Durham' provinces are termed the Sneaton Halite and Sleights Siltstone formations (Smith et al. 1986; Smith 1989). In the Dutch sector of the Southern North Sea, laterally equivalent strata are termed the Z4 Salt Member of the Zechstein 4 Formation (NAM & RGD 1980). No lateral equivalent of the saliferous mudstone unit have been recognized in the offshore Netherlands area.

In the Anglo-Dutch Basin, where halokinetic deformation is locally intense, the Aller Halite Formation passes laterally into undifferentiated Zechstein salts of the Z2, Z3 and Z4 cycles. The Aller Halite Formation is absent over much of the Mid North Sea High, although it may pass laterally into thick undifferentiated evaporites of the Shearwater Salt Formation in a north-south trending, trough-like feature crossing Quadrant 37 (Jenyon et al. 1984; Cameron 1993) (e.g. 37/12-1, not illustrated). In the South Hewett Shelf area, equivalent strata are included in the mudstones and anhydrites of the newly defined Scott Head Formation (Panel 4S).

Units A1 to A3 can be correlated with the five units of the Sneaton Halite Formation (formerly the Upper Halite Formation) of Smith & Crosby (1979). Unit A1 corresponds to Sneaton units A and B and unit A2 equates with Sneaton units C (also known as the Sneaton Potash Member) and D (hasselegerite salt). Unit A3 corresponds to Sneaton unit E. Unit A4 is correlated with the Sleights Siltstone Formation (Smith et al. 1974).

Genetic interpretation
The Aller Halite Formation was largely deposited on extensive salt flats, surrounding a basin-centre saline playa, that were subject to regular flooding. The playa may have suffered periodic complete desiccation, at times accompanied by encroachment of continental clastic depositional environments. The lower part of unit A1 (Sneaton unit A of Smith & Crosby 1979), comprising anhydritic layered halite in northeast England, was deposited in shallow subaqueous conditions (Smith 1989). Longer periods of subaerial exposure and increased salinity levels are interpreted for the deposition of the upper part of unit A1 and the lower part of unit A2 (Sneaton unit C, also known as the Sneaton Potash Member, Smith et al. 1986). The upper part of unit A2 (Sneaton unit D or hasselegerite salt of Smith & Crosby 1979) is a mainly clastic terrigenous deposit in north-east England (Smith 1980) and its passage to potassium salt deposits in the centre of the Southern North Sea suggests that the basin-centre playa was much reduced in size or had dried up completely. Unit A3 is interpreted as the product of a more short-lived expansion of the basin centre plays following an influx of fresher water and unit A4 represents a second, major period of playa desiccation and basinward progradation of continental clastic sedimentation.

Age
Late Permian.

References
Due to extensive halokinetic deformation, Aller Halite Formation locally passes laterally into isolated patches of undifferentiated Zechstein salt.

See also Correlation Panel 2.
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The term Basalanhydrit Formation was first applied to the UK offshore area by Rhys (1974) for a unit of white to pale grey anhydrite, locally dolomitic, that lies between the Hauptdolomit Formation and the Stassfurt Halite Formation. The Basalanhydrit Formation represents the basal part of the Z2 evaporite phase.

Name
From the German stratigraphic nomenclature.

UK reference sections
49/21-2: 2262.5-2267m (7422-7437ft)
49/26-4: 4857m (16044ft) (G&K, 1974, table 2, fig. 3)
1772-1807m (5813-5928ft) (revised depths)

Lithology
In marginal, shelf sections, the Basalanhydrit Formation typically consists of white to pale grey, amorphous, microcrystalline anhydrite and argillaceous anhydrite with local intercalations of pale grey to pale brown microcrystalline dolomite and argillaceous dolomite (e.g. 49/26-4). Near the southern limit of the Basalanhydrit Formation, where it passes laterally into the Blakeney Formation, red mudstone is interbedded with anhydrite (e.g. 53/1-1, Panel 45). In more basinal sections, the Basalanhydrit Formation is represented by a thin unit of white, amorphous anhydrite and dolomitic anhydrite.

Upper boundary
The top of the Basalanhydrit Formation is normally defined by a downward change from halite of the Stassfurt Halite Formation to white and pale grey anhydrite and dolomitic anhydrite. It is marked on wireline logs by a sharp downward increase in density. Locally, in the basin centre, the top is marked by a downward increase from high-gamma polyhalite or interbedded anhydrite and polyhalite of the Stassfurt Halite Formation to low-gamma, amorphous, white anhydrite (e.g. 44/21-1 see Cameron et al. 1992, fig. 35 and 48/7-4, p.79). In sections at the southern and western margins of the basin, where the Stassfurt Halite Formation is absent, the Basalanhydrit Formation is directly overlain by grey dolomite of the Plattendolomit Formation (e.g. 41/8-1, Panel 2).

Lower boundary
In shelf sections, the base of the Basalanhydrit Formation is generally marked by a downward change from white or pale grey anhydrite and dolomitic anhydrite to pale grey and pale brown dolomite and anhydritic dolomite (e.g. 49/26-4) of the Hauptdolomit Formation. In basinal sections, the anhydrite rests on dark grey, finely laminated, bituminous limestone or dolomite (e.g. 49/21-2 & 44/21-1 see Cameron et al. 1992, fig. 35). On wireline logs, the base of the Basalanhydrit Formation normally coincides with a downward decrease in density. Commonly, a downward increase in velocity is also recorded (e.g. 49/26-4). Locally, the boundary is gradational due to the interbedded nature of the anhydrite/dolomite sequence and here it is taken at the top of the dolomite-dominated section (e.g. 48/30-4, Panel 4N).

Beyond the southern depositional limit of the Hauptdolomit Formation, the base of the Basalanhydrit Formation is taken at the downward change from white to grey anhydrite with interbedded red mudstone to pale brown dolomite of the Zechsteinkalk Formation (e.g. 48/30-1, p.111 and 53/1-1, Panel 45).

Distribution and thickness
The Basalanhydrit Formation is best developed near the margins of the Zechstein Basin, where it is typically 10 to 55m thick. It is often thin or absent from the central basin floor, where the Stassfurt Halite Formation rests directly upon the Hauptdolomit Formation (e.g. 44/11-1, Panel 3).

Regional correlation
Equivalent evaporitic strata in northeast England are included in the lower part of the Fordon (Evaporite Formation) (Smith et al. 1974). In the Netherlands offshore, correlative rocks are known as the Z2 Basal Anhydrite Member of the Zechstein 2 Formation (NAM & RGD 1980). According to Cameron et al. (1992) equivalent strata may be represented in the central basin by interlaminated carbonates and anhydrite included within the top of the Hauptdolomit Formation. In the north of quadrants 36, 37, 38 and 39, on the Mid North Sea High, the Basalanhydrit Formation passes laterally into the Turbot Bank Formation (e.g. 38/25-1, Panel 1) (Cameron 1993). Around the southern margin of the basin, the Basalanhydrit Formation passes laterally into corral interbedded red mudstones and thin anhydrites and localized sandstones of the Blakeney Formation (e.g. 52/5-1IX, Panel 48).

Genetic interpretation
The anhydrites of the Basalanhydrit Formation and equivalent rocks in eastern England were largely formed in a range of peritidal, subtidal and shallow-marine shelf environments at and near the basin margin, whilst deep-water conditions existed in the basin centre (Colter & Reed 1980; Smith 1980; Clark 1986).

Age
Late Permian.

References

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The term Blakeney Formation is introduced for a unit of continental and marginal marine, red-brown mudstones and interbedded anhydrites with localized sandstones that lies between the Grauer Salzton Formation and the Zechsteinkalk Formation, at the southern margin of the Southern Permian Basin. Equivalent strata in northeastern England are known as the Edlington Formation (Smith et al. 1986; Smith 1989).

**Name.** From Blakeney Point on the Norfolk coast.

**Type section**

53/7-2: 1541-1591.5 m (5056-5222 ft)

**Reference section**

52/5-1IX: 1472-1525 m (4830-5003 ft)

**Lithology**

The Blakeney Formation consists of mudstones with interbedded thin anhydrites and localized thin sandstones. The mudstones are commonly dolomitic and anhydritic and usually red-brown, but locally grey or mottled with grey and pale green. They vary from soft to firm, laminated and subfissile to amorphous and waxy. The anhydrite beds vary from soft, white and amorphous to pale grey, microcrystalline or sucrosic. The sandstones reach 4 m thick and are described as white to grey, fine to medium grained, poorly sorted and cemented with dolomite.

**Upper boundary**

The top of the Blakeney Formation is usually marked by a downward change from grey mudstone of the Grauer Salzton Formation to interbedded white amorphous anhydrite and red-brown mudstone. It typically coincides with a downward decrease in gamma values and an increase in velocity.

**Lower boundary**

The base of the Blakeney Formation is marked by a downward change from red mudstones to buff dolomite of the Zechsteinkalk Formation. It is characterized by a downward decrease in gamma values and an increase in velocity.

**Distribution and thickness**

The Blakeney Formation is present across the South Hewett Shelf area, and forms a marginal facies to the Southern Permian Basin. Like the Edlington Formation (formerly Middle Marls of Smith et al. 1974), the Blakeney Formation is roughly coextensive with the flat shelf of the Z1 carbonates (Smith 1980). The Blakeney Formation is about 50 m thick.

**Regional correlation**

In the Dutch sector of the Southern North Sea, lateral equivalents of the Blakeney Formation are included in the Zechstein Fringe Formation (NAM & RGD 1980). At outcrop in the 'Yorkshire Province', laterally equivalent strata are included in the Edlington Formation (table 1 in Smith et al. 1986).

**Genetic interpretation**

By analogy with the Edlington Formation, the Blakeney Formation accumulated in a range of alluvial plain, aeolian, lagoonal and marginal marine environments (Smith 1989).

**Age**

Late Permian.

**References**


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The term Grauer Salzton Formation was first applied to the UK offshore area by Rhys (1974) for a thin unit of marine mudstone that overlies between the Deckanhydrit Formation and the Plattendolomit Formation. This usage is retained in this study, although the Deckanhydrit is included here as an informal sub-unit within the Stassfurt Halite Formation. The Grauer Salzton Formation represents the marine transgression at the base of the Z3 cycle.

**Name.** From the old German stratigraphic term.

**UK reference sections**
47/15-1: 2423.5-2434m (7958-7975ft)
49/26-4: Rhys 1974, table 2, fig. 3
1744.5-1745.5m (5723-5727ft) (revised depths).

**Lithology**

The Grauer Salzton Formation consists of pale to dark grey, locally black and laminated, illitic, unsaline mudstones. Chlorite and kaolinite and subsidiary minerals in the mudstones (Taylor & Colter 1975), which are usually described on composite logs as soft and sticky. Locally the mudstones are silty (e.g. 48/7b-4, Panel 3) or dolomitic and marly with various gamma-ray and velocity log signatures are recorded, including a simple gamma-ray / low velocity spike, upward-increasing gamma values (e.g. 47/15-1), upward-decreasing gamma values (e.g. 42/10-1, Panel 3) and erratic gamma values (e.g. 40/17-1, not illustrated).

**Upper boundary**

In sections around the basin margins, the top of the Grauer Salzton Formation is normally defined by a downward change from grey, microcrystalline, partly pelleted or laminated anhydritic dolomite of the Plattendolomit Formation to grey mudstone. It is typically marked on wireline logs by a sharp downward increase in gamma-ray values and a decrease in velocity. In the basin centre, the Grauer Salzton Formation is overlain by white to grey, amorphous or microcrystalline anhydrite with bands of dolomite of the Plattendolomit Formation (e.g. 42/10-1, Panel 3) or anhydrite of the Plattendolomit/Hauptdolomit formations (e.g. 44/11-1, Panel 3). This boundary is also marked by a downward increase in gamma-ray values and a decrease in velocity.

**Lower boundary**

The base of the Grauer Salzton Formation is normally defined by a downward change from pale to dark grey, illitic mudstone to anhydritic-capped (Deckanhydrit) halite of the Stassfurt Halite Formation (e.g. 36/26-1, Panel 2). It is marked on wireline logs by a downward decrease in gamma-ray values and an increase in velocity. Where the Deckanhydrit is absent, the Grauer Salzton Formation rests directly on halite or interbedded halite, anhydrite, polyhalite, carnallite and kieserite of the Stassfurt Halite Formation. At the southern basin margin, the Grauer Salzton Formation locally rests on anhydritic red-brown mudstones of the Blakeney Halite Formation (e.g. 53/1-2, Panel 45). This boundary is marked by a downward decrease in gamma-ray values and an increase in velocity.

**Distribution and thickness**

The Grauer Salzton Formation is present throughout much of the Southern North Sea Basin. It is, however, absent from the Mid North Sea High and the South Hewett Shelf/London-Brabant Platform. It is also locally absent in the basal areas due to local halokinesis which has disturbed the normal stratigraphic succession. The Grauer Salzton Formation is typically 1 to 3m thick, but locally reaches over 7m (e.g. 47/15-1).

**Regional correlation**

In the subsurface of the ‘Yorkshire Province’, argillaceous beds equivalent to the Grauer Salzton Formation are included at the base of the Brotherton (Magnesian Limestone) Formation (Smith et al. 1980) (formerly the Upper Magnesian Limestone of Smith et al. 1974). However, Smith (1989) informally separated the Grauer Salzton Formation from the Brotherton Formation. Equivalent strata in the Dutch sector of the Southern North Sea are known as the Grey Salt Clay Member of the Zechstein 3 Formation (NAM & RGD 1980).

**Genetic interpretation**

The mudstones of the Grauer Salzton Formation are believed to have accumulated in an extensive, shallow sea which transgressed over a salt and gypsum flats of the Stassfurt Halite Formation (Smith 1980, Smith 1989). Smith (1980) postulated that the dissolution of the Stassfurt Halite Formation at the beginning of the marine incursion may have resulted in initially high salinities in the marine waters which deposited the Grauer Salzton Formation.

**Age**

Late Permian.

**References**


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The term Grenzanhydrit Formation was first applied in the UK Southern North Sea by Rhys (1974) for a thin unit of anhydrite lying between the Aler Halite Formation and the Bunter Shale Formation. The base of the Grenzanhydrit Formation is believed to mark the base of the relatively minor Z3 cycle (Smith 1980).

Name
From the old German stratigraphic term.

UK reference sections
36/26-1: 975.5-982.5m (3200-3224ft)
47/13-2: 2208-2212m (7244-7257ft)
36/26-1: 1526.5-1527.5m (5009-5012ft)

Lithology
The Grenzanhydrit Formation consists of white, pale grey and orange or red-brown anhydrite that is variously described as soft and amorphous or hard and micro-crystalline, sometimes friable, brittle or sucrosic. Locally the Grenzanhydrit Formation contains a unit of red-brown and grey anhydritic claystone and mudstone (e.g. 47/13-2) or white, yellow or red, clear to opaque halite (e.g. 47/15-1, not illustrated).

Upper boundary
The top of the Grenzanhydrit Formation is normally marked by a sharp downward change from red-brown anhydritic mudstone and siltstone of the Bunter Shale Formation to white and pale grey anhydrite. It coincides with a sharp downward increase in velocity and density and a sharp decrease in gamma values.

Lower boundary
The lower boundary of the Grenzanhydrit Formation is normally marked by a sharp downward change from white and pale grey anhydrite to halite, K/Mg salts and local, red-brown, saliferous mudstones of the Aller Halite Formation. It coincides with a downward decrease in density and velocity and an increase in gamma values.

Distribution and thickness
The Grenzanhydrit Formation is widely distributed across the Southern North Sea Basin. Its thickest development is around the northern margin where it reaches 5-8m (e.g. 36/26-1). Sections of 2-5m thickness occur over much of the western and southern parts of the basin (e.g. 47/13-2), thinning to 1m or less close to the southern feather-edge (e.g. 49/26-4; Panel 4N). Over the central part of the basin, the formation is usually less than 2m thick, but is locally absent or below wireline-log resolution.

Regional correlation
Equivalent strata in the ‘Yorkshire’ and ‘Durham’ provinces are termed the Littlebeck Anhydrite Formation (Smith et al. 1986). Laterally equivalent strata in the Dutch sector of the Southern North Sea Basin are included in the Z4 Salt Member of the Zechstein 4 Formation (NAM & RGD 1980), although in North Germany and Holland correlative strata of the Grenzanhydrit Formation are termed the Ohre Anhydrite (Smith 1989).

On the Mid North Sea High, the Grenzanhydrit Formation passes into undifferentiated anhydrites of the Turbot Anhydrite Formation (Cameron 1993) (Panel 1). On the South Hewett Shelf, it passes into red-brown mudstones and anhydrites of the newly defined Scott Head Formation (Panel 4S).

Genetic interpretation
Smith (1980) has interpreted the Grenzanhydrit Formation as the deposits of a final, but short-lived, end-Permian expansion of the basin-centre saline play. Continental facies had already been established beyond the limit of the Grenzanhydrit transgression, and these spread rapidly across the whole of the basin after the end of the Permian.

Age
Late Permian.

References
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Deegan & Scull (1977) introduced the term Halibut Bank Formation for undifferentiated dolomites which, with minor limestones and mudstones, form a lower division of the Zechstein Group in the Moray Firth. This unit was revised in Part 4 of this series (Cameron 1993) and renamed the Halibut Carbonate Formation. As redefined, the Halibut Carbonate Formation comprises both the carbonate and anhydrite components of the Z1 cycle of the Northern Permian Basin, together with basal mudstones and carbonates of the Z2 cycle. These carbonates and anhydrites are respectively designated the Argyll Carbonate, Iris Anhydrite and Innes Carbonate members. A brief description of the Halibut Carbonate Formation is included here since it extends onto the Mid North Sea High in Quadrants 37, 38, and 39, flanking the northern border of the Southern Permian Basin.

In many sections, the Halibut Carbonate Formation consists of two carbonate units separated by a unit of anhydrite (e.g. 38/3-1, Panel 1), in others it consists of carbonate alone (e.g. 39/1-1, Panel 1). The Argyll (Z1) and Innes (Z2) carbonate members are generally described as comprising pale grey and pale brown dolomite and minor dolomitic limestones. However, their variable gamma-ray values suggest the presence also of sporadic laminae of mudstone or sapropelic dolomite. The Iris Anhydrite Member consists of white, pale pink or beige anhydrite.

The Halibut Carbonate Formation overlies basal Upper Permian mudstones of the Kupferschiefer Formation, or locally oversteps these to rest on Lower Permian desert sediments or pre-Permian strata. It is generally overlain conformably by the Turbot Anhydrite Formation and passes southwards into the carbonate-evaporite cycles of the Anglo-Dutch Basin.

The carbonates of the Halibut Carbonate Formation were deposited when oceanic waters from the Boreal Ocean circulated freely in the Northern Permian Basin. This occurred in two separate phases, following the first (Z1) and second (Z2) regional transgressions. The Iris Anhydrite Member precipitated during the latter stages of the Z1 cycle, when restricted circulation of the Boreal Ocean led to an increase of salinity, particularly around the margins of the basin.

References


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HAUPTANHYDRIT FORMATION

The term Hauptanhydrit Formation was first applied to the UK offshore area by Rhys (1974) for a unit of white to pale grey anhydrite that lay between the Plattendolomit Formation and the Leine Halite Formation. This definition is retained in this report. It represents the anhydritic phase of the Z3 cycle.

Reference

Name. From the old German stratigraphic term.

UK reference sections
41/25a-l: 1238-1258m (4061-4127ft)
43/26-5: 2650-2655m (8694-8711ft)
48/13-2A: 1978-2008.5m (6490-6590ft)
49/26-4: 1691.5-1695.5m (5550-5563ft) (revised depths)
Lithology
The Hauptanhydrit Formation consists of white or pale grey anhydrite. It is often described as soft and amorphous, or microcrystalline and hard (e.g. 41/25a-l). Locally, minor intercalations of yellow-brown, microcrystalline dolomite are recorded (e.g. 49/25-1, not illustrated). Thin argillaceous laminae have been noted in a number of wells. At its extreme landward margin, the Hauptanhydrit Formation includes interbedded soft, grey and dark grey mudstone (e.g. 53/2-2, not illustrated) and passes laterally into grey, dark grey and red-brown mudstone with anhydrite interbeds of the Blakeney Formation (e.g. 55/1-1, Panel 45 and 53/1-2, Panel 48). Marginal facies of the Z3 anhydrites have been cored in many boreholes in northeast England, where they are mainly composed of nodular and cumuloid anhydrite interbedded with laminated anhydrite (Smith 1989 and references therein). In more basinal sections, a thin unit of halite up to about 4m thick locally occurs at the base of the Hauptanhydrit Formation (e.g. 43/26-5 and 48/13-2A).

Upper boundary
The top of the Hauptanhydrit Formation is normally marked by a sharp downward change from white to clear and pink halite of the Leine Halite Formation or undivided Zechstein salt to white or pale grey anhydrite and dolomitic anhydrite. It is characterized on wireline logs by a sharp downward increase in velocity and density. At the extreme margins of the Hauptanhydrit Formation, where it includes a significant proportion of mudstone, the log character associated with this boundary becomes variable (e.g. 53/1-1, Panel 4N).

Lower boundary
The lower boundary of the Hauptanhydrit Formation is usually marked by a sharp or gradual downward change from white or pale grey anhydrite to grey, microcrystalline dolomite (e.g. 41/25a-l) or anhydritic dolomite of the Plattendolomit Formation. It is marked on wireline logs by a downward decrease in density, an increase in gamma-ray values and commonly an increase in velocity (e.g. 41/25a-l). In some sections (e.g. 42/10-1) the underlying Plattendolomit Formation consists of interbedded anhydrite and dolomite, but its significantly higher argillaceous content sometimes serves to distinguish it from the Hauptanhydrit Formation. Where a thin unit of halite occurs at the base of the Hauptanhydrit Formation (e.g. 43/26-5 and 48/13-2A), the lower boundary with the Plattendolomit Formation is characterized by a sharp downward increase in velocity. However, in some basinal sections the Hauptanhydrit Formation is inseparable from the Plattendolomit Formation.

Distribution and thickness
The Hauptanhydrit Formation is widely distributed across the Southern Permian Basin and passes northwards into the Turbot Anhydrite Formation on the Mid North Sea High (Cameron 1993). Generally, the Hauptanhydrit Formation is thicker in more marginal sections, with thin developments in the basin centre (e.g. 42/10a-l, p.91). However, it locally shows dramatic and complex thickness variation over relatively short distances. For example, it reaches over 45m thick in 49/24-4 (not illustrated), but is less than 3m thick in the nearby well 49/23-2 (not illustrated).

Regional correlation
In northeast England, equivalent strata are designated the Billingham (Anhydrite) Formation (Smith et al. 1986) (formerly the Billingham Main Anhydrite Formation of Smith et al. 1974). In the Dutch sector of the Southern North Sea Basin, laterally equivalent strata are defined as the Z3 Main Anhydrite Member of the Zechstein 3 Formation. Where the combined carbonate and anhydrite units of the Zechstein 3 cycle are clearly separable from the underlying and overlying units but cannot themselves be separated, equivalents of the Hauptanhydrit Formation are included in the Z3 Anhydrite-Carbonate Member (NAM & RGD 1980).

The Hauptanhydrit Formation passes northwards into the Turbot Anhydrite Formation on the Mid North Sea High (Cameron 1993). On the South Hewett Shelf, the Hauptanhydrit Formation probably passes laterally into the basal Scolt Head Formation.

Genetic interpretation
The Z3 anhydrites have been cored in many boreholes in northeast England, and this evidence suggests that they were deposited in an exceptionally broad coastal sabkha (Smith 1980). The lithology and depositional environment of the Hauptanhydrit Formation are less well known in the centre of the Southern North Sea. Smith (1980) suggested that the basin-floor anhydrites could have accumulated either by precipitation from brine which was between 60 and 80m deep in the centre of the basin, or by basinward extension of the sabkha facies across this area following a 60 to 80m fall in sea level.

Age
Late Permian.

References
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HAUPTDOLOMIT FORMATION

The term Hauptdolomit Formation was first applied to the UK offshore area by Rhys (1974) for a unit of calcitic and anhydritic dolomite and limestone that lies between the Werraanhydrit and Basalanhydrit formations. This definition is retained here. It represents the carbonate phase of the second Zechstein cycle and includes thick, shelf/slope and thin, basinal facies.

Rhys (1974) and Clark (1986) recognized distinct platform, slope and basinal lithofacies within the Hauptdolomit Formation and Clark (1986) noted that in German lithostratigraphic nomenclature, the term Hauptdolomit is generally restricted to the marginal platform facies. Rhys (1974) and Clark (1986) informally introduced the German stratigraphic terms ‘Stinkdolomit’ or ‘Stinkkalk’ for the slope facies, and ‘Stinkschiefer’ for the thin basinal facies.

According to Taylor (1990), the ‘Stinkschiefer’ is overlain in basinal sections by the less argillaceous ‘Stinkkalk’. On the basis of wireline log correlations, Taylor (1980) postulated that in the basin-floor facies the lower part of the Hauptdolomit Formation is laterally equivalent to the upper Werraanhydrit platform facies. However, wireline log correlation by Cameron et al. (1992) suggests that all of the Hauptdolomit Formation can be referred to the Z2 cycle.

References


Name. From the old German stratigraphic term.

UK reference sections

41/8-1: 917.5-1010m (3010-3313ft)
48/7b-4: 3224-3245.5m (10577-10648ft)
49/25-1: 2491-2541 m (8172-8737ft)
49/26-4 (Rhys 1974, table 2, fig.3): 1807-1855m (5928-6086 ft)
(revised depths)
Lithology
The lithofacies and thickness of the Hauptdolomit Formation were largely controlled by depositional environment, with thick shelf facies passing into a thin basinal facies. Shelf sections are composed mainly of very fine detritic, peloidal, bioclastic and pisolithic grainstones, and hard, microcrystalline carbonate mudstones (e.g. 41/8-1), and locally contain a restricted fauna of bivalves, gastropods, foraminifera and ostracods. Large pisoliths and algal sheets characterize the barrier facies developed near the shelf edge. Locally, the shelf facies overlies more argilaceous slope facies and this is reflected in a downward increase in gamma-ray values (e.g. 48/22-2, Clark 1986, fig. 19). The shelf facies consist largely of dark, thinly bedded and slumped, locally argillaceous and anhydritic, dolomitized lime mudstones, together with pelleted and burrowed, structureless, argilaceous, dolomitized lime mudstones (e.g. 48/22-2, Clark 1986, fig. 19). Lenses and beds of oolitic and bioclastic grainstones occur in both the bedded and structureless slope deposits (Clark 1986). The base of the basin-floor facies is made up of dark, finely laminated, organic-rich, argilaceous, carbonate mudstones (e.g. 44/21-1, p. 107). Coarsely crystalline limestone predominates at the centre of the basin floor, and microcrystalline dolomite around its margins. Anhydrite laminates occur up to 2m above the base, and recur near the top of the basin-floor carbonates (Taylor 1989).

Upper boundary
In shelf sections, the top of the Hauptdolomit Formation is normally defined by a downward change from white to pale grey anhydrite with beds and stringers of dolomite of the Basalanhydrit Formation to pale grey to pale brown dolomite and anhydritic dolomite. It is usually marked on wireline logs by a downward decrease in density and sometimes by an increase in gamma values (e.g. 41/8-1, 48/7-4). Commonly it also coincides with a downward decrease in reflectivity (e.g. 41/8-1), but locally, the reverse is evident (e.g. 42/3-1, Panel 2 & 49/26-4). Locally, the boundary is made gradational with the interbedded nature of the dolomite/anhydrite sequence and here it is taken at the top of the dolomite/anhydrite laminated section (e.g. 48/3-4, Panel 4N).

In basin sections, the top of the Hauptdolomit Formation is normally defined by a downward change from white, amorphous anhydrite of the Basalanhydrit Formation to dark, laminated, organic-rich dolomite. It is characterized on wireline logs by a downward decrease in density and commonly an increase in gamma-ray values and velocity. In basin sections where the Basalanhydrit Formation is absent, the top of the Hauptdolomit Formation is taken marked by a downward change from halite and polyhalite of the Stassfurt Halite Formation to dark, bituminous dolomite (e.g. 47/8-1, Panel 2). It is marked on wireline logs by a sharp downward increase in velocity.

Lower boundary
In shelf sections, the base of the Hauptdolomit Formation is normally marked by a downward change from pale grey or pale brown dolomite to white or grey anhydrite of the Werraanhydrit Formation. It coincides with a downward increase in density and typically by a decrease in gamma-ray values (e.g. 49/26-4). In basin sections, the base of the Hauptdolomit Formation is absent, the top of the Hauptdolomit Formation is taken marked by a downward change from bituminous carbonate mudstone to interlaminated anhydrite and dolomite or limestone of the Werraanhydrit Formation. It coincides with a downward increase in density and a gradual decrease in gamma-ray values immediately below a high-gamma spike (e.g. 42/10-1 Panel 3 & 44/21-1, p.107 and Taylor 1980, fig. 5).

Lithostratigraphic subdivision
Slope and basinal facies have been informally designated ‘Stinkdolomit’/‘Stinkkalk’ and the ‘Stinkschichter’, respectively (e.g. Taylor 1990), but these terms are not applied in this report.

Distribution and thickness
The Hauptdolomit Formation is present throughout most of the Southern North Sea. It is, however, absent from the London-Brahabit Platform, which was a palaeohigh, and across the marginal platform of the Zechstein Kalk Formation, where the ‘Yorkshire Province’ is directly overlain by the Basalanhydrit Formation (e.g. 53/1-1, Panel 48). On the Mid North Sea High, the northwestern extent of the Hauptdolomit Formation has not been encountered by drilling, but in the northern parts of quadrants 37, 38 and 39, equivalent strata are included in the Halibut Carbonate Formation (Cameron 1993) (e.g. 38/3-1 Panel 1).

Across a 10 to 40km-wide shelf around the southern margin of the basin, the Hauptdolomit Formation is typically about 25 to 50m thick, but locally reaches over 90m. Thick, shelf sections are also locally present on the margins of the Mid North Sea High (e.g. 38/6-1 Panel 1 and 41/8-1, Panel 2). In the basinal sections, however, the Hauptdolomit Formation is typically about 10 to 15m thick.

Regional correlation
Carbonate rocks equivalent to the Hauptdolomit Formation occur in eastern England, offshore and in the Netherlands, and are widespread in the Northwest European Zechstein Basin (Taylor 1990). Equivalents of the Hauptdolomit Formation in the ‘Yorkshire Province’ are included in the Kirkham Abbey Formation (Smith et al. 1974). In the ‘Durham Province’, correlative rocks are the Roker (Dolomite) Formation and the Concretionary Limestone Formation (Shipton et al. 1986). In the Netherlands offshore, equivalent strata are defined as the Z2 Carbonate Member of the Zechstein 2 Formation (NAM & RGD 1980). Around the margins of the basin, the Hauptdolomit Formation may pass laterally into continental clastics of the Blakeney Formation. Smith (1989) demonstrates a similar lateral facies transition in eastern England from the Kirkham Abbey Formation to the Edlington Formation.

Genetic interpretation
The Hauptdolomit Formation represents the carbonate phase of the Z2 cycle. It was initiated by a freshening of the Zechstein Sea, which ended gypsum precipitation and recommended carbonate deposition. The presence of a broad asymmetrical shelf of Z1 deposits resulted in the immediate creation during Z2 of shelf, slope and basin environments. The Hauptdolomit shelf facies is mainly located on top of the platform of the Werraanhydrit Formation, but is locally more extensive, due to progradation into the basin. It includes oolites, bioclastic grainstones and carbonate mudstones that accumulated in a range of shallow marine environments. Landward, these deposits pass into pisolithic grainstones which are typical of a marginal sabbka (Clark 1986). The slope facies includes redeposited shelf deposits and slumped masses. Deposits of the upper slope contain a low diversity bivalve-ostracod fauna, but the lower slope facies are usually devoid of a shelly fauna. The finely laminated nature of the thin, organic-rich, basin-floor facies, together with the absence of a shelly fauna indicates a starved, anoxic environment, and Smith (1980) suggested that water depths at the foot of the marginal slope may have exceeded 200m.

Age
Late Permian

References
DISTRIBUTION MAP

HAUPTDOLOMIT FORMATION

LITHOLOGY
- Mudstone / siltstone
- Limestone
- Dolomite
- Halite
- Dolomite, argillaceous
- K / Mg salts and halite

See also Correlation Panel II

See also Correlation Panel III

See also Correlation Panel IV
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The Kupferschiefer Formation is a widespread, organic-rich mudstone unit deposited during the Late Permian in the Zechstein Basin. It is typically 1 to 3 m thick and provides an excellent wireline log marker characterized by high gamma-ray values and a sharp downward increase in velocity. The formation is overlain by white to pale grey anhydrite of the Werraanhydrit Formation and underlain by dark grey or black bituminous mudstone. The stagnant waters may have developed after seasonal blooms of phytoplankton, and biological fixation may account for the characteristically high metal content in the Kupferschiefer Formation.

References


LEINE HALITE FORMATION

The term Leine Halite Formation was first applied in the UK Southern North Sea by Rhys (1974) for a unit of halite and potassium salts lying between the Hauptanhydrit Formation and the Roter Salzton Formation. This definition is followed here. The Leine Halite Formation marks the main evaporitic phase of the Z3 cycle. In areas of intense halokinetic deformation, the Leine Halite Formation passes laterally into undifferentiated Zechstein salts.

References


Name. From the old German stratigraphic term.

UK reference sections

36/26-1: 1043.5-1071m (3423-3513ft)
42/10a-l: 1711.5-1970.5m (5615-6465ft)
49/26-4 (Rhys 1974, table 2, fig. 3): 1596.5-1691.5m (5238-5550ft)
50/21-1: 1744.5-1903m (5723-6244ft)
Lithology
The Leine Halite Formation consists of colourless, white, grey or pink, clear to translucent, locally opaque, generally hard and crystalline halite with interbedded and intergrown pink to red, opaque, hard K/Mg salts, principally sylvite and carnallite with some polyhalite. Minor beds of white to grey, soft to moderately hard, crystalline to amorphous anhydrite and red-brown to pale grey-brown, locally silty, saliferous, soft and amorphous mudstone have been recorded.

Upper boundary
The top of the Leine Halite Formation is defined by a downward change from red-brown, halite and K/Mg salt bearing mudstones of the Roter Salzton Formation to colourless, white, grey or pink halite with pink to red K/Mg salts. It is characterized by a sharp downward increase in velocity. Where halite occurs at the top of the Leine Halite Formation, the gamma log shows a sharp downward decrease in values (e.g. 36/26-1 and 41/25a-1, Panel 2). In wells where K/Mg salts occur at the top of the formation, the gamma log shows a sharp downward increase in values (e.g. 42/10-1 and 49/22-3, Panel 4N).

Lower boundary
The base of the Leine Halite Formation is normally defined by a sharp downward change from colourless or pink halite to white to pale grey anhydrite and dolomitic anhydrite of the Hauptanhydrit Formation. This boundary is characterized on wireline logs by a sharp downward increase in velocity and density. Near the basin margin, where the underlying Hauptanhydrit Formation includes a significant proportion of mudstone, there is a less sharp change in velocity and density (e.g. 53/2-2, not illustrated). The gamma log generally shows a slight, occasionally marked, downward increase in values across the formational boundary, although in some wells there is no significant log break (e.g. 36/26-1). Where the Hauptanhydrit Formation is locally absent the Leine Halite Formation sits directly on the Plattendomlit Formation (e.g. 47/8-1, Panel 2).

Lithostratigraphic subdivision
An informal threefold subdivision of the Leine Halite Formation is recognized here (termed units L1, L2 and L3), on the basis of relative amounts of K/Mg salts and the associated wireline log signatures. These units broadly equate to the four units of the Boulby (Halite) Formation recognized by Smith & Crosby (1979). Unit L1 corresponds to Boulby units A and B, as rarely can these be separated in the Southern North Sea. Unit L2 equates to Boulby unit C, that is also known as the Boulby Potash Member, and unit L3 corresponds to Boulby unit D (Smith & Crosby 1979).

Unit L1, at the base of the formation, consists of relatively pure halite (e.g. 49/26-4), locally with thin beds of anhydrite occurring in its basal or middle parts (e.g. 42/10-1, 50/21-1). It is characterized by uniformly low gamma values and low velocity (e.g. 49/26-4). Unit L2 consists of varying proportions of K/Mg salts and halite. Sylvite is the principal potassium salt in northeast England (Smith & Crosby 1979) and sylvite and carnallite are commonly recorded in the Southern North Sea. Unit L2 is characterized by a spiky, high-gamma signatures. Its base is defined by a sharp downward decrease in gamma values and a downward increase in velocity (e.g. 42/10-1, 50/21-1). Unit L3 consists of a thin, relatively pure halite. Its base is defined by a sharp downward increase in gamma values and a downward decrease in velocity (e.g. 50/21-1).

Distribution and thickness
The Leine Halite Formation is present throughout much of the Southern North Sea. Unit L1 is the most widespread sub-unit, and units L2 and L3 occupy successively more restricted areas. The Leine Halite Formation is up to around 300m thick, although its depositional thickness is difficult to determine in the central part of the basin where sections have been extensively disrupted by halokinesis. Unit L1 thicknesses range from around 50m on the coast of Yorkshire (Smith 1980) to approximately 200m in the centre of the Southern North Sea Basin. The limit of unit L2 lies 10-20km basinward of the limit of unit L1 and it thickens from 11m on the Yorkshire coast (Smith 1980) to approximately 100m in the centre of the basin. The limit of unit L3 lies between 40km and 80km basinward of the limit of unit L1 and the unit is 3-11m thick.

The Leine Halite Formation is absent over much of the Mid North Sea High.

Regional correlation
Equivalent strata in the 'Yorkshire' and 'Durham' provinces are termed the Boulby (Halite) Formation (including the Boulby Potash Member) (Smith et al. 1974, Smith et al. 1986). Equivalent strata in the Dutch sector of the Southern North Sea Basin are known as the Z3 Salt Member of the Zechstein 3 Formation (NAM & RGD 1980).

In the central part of the Southern North Sea Basin, evaporites of the Leine Halite Formation are locally inseparable from those of the preceding and succeeding Zechstein cycles due to the effects of halokinesis. Where this is the case, Z3 salts are included in a unit of undifferentiated Zechstein salt (e.g. 38/24-1). The Leine Halite Formation probably also passes into the Shearwater Salt Formation in a north-trending channel-like feature crossing the Mid North Sea High in Quadrant 37 (Jenyon et al. 1984; Cameron 1993) (e.g. 37/12-1, not illustrated). In the South Hewett Shelf area, the Leine Halite Formation passes laterally into mudstones, siltstones and anhydrites of the newly defined Scolt Head Formation (Panel 4S).

Genetic interpretation
The Leine Halite Formation was deposited on extensive marginal salt flats that were generally aerially exposed but suffered regular flooding by hypersaline seawater; a more or less permanent playa is likely to have existed in the centre of the basin (Smith 1980). The compositional changes recorded in the evaporites of units L1 and L2 document overall increasing levels of salinity. The relatively pure halite of unit L3 is interpreted as the deposit of a brief expansion of the playa due to an influx of fresher water into the basin.

Age
Late Permian

References
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**PEGMATITANHYDRIT FORMATION**

The term Pegmatitanhydrit Formation was first applied in the UK Southern North Sea Basin by Rhys (1974) for a thin unit of grey to red-pink anhydrite lying between the Roter Salzton and Aller Halite formations. In contrast to Rhys (1974), Cameron et al. (1992) regarded the base of the Pegmatitanhydrit Formation as marking the transgressive base of the Z4 cycle.

### Name

From the old German stratigraphic term.

### UK reference sections

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<th>Section</th>
<th>Interval</th>
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</thead>
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<td>41/25a-1</td>
<td>1165.5-1177.5m (3834-3863ft)</td>
</tr>
<tr>
<td>49/26-4</td>
<td>(Rhys 1974, table 2, fig. 3)</td>
</tr>
</tbody>
</table>

### Lithology

The Pegmatitanhydrit Formation consists of distinctive, white to grey, occasionally pale orange anhydrite that is variably soft, firm or hard, amorphous or crystalline (sucrosic) to microcrystalline. Locally the formation may contain interbedded halite (e.g. 47/13-2, not illustrated) or dark red-brown mudstone (e.g. 49/21-1, not illustrated).

#### Upper boundary

The top of the Pegmatitanhydrit Formation is normally marked by a sharp downward change from halite of the Aller Halite Formation to white-grey anhydrite (e.g. 47/13-2, p.61.). It is characterized on wireline logs by a sharp downward increase in density and velocity. The gamma log response to this boundary is variable, although there is commonly no significant downward change. Locally, a slight downward decrease is seen on the gamma log due to the presence of high gamma, argillaceous/potassic halite at the base of the Aller Halite Formation (e.g. 41/25a-1 and 49/26-4).

#### Lower boundary

The lower boundary of the Pegmatitanhydrit Formation is defined by a sharp downward change from white-grey anhydrite to red-brown, saliferous mudstones of the Roter Salzton Formation. It coincides with a sharp downward decrease in density and velocity and a downward increase in gamma-ray values. Where the Pegmatitanhydrit Formation is thinly developed and/or the underlying Roter Salzton Formation contains abundant halite and potassium salts the boundary is less well defined, particularly on the gamma log (e.g. 44/22-3, Panel 3).

### Distribution and thickness

The Pegmatitanhydrit Formation is widely distributed across the Southern North Sea Basin. It is generally around 9 m thick in the southeast where the maximum thickness reached is 5m. It is locally absent or not recognisable in the centre of the basin due to deformation resulting from halokinasis (e.g. 43/26-5, Panel 3), but where present the formation is commonly only thinly developed.

### Regional correlation

The Pegmatitanhydrit Formation passes northwards into the Turbot Anhydrite Formation (Cameron 1993) on the eastern part of the Mid North Sea High. Equivalent strata to the south, in the South Hewett Shelf area, are contained in the mudstones, siltstones and thin anhydrites of the newly defined Scott Head Formation. In the subsurface of the ‘Yorkshire’ and ‘Durham’ provinces, equivalent strata are known as the Sherburn Anhydrite Formation (Smith et al. 1986; Smith 1989); these beds were previously designated the Upper Anhydrite Formation (Smith et al. 1974). Equivalent strata in the Dutch sector of the Southern North Sea Basin are defined as the Z4 Pegmatite Anhydrite Member of the Zechstein 4 Formation (NAM & RGD 1980).

### Genetic interpretation

The Pegmatitanhydrit Formation probably formed in a shallow, hypersaline lagoonal sea with a restricted marine connection (Cameron et al. 1992). The laterally equivalent Sherburn Anhydrite Formation is believed to have been precipitated as selenitic bottom-growth gypsum and contains layers of former gypsarenite that may have resulted from current and storm reworking (Smith 1989).

#### Age

Late Permian.

### References


PLATTENDOLOMIT FORMATION

The term Plattendolomit Formation was first applied to the UK offshore area by Rhys (1974) for a unit of pale to dark grey argillaceous and locally anhydritic dolomite that lay between the Grauer Salzton Formation and the Hauptanhydrit Formation. It represents the carbonate phase of the Z3 cycle and includes thick shelf and thin basinal facies.

Name. From the old German stratigraphic term meaning 'Platy Dolomite'.

UK reference sections
41/25a-1: 1258-1302m (4127-1272ft)
42/10a: 1975.5-2010.5m (6482-6596ft)
49/26-4 (Rhys, 1974, table 2, fig. 3): 1695.5-1744.5m (5563-5723ft)
53/7-2: 1513-1540m (4964-5052ft)

(metric conversion revised)
Lithology

In shelf sections, the Plattendolomit Formation consists dominantly of dark to pale grey or tan, hard, microcrystalline, locally argillaceous, partly pelleted and anhydritic dolomite mudstones. Thin partings of grey mudstone are common. The dolomite is locally pyritic and commonly contains secondary, soft, white, amorphous anhydrite (e.g. 48/30-3, not illustrated). Oolitic grainstones occur locally, particularly in the upper parts of marginal sections (e.g. 36/26-1, Panel 2 and 48/30-4, Panel 4N). A restricted fauna, dominated by two species of thin-sheled bivalves and the tubular calcareous alga Calcinema permiana is confined to sections within about 50 km of depositional limit. Where the algal tubes are present, they form layers up to a few centimetres thick consisting almost entirely of horizontal stems; these alternate with thicker layers ofmicrodolomite containing scattered fragments of the alga (Taylor & Colter 1975). The algal tubes have sometimes been mistaken for oolites on some oil company composite logs. Algal-stromatitic dolomite is common at the top of marginal sections and is associated with bands of nodular, displacive anhydrite (Taylor & Colter 1975).

The shelf facies pass basinally into thick, slope facies consisting of dark brown, thinly bedded, unfossiliferous pyrite dolomite that contains abundant laths of replacive anhydrite (Taylor & Colter 1975). Subordinate beds of beige or pale grey limestone are common towards the base (e.g. 49/22-3, not illustrated). Sporadic, thin interbeds of grey, brown or black mudstone and bituminous laminae (e.g. 41/25a-1) are present and generally more common in basal strata. In the basin centre, the Plattendolomit Formation largely consists of white to medium grey, amorphous to cryptocrystalline anhydrite with laminations of bituminous mudstone and argillaceous dolomite (e.g. 42/10-1) and is often inseparable from the Hauptdolomit Formation (e.g. 44/11-1, Panel 3).

Upper boundary

In most shelf and slope sections, the top of the Plattendolomit Formation is defined by a sharp downlap into the underlying Hauptanhydrit Formation to grey microcrystalline dolomite or anhydritic dolomite. It is marked on wireline logs by a downward decrease in gamma-ray values and a decrease in velocity. Where the Hauptanhydrit Formation is locally absent, the Plattendolomit Formation rests directly upon the Stassfurt Halite Formation (e.g. 49/12-3, not illustrated).

Distribution and thickness

The Plattendolomit Formation is widely distributed across the Southern Permian Basin. From a "feather-edge" at its southern depositional limit, the Plattendolomit Formation thickens northwards to about 90m at a weakly developed shelf edge before thinning to about 30m across the basin floor. Although there are few wells bordering the Mid North Sea High, a similar depositional wedge geometry appears to be developed from shelf to basin on the southeastern flank of the structure. On the southeastern flank of the Mid North Sea High, the Plattendolomit Formation passes laterally into the Turbot Anhydrite Formation, where it equates to the Turbot Carbonate unit of Cameron (1993).

Regional correlation

Carbonate rocks equivalent to the Plattendolomit Formation occur in eastern England, offshore the Netherlands and are widespread in the Northwest European Zechstein Basin (Taylor 1990). In the "Yorkshire Province", equivalent strata are included in the Brotherton (Magnesian Limestone) Formation (Smith et al. 1986) (formerly the Upper Magnesian Limestone of Smith et al. 1974) (but see discussion contribution by D.B. Smith in Richter-Bernberg 1986). Equivalent strata in the "Durham Province" are defined as the Seaham Formation (Smith et al. 1974). In the Dutch sector of the Southern North Sea, equivalent strata are designated the Z3 Carbonate Member of the Zechstein 3 Formation (NAM & RGD 1980). Where the Z3 carbonate and Z3 anhydrite can be separated from the under- and overlying strata, but the individual rocks cannot be identified, they are included in the Z3 Anhydrite-Carbonate Member of the Zechstein 3 Formation (NAM & RGD 1980).

According to some authors (e.g. Smith 1980; NAM & RGD 1980), the Z3 carbonate can pass laterally into the Z3 anhydrite in the basin centre. Taylor & Colter (1975), however, considered the Plattendolomit Formation to be entirely older than the Hauptanhydrit Formation, which formed from more concentrated brines. Clark (1986) postulated that the Plattendolomit Formation passes laterally into thin basinal mudstones that are indistinguishable from the Grauer Salzton Formation.

On the southeastern flank of the Mid North Sea High, where sections are relatively condensed and incomplete, strata equivalent to the Plattendolomit Formation are included in the Turbot Carbonate unit of the Turbot Anhydrite Formation (e.g. 38/3-1, Panel 1) (Cameron 1993).

Genetic interpretation

The carbonate and mudstone sections of the Plattendolomit Formation were probably deposited in marine waters varying from a few metres to a few tens of metres deep (Smith 1980). There is no evidence of abnormally high salinities during deposition and the lack of fauna in the thinly bedded slope facies may be partly explained by a lack of turbulence and consequently low nutrient and oxygen supplies (Smith 1988). Sedimentary structures in coeval carbonates in eastern England include low-amplitude ripples, small- to medium-scale cross-lamination and broadly lenticular bedding from which low to moderate energy levels are inferred, although sheets of bioclastic debris may have resulted from periodic storms (Smith 1989). The stromatitic dolomite and interbedded anhydrite at the top of marginal sections are interpreted as sabkha deposits (Taylor & Colter 1975), suggesting that carbonate production had built the shelf up to sea level.

Age

Late Permian.

References


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The term Roter Salzton Formation was first applied in the UK Southern North Sea by Rhys (1974) for a thin unit of red-brown, saline mudstone lying between the Leine Halite Formation and the Pegmatitanhdyrit Formation. The Roter Salzton Formation was placed at the base of the Z4 cycle by Rhys (1974). However, Taylor & Colter (1975) and Cameron et al. (1992) considered it to be a regressive deposit marking the top of the Z3 cycle. Smith (1989) considered the Roter Salzton to have formed between the Z3 and Z4 cycles.

**Name.** From the old German stratigraphic term.

**UK reference sections.**
- 41/25-1: 1177.5-1198m (3863-3900ft)
- 49/26-4 (Rhys 1974, table 2, fig. 3)
- 41/25a-1 (1558-1596.5m (5120-5238ft))

**Lithology.**
The Roter Salzton Formation consists of red-brown, occasionally purple-brown to grey, commonly silty, soft to firm, amorphous to blocky mudstones. The formation contains varying quantities of interbedded clear, colourless to pale pink-orange, massive halite and bright orange-red, opaque, massive, hard potassium and salts (most commonly carnallite). The most salt-enriched sequences occur towards the centre and southeast of the basin (e.g. 49-24-1, not illustrated). Laminates of white to grey anhydrite are recorded locally (e.g. 42-20-1, not illustrated).

**Upper boundary.**
The upper boundary of the Roter Salzton Formation is normally marked by a sharp downward change from white-grey anhydrite of the Pegmatitanhdyrit Formation to red-brown, halite and K/Mg salt bearing mudstones. It is characterized on density and velocity logs by a similar sharp increase in density and velocity below the gamma log. The boundary is less well defined, particularly on the gamma log, where the overlying Pegmatitanhdyrit Formation is thin or absent and the Roter Salzton Formation contains abundant halite and K/Mg salts (e.g. 44/22-3, Panel 3).

**Lower boundary.**
The lower boundary of the Roter Salzton Formation is defined by a downward change from red-brown, saline mudstones to halite and K/Mg salts of the Leine Halite Formation. It is marked by a sharp downward decrease in velocity. Where halite is present at the top of the Leine Halite Formation, the gamma log shows a sharp downward decrease in velocity (e.g. 43/25a-1). In wells where K/Mg salts occur at the top of the Leine Halite Formation, the gamma log shows a sharp downward increase (e.g. 49/22-3, Panel 4N).

**Distribution and thickness.**
The Roter Salzton Formation is present throughout much of the Southern North Sea Basin. It is, however, absent from the Mid North Sea High and is locally absent, or not recognizable, in the centre of the basin, where halokinesis has disturbed the normal stratigraphic succession. The Roter Salzton Formation is typically 10m thick, but locally reaches over 20m (e.g. 47/8-1, Panel 2).

**Regional correlation.**
Strata laterally equivalent to the Roter Salzton Formation in the ‘Yorkshire Province’ and ‘Durham Province’ are respectively known the Carnallitic Marl and the Rotten Marl formations (Smith et al. 1974; Smith et al. 1986). In the Dutch sector of the Southern North Sea Basin, equivalent strata are termed the Red Salt Clay Member of the Zechstein 4 Formation (NAM & RGD 1980). On the southern margin of the basin, the Roter Salzton Formation passes southwards into mudstones and siltstones with thin anhydrites of the newly defined Scolt Head Formation (Panel 4S). The Roter Salzton Formation may be partly equivalent to the Hake Mudstone Member of the Torbet Anhydrite Formation of the Central North Sea (Cameron 1993).

**Genetic interpretation.**
The mudstones of the Roter Salzton Formation were deposited on a coastal plain across which distal alluvial fans prograded into the centre of the basin (Smith 1980). The basinward increase in halite and K/Mg salt content in the Roter Salzton Formation suggests that an extensive, highly saline, shallow playa lake may have been present in the centre of the basin (Smith 1980; Cameron 1992). Some dissolution and leaching of the underlying Leine Halite Formation probably occurred prior to and during the early stages of deposition of the Roter Salzton Formation (Smith 1980).

**Age.**
Late Permian.

**References.**

**Correlation Panel.**
See also Correlation Panel 2
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SCOLT HEAD FORMATION

The term Scolt Head Formation is introduced for a unit of continental and marginal marine, red-brown mudstones and interbedded anhydrites with localized sandstones, that lies between the Bunter Shale Formation and the Plattendolomit Formation at the southern margin of the Southern Permian Basin. Laterally equivalent mudstones and anhydrites in northeast England are known as the Roxby Formation (Smith et al. 1986; Smith 1989).

**Name.** From Scolt Head Island just off the Norfolk coast.

**Type section**
53/14-1: 997.5-1024m (3273-3359ft)

**Reference section**
53/1-2: 1562-1580m (5125-5183ft)

**Lithology**
The Scolt Head Formation consists of mudstones with interbedded anhydrite. Stringers of sandstone are locally present. The mudstones and siltstones are commonly dolomitic and anhydritic and usually red-brown, but locally grey or mottled with grey and pale green. They vary from soft to firm, laminated and subfissile to amorphous and waxy. The anhydrite beds vary from soft, white and amorphous to pale grey, microcrystalline or sucrosic.

**Upper boundary**
The top of the Scolt Head Formation is normally characterized by a downward change from red-brown mudstones to buff dolomite of the Plattendolomit Formation. It normally corresponds to a downward decrease in gamma ray values and an increase in velocity.

**Lower boundary**
The base of the Scolt Head Formation is characterized by a downward change from red-brown mudstones to buff dolomite of the Plattendolomit Formation. It normally corresponds to a downward decrease in gamma ray values and an increase in velocity.

**Distribution and thickness**
The Scolt Head Formation is present in the South Hewett Shelf area, and forms a marginal facies to the Southern Permian Basin. Like the Edlington Formation in eastern England, the Scolt Head Formation is roughly coextensive with the flat shelf of the Z1 carbonates (Smith 1980). The Scolt Head Formation attains a thickness of about 30m.

**Regional correlation**
The Edlington Formation passes laterally into evaporites of the Z3 and later Zechstein cycles in the Anglo-Dutch Basin. In the Dutch sector of the Southern North Sea, lateral equivalents are included in the Lower Bunter Formation (NAM & RGD 1980). At outcrop in the Yorkshire Province, equivalent strata are included in the Roxby Formation (Smith et al. 1986).

**Genetic interpretation**
By analogy with the Roxby Formation, the Scolt Head Formation accumulated in a range of alluvial plain, aeolian, lagoonal and marginal marine environments (Smith 1989).

**Age**
Late Permian.

**References**


The term Shearwater Salt Formation was introduced in part 4 of this revision (Cameron 1993) for thick Upper Permian halite and K/Mg salt dominated sections in the Northern Permian Basin. The Shearwater Salt Formation extends into an embayment of salts that crosses the Mid North Sea High (Jenyon et al. 1984) and a brief description of these sections marginal to the Anglo-Dutch Basin is, therefore, included here.

The Shearwater Salt Formation includes deposits of the Z2, Z3 and Z4 cycles and is generally comprised of halite, but includes significant components of polyhalite, anhydrite, sylvite and carnallite, together with minor amounts of displaced or in situ carbonates and mudstones. It is generally overlain by uppermost Permian anhydrites and minor mudstones forming the Morag Member of the Turbot Anhydrite Formation (e.g. 37/12-1, not illustrated). The top of the Shearwater Salt Formation is defined by the downward incoming of salt and coincides with sharp wireline log breaks. It almost invariably overlies the Turbot Anhydrite Formation and this boundary is defined by the lowest occurrence of salts and the downward incoming of higher-velocity anhydrite. Halokinetic mobilization and partial dissolution of the Upper Permian salt have generally modified primary thickness trends in the Shearwater Salt Formation, which is about 590m thick in 37/12-1 (not illustrated).

Towards the basin margins, the Shearwater Salt Formation passes laterally into Z2, Z3 and Z4 deposits of the Turbot Anhydrite Formation. Its equivalents in the Anglo-Dutch Basin include the Stassfurt, Leine and Aller Halite formations and undivided Zechstein salts of the Z2, Z3 and Z4 cycles.

The halites and K/Mg salts of the Shearwater Salt Formation precipitated during phases of high salinity within the Northern Permian Basin. Carbonate and anhydrite sections within the Shearwater Salt Formation accumulated during periods of relatively low salinity when oceanic waters circulated more freely in the Northern Permian Basin. These periods occurred during the third (Z3) and fourth (Z4) Zechstein transgressions.

References
The term Stassfurt Halite Formation was first applied to the UK offshore area by Rhys (1974) for a unit of halite and potassium salts lying between the Basalanhydrit Formation and the 'Deckanhydrit Formation'. Following Taylor & Colter (1975) and Cameron et al. (1992), the Deckanhydrit is here regarded as a solution residue and included as informal sub-unit within the Stassfurt Halite Formation. The Stassfurt Halite Formation marks the main evaporite phase of the Z2 cycle and forms the thickest salt sequence in the Southern North Sea. In localized areas of intense halokinetic deformation, the Stassfurt Halite Formation passes laterally into undifferentiated Zechstein salts of the Z2, Z3 and Z4 cycles.

References

Name. From the old German stratigraphic term.

UK reference sections
44/11-1: 2747-3360m (9012-11024ft)
47/8-1: 2362-2771m (7750-9091ft)
48/13-2A: 2079.5-2375.5m (6822-7794ft)
49/26-4: 1745.5-1772m (5727-5813ft)
Lithology

The Stassfurt Halite Formation has not generally been cored in the Southern North Sea and lithological information is therefore based largely on drill cuttings, wireline log evidence and analogy with equivalent cored successions of outcrop sections in eastern England (e.g. Colter & Reed 1980). The Stassfurt Halite Formation consists of halite with subordinate interbedded anhydrite, polyhalite and kieserite. Minor amounts of carnallite are also present near the top of the Formation that is generally coarsely crystalline, transparent, translucent, locally coloured orange or pink, and occasionally white and opaque. The anhydrite is interbedded and intergrown with the halite and is generally white and amorphous to microcrystalline. The beds of polyhalite are white to pale grey, occasionally brick red, pink and orange, and amorphous to microcrystalline. A thin unit (usually about 1m thick) of white to pale grey anhydrite (Deckanhydrit) commonly caps the formation. Where seen in cores, it consists of spindle-shaped microcrystalline anhydrite crystals aligned with the bedding.

Upper boundary

The base of the Stassfurt Halite Formation is formed by a downward change from pale grey to grey, illicitic, unfossiliferous marine mudstones of the Grauer Salzton Formation in anhydrite-capped (Deckanhydrit) halite with subordinate anhydrite, polyhalite, kieserite and carnallite. It is marked on wireline logs by a sharp downward decrease in gamma-ray values and an increase in velocity. Locally, the Deckanhydrit is absent and the Grauer Salzton Formation rests directly on halite (e.g. 44/11-1). Where the Grauer Salzton Formation is absent, grey dolomite or anhydrite of the Plattendomelit Formation rests directly on the Stassfurt Halite Formation (e.g. 43/26-5, Panel 3).

Lower boundary

Near basin margins, the base of the Stassfurt Halite Formation is taken at a downward change from dominantly halite to pale grey anhydrite of the Basalanhydrit Formation. It is marked on wireline logs by a sharp downward decrease in velocity and an increase in density (e.g. 49/24-26). In many basinal sections, the Basalanhydrit Formation is absent and the base of the Stassfurt Halite Formation is marked by a downward change from interbedded anhydrite and polyhalite to dark grey dolomite or dolomitic limestone of the Hauptdolomit Formation (e.g. 44/11-1 and 47/8-1). The associated changes in wireline log character are somewhat variable, depending upon whether a widespread polyhalite-rich section, characterized by many, high gamma-ray spikes, is at or near the base of the Stassfurt Halite Formation.

Lithostratigraphic subdivision

An informal threefold subdivision is recognized in the Stassfurt Halite Formation (designated units S1, S2 and S3), on the basis of the relative amounts of anhydrite, polyhalite and kieserite, and the associated wireline log signatures. The Stassfurt Halite units recognized here broadly equate to the three Fordon cycles (comprising units 1-8) of Colter & Reed (1980).

Unit S1 generally consists of interbedded anhydrite and halite, and equates to the upper part (Lower Halite-Anhydrite Subzone) of the Fordon 'Lower Cycle' (unit 1) (Colter & Reed 1980). In complete sections, the base of unit S1 is marked by a downward change from halite with interbedded anhydrite to anhydrite of the Basalanhydrit Formation and is characterized by a downwadws increase in velocity and density (e.g. 48/11-2A). Where the Basalanhydrit Formation is absent, unit S1 rests directly on the Hauptdolomit Formation (e.g. 47/8-1). Unit S2 consists of halite with interbedded anhydrite, polyhalite, kieserite and carnallite. The interbedded potassium salts produce many high-gamma spikes, particularly at the base and top of unit S2 (e.g. 47/8-1). Unit S2 equates to the Fordon 'Middle Cycle' (units 2 to 7) of Colter & Reed (1980). Its boundary with unit S1 is generally marked by a sharp downward decrease in gamma-ray values (e.g. 47/8-1). Unit S3 consists of halite with subordinate anhydrite and equates to the Fordon 'Upper Cycle' (Colter & Read 1980). Its base is generally marked by a downwadws decrease in anhydrite content and the incoming of kieserite and, locally, carnallite. On wireline logs it commonly corresponds to a downward increase in gamma-ray values and a decrease in velocity (e.g. 47/8-1).

Following Taylor & Colter (1975) and Cameron et al. (1992), the Deckanhydrit is regarded as a solution residue from the top of the Stassfurt Halite Formation and included as an informal sub-unit within the formation. It typically comprises a thin unit of white to pale grey anhydrite. It occurs at the top of unit S3 (e.g. 48/13-2A), or where this is absent, at the top of S2 (e.g. 49/36-5, not illustrated).

Distribution and thickness

The Stassfurt Halite Formation is present over much of the Southern North Sea Basin. It is absent from the Mid North Sea High, although it passes laterally into thick halites and anhydrites of the Shearwater Evaporite Formation in a north-trending, trough-like feature in quadrants 37 (Jenyon et al. 1984) and 37/12-1, not illustrated). According to Taylor (1991), Z2 evaporites may have originally been far more extensive over the Mid North Sea High, having been removed by dissolution beneath thick overburden. In the central parts of the Southern North Sea, where sections have been extensively disrupted by halokinesis, the Stassfurt Halite Formation passes laterally into undivided Zechstein salts.

The Stassfurt Halite Formation may have been over 500m thick in the centre of the basin, but depositional thicknesses in this area are difficult to estimate because of the extensive deformation by halokinesis (Cameron et al. 1992). Where the Stassfurt Halite Formation overlies the slope and adjacent basin-floor facies of the Basalanhydrit and Hauptdolomit formations, it may be about 250m thick, but thins rapidly onto the shelf (e.g. 49/22-3, Panel 4N). At the basin margins, the Stassfurt Halite Formation passes laterally into red mudstones of the Blakeney Formation.

Regional correlation

Evaporites equivalent to the Stassfurt Halite Formation are widely distributed across the Zechstein Basin of Northwest Europe (Taylor 1990). In the subsurface of the 'Yorkshire Province', broad equivalents of the Stassfurt Halite Formation are referred to the Forodon (Evaporite) Formation (Smith et al. 1974, Smith et al. 1986). In the offshore Netherlands, correlative strata of the revised Stassfurt Halite Formation are included in the Z2 Salt Member and the Z2 Roof Anhydrite Member of the Zechstein 2 Formation (NAM & RGD 1980). In the UK Central and Northern North Sea Basins, however, the evaporites of the Z2 cycle are generally not separable from those of later cycles and are included in the Shearwater Evaporite Formation (Cameron 1993).

Genetic interpretation

The Stassfurt Halite Formation comprises a complex succession of evaporites which filled, or nearly filled, the Southern Permian Basin during the later stages of the Z2 cycle. Well correlation suggests that units S1 and S2 may have a lenticular foreset geometry like equivalents in the Fordon Formation, thickening from the shelf over its submarine slope, but thinning into the central parts of the basin (Taylor & Colter 1975; Colter & Reed 1980). As with the underlying Z2 carbonates and anhydrites, this had the effect of extending the marginal shelf. In contrast, unit S3 is thickest in the centre of the basin. From the foreset geometry, Colter & Reed (1980) inferred that the lower and middle Z2 evaporites, at least, were deposited at the margins and within in a deep body of hypersaline sea water. However, marginal sections in the upper part of the Fordon Formation, provide evidence of shallow-water depositional environments (Smith 1989). According to Smith (1980), the middle of the Forodon Formation of salinity about 10m from the top of the Stassfurt Halite Formation, as reported by Taylor & Colter (1975), suggests virtually total evaporation of the basin at the end of this cycle.

Taylor & Colter (1975) interpreted the Deckanhydrit as a solution residue from the cupola of the Stassfurt Halite Formation that formed as less saline waters flooded the basin during the third major Zechstein marine transgression.

Age

Late Permian.

References


STASSFURT HALITE FORMATION

LITHOLOGY

- Anhydrite
- Dolomite
- Halite
- Artesial halite and clay
- K/Mg salts and halite

DISTRIBUTION MAP

100 km

0 100 m

See also Correlation Panel 3
See also Correlation Panel 2
See also Correlation Panel 4N
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The term Turbot Anhydrite Formation was introduced in Part 4 of this revision (Cameron 1993) for a unit of anhydrite with minor carbonate and mudstone in the Zechstein Group of the UK Northern Permian Basin. It generally comprises the anhydrite component of the Z2 and subsequent Zechstein cycles, with minor units of carbonate and mudstone. However, it extends down to the base of the Z1 anhydrite in a few areas where the Z2 carbonate is thin or absent. These strata were formerly assigned to the Turbot Bank Formation by Deegan & Scull (1977). A brief description of the Turbot Anhydrite Formation is included here since it extends onto the Mid North Sea High in Quadrants 36, 37, 38 and 39 flanking the northern border of the Southern Permian Basin.

The Turbot Anhydrite Formation includes a Z3 carbonate, informally designated the Turbot Carbonate unit, which is much less widespread than the equivalent Plattendolomit Formation of the Southern Permian Basin. It also includes a distinctive argillaceous unit, termed the Hake Mudstone Member, that may be partly coeval with the Roter Salzton of the Southern Permian Basin. Sediments above the lowest of the prominent gamma-ray spike or spikes noted near the top of the Permian are designated the Upper Turbot Anhydrite unit (Cameron 1993) (Panel 1).

The Turbot Anhydrite Formation is largely composed of white or pale grey anhydrite that is variously described as being amorphous, granular, cryptocrystalline or microcrystalline from cuttings; in cores it sometimes displays a replacive, 'chickenwire' texture. Thin interbedded and interlaminated mudstones are red-brown or grey-green, hard, blocky to subfissile and anhydritic. The Turbot Carbonate unit is patchily developed and generally less than 10m thick. It consists ofbuff-coloured or grey and commonly argillaceous dolomite, with a sucrosic, microcrystalline or vuggy texture. On the Mid North Sea High, the Turbot Anhydrite Formation is unconformably overlain by Jurassic and Cretaceous mudstones and the boundary corresponds to a sharp downward decrease in gamma values and an increase in velocity (e.g. 39/1-1, Panel 1). The Turbot Anhydrite Formation generally overlies the Halibut Carbonate Formation (e.g. 38/3-1 and 39/1-1, Panel 1), but in a transitional zone between the Southern and Northern Permian Basins directly rests on the Hauptdolomit Formation (e.g. 38/16-1 and 38/25-1, Panel 1). It passes southwards into the carbonate-evaporite cycles of the Anglo-Dutch Basin.

Much of the Turbot Anhydrite Formation formed by precipitation during intervals of high salinity in the Northern Permian Basin. As in the Southern Permian Basin, sheets of anhydrite accumulated in basin-fringing sabkhas, but the thickest anhydrites were deposited allochthonously in a slope setting directly basinward of these sabkhas (Taylor 1990). Intercalated carbonate units accumulated while oceanic waters of the Boreal Ocean circulated more freely in the basin following marine transgression.

References


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In this study, the Werraanhydrit Formation is revised to include strata formerly assigned to the Lower Werraanhydrit Formation, Werra Halite Formation and Upper Werraanhydrit Formation (Rhys 1974). Rhys first applied these terms to the UK offshore area for units of anhydrite and minor halite that lay between the Zechsteinkalk and Hauptdolomit formations. These strata represent the evaporite phase of the Z1 cycle and include thick, shelf/slope and thin, basinal facies. Within the shelf facies, locally developed, carbonate units were informally assigned to the ‘Werradolomit’ by Rhys (1974).

On the basis of wireline log correlation, Taylor (1980) recognized six sub-units in the Werraanhydrit shelf facies and equated the upper two sub-units to the lower part of the basinal Hauptdolomit Formation (‘Stinkdolomit’ or ‘Stink-kalk’) of the Z2 cycle. However, the correlations by Cameron et al. (1992), which assign all the Werraanhydrit Formation to the Z1 cycle, are adopted in this report.

**References**


**Name.** From the old German stratigraphic term.

**UK reference sections**

36/26-1: 1419-1472m (4655-4830ft)
44/21-1: 3834.5-3855m (12580-12648ft)
49/26-4 (Rhys 1974, table 2, fig. 3) 1855-2007m (6086-6584ft)
(revised upper boundary depth)
48/30-4: 1890-2065.5m (6200-6777ft)
Lithology
The Werraanhydrit Formation has not generally been cored in the Southern North Sea and lithological information is therefore based largely on drill cuttings and wireline log evidence. Lithofacies and thickness are highly variable, being strongly controlled by depositional setting with both shelf/slope and basinal facies developed.

Shelf/slope sections around the basin margin are characterized by thick anhydrite beds with subordinate interbedded dolomite and halite. The anhydrite is generally described as white or yellowish white to pale grey, soft to hard, amorphous or massive and microcrystalline with sporadic argillaceous beds. It occurs as lenticular bands, large erosional masses and replacement crystals associated with microcrystalline dolomite (Taylor & Colter 1975). The interbedded dolomite is commonly described as pale grey to pale brown, dense, microcrystalline, argillaceous and anhydritic. Irregular, dark laminations are present in the dolomite, which in places has a vaguely pelletoid fabric (Taylor & Colter 1975). The dolomite is generally characterized by relatively high gamma-ray values compared to the surrounding evaporite units. Very locally, a thin unit of transparent to pink halite, here informally designated Werra Halite, is developed in the Werraanhydrit Formation (e.g. 49/26-4).

The basinal facies commonly consists of a vertical sequence of four anhydrite/ carbonate couples which are recognized from both core examination and wireline log responses (Taylor & Colter 1975; Taylor 1980). Broadly, each unit comprises a 1-2m layer of nodular and mosaic, displaceable anhydrite that grades up into 4-6m of finely and evenly interlaminated microcrystalline anhydrite and dark, bituminous dolomite or limestone with some bands of anhydritic nodules (Taylor 1980). Halite fills vugs and forms discontinuous lenses between carbonate laminae in the first couplet in some wells (Taylor 1980), and halite dissolution may have caused the disturbed bedding which occurs at this level in the centre of the basin. Locally, the basinal facies is carbonate-dominated (e.g. 41/25a-1, Panel 2).

Upper boundary
Around the basin margin, the top of the Werraanhydrit Formation is normally designated by a downward change from pale grey to pale brown oolitic, pelletaloidal, bioclastic and pisolithic, dolomitic grainstones and carbonate mudstones of the Hauptdolomit Formation, to nodular and mosaic, white anhydrite or anhydrite with carbonate layers. Typically, it is marked on wireline logs by a decrease in gamma-ray values and locally by a decrease in velocity. In basinal sections, the top of the Werraanhydrit Formation is normally characterized by a downward change from thick, white, microcrystalline, nodular and mosaic anhydrite with subordinate carbonate and argillaceous layers to pink to brown, microcrystalline, calcitic dolomite and dolomitic limestone with anhydrite nodules of the Zechsteinkalk Formation. It is marked on wireline logs by a downward increase in gamma-ray values (e.g. 48/30-5 and 49/26-4).

In basinal sections, the base of the Werraanhydrit Formation is marked by a downward change from finely interlaminated anhydrite and dark, bituminous dolomite or limestone with basal layers of nodular and mosaic anhydrite, to dark, pyritic, argillaceous dolomite and limestone of the Zechsteinkalk Formation. Typically, it is marked on wireline logs by a downward increase in gamma-ray values (e.g. 44/21-1). Locally, the Zechsteinkalk Formation is absent and the Werraanhydrit Formation rests conformably upon organic-rich mudstone of the Kupferschiefer Formation (e.g. 38/24-1, Panel 1) or unconformably on pre-Zechstein strata (e.g. 37/23-1, Upper Old Red Group, not illustrated).

Lithostratigraphic subdivision
No formal subdivision of the Werraanhydrit Formation is proposed in this report, but localized units of halite occur within the shelf/slope facies and are informally designated the Werra Halite (e.g. 49/26-4). The Werra Halite consists of transparent to pink halite and is characterized on wireline logs by its low velocity.

Distribution and thickness
The Werraanhydrit Formation is present throughout most of the Southern North Sea Basin. It is, however, absent through non-deposition from the shelf and slope facies of the Northern North Sea High, as well as from the shelf/slope facies of the Werraanhydrit Formation which was probably an area of palaeo-reef. It is also absent from the southern margins of the basin where the shelf facies of the Zechsteinkalk Formation is directly overlain by the Basalanhydrit Formation and red mudstones and sandstones of the Blakeney Formation. It is not recognized in the north of quadrants 37, 38 and 39, on the Mid North Sea High, where equivalent strata are included in the Halibut Carbonate Formation (Cameron). At the southern margin of the basin, and bordering the Mid North Sea High to the north (e.g. 36/26-1), the Werraanhydrit Formation forms a prograding shelf/slope wedge about 50km wide that is absent, and is enclosed by, the shelf facies of the Zechsteinkalk Formation. This shelf/slope facies is typically 100-200m thick, but locally reaches up to 300m. The Werraanhydrit Formation thins rapidly basinwards, and across most of the basin floor is about 10-25m thick.

Regional correlation
Anhydrite-dominated units equivalent to the Werraanhydrit Formation are widespread in the Northwest European Zechstein Basin, and occur in the subsurface of eastern England, offshore and onshore the Netherlands and in northwest Germany and Poland (e.g. Taylor 1990). The Werraanhydrit Formation correlates with the Zn L Anhydrite (Anhydrite) formations in northeastern England (Smith et al. 1974, Smith et al. 1986). Equivalent strata in the Dutch offshore are included in the Z1 Anhydrite Member, Z1 Lower Anhydrite Member, Z1 Upper Anhydrite Member and the Z1 Anhydrite-Carbonate Member of the Z1 Formation (NAM & RGD 1980).

On the basis of wireline log correlations, Taylor (1980) postulated that the upper part of the Werraanhydrit shelf facies equates with the lower part of the Hauptdolomit Formation in the basin. However, this correlation was considered unlikely by Smith (1988), Richter-Bernburg (1986) and Cameron et al. (1992), and in this report all of the Werraanhydrit Formation is referred to the Z1 cycle.

On the Mid North Sea High, the Werraanhydrit Formation passes laterally into the Halibut Carbonate Formation (see Panel 1). On the South Hewett Shelf, the upper part of the Werraanhydrit shelf facies probably passes laterally into red mudstones of the Blakeney Formation. Smith (1989) demonstrates a similar lateral facies transition in eastern England from the Hayn Anhydrite Facies to the Edlington Formation.

Genetic interpretation
The depositional environments of the Werraanhydrit Formation and equivalents has been the subject of much debate (e.g. Taylor and Fong 1969; Taylor 1980; Richter-Bernburg 1986; Langbein 1987). The thick, marginal facies are generally considered as relatively shallow-water or platform deposits, for which Taylor & Fong (1969) and Taylor (1980) favoured a sabkha model with isolated salt pans where halite accumulated. However, the thickest anhydrites may have accumulated aholoholimically in a slope setting directly basinward of these sabkhas. Richter-Bernburg (1986) postulated deposition on a platform under water 5-10m deep where a high evaporation rate and high salinities resulted in faster deposition of calcium sulphate relative to the basinal areas. The widespread nodular facies may be secondary and the rock possibly accumulated as 1-3 cm layers of seafloor-grown selinite crystals (Richter-Bernburg 1986; Smith 1989).

According to Taylor (1980), the finely laminated parts of the basinal facies were formed under water probably 150-300m deep, but the interbedded nodular anhydrite may have formed during phases of deep evaporite drawdown and partial desiccation. However, Richter-Bernburg (1986) proposed that changes of climate and/or current flow within the basin could explain the sharp changes from nodular to laminated anhydrite in the deep water basinal facies.

Age
Late Permian

References
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See also Correlation Panels 2, 4N.
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The term Zechsteinkalk Formation was first applied to the UK offshore area by Rhys (1974) for a unit of dolomitic limestone and calcitic dolomite between the Lower Werraanhydrit Formation and the Kupferschiefer Formation. This usage is retained here. It represents the carbonate phase of the first Zechstein cycle and includes shelf, slope and basinal facies. Equivalents of the Zechsteinkalk Formation are present in eastern England and in the Dutch sector of the Southern North Sea (see Regional Correlation, p. 110).

References


Name. From the old German stratigraphic term.

UK reference sections
38/25-1: 2182.5-2213m (7160-7260ft)
48/30-1: 1693.5-1795.5m (5556-5890ft)
49/26-4 (Rhys 1974, table 2, fig. 3): 2007-2011.5m (6584-6600ft)
53/1-2: 1626-1698m (5335-5571ft)
Lithology
The Zechsteinalk Formation includes a wide range of carbonate lithofacies that accumulated in ramp, shelf, slope and basinal settings. In ramp, shelf, and slope sections, the Zechsteinalk Formation is thickly developed and typically consists of two, broad facies. Firstly, pale grey-brown, hard, variably dolomitised, locally argillaceous and pelletoidal carbonate mudstones. These commonly pass up into carbonate grainstones, which are oolitic, pelletoidal and dolomitsed. Several upward-decreasing gamma-ray sections are commonly present, reflecting upward-coarsening cycles (e.g. 49/26-1). Shelf carbonate mudstones are generally bioturbated, whereas the slope facies commonly includes dark coloured, thinly bedded carbonate mudstones (Clark 1986). Core from well 53/1-2 indicates carbonate mudstones with large bryozoan stems, some of which are in growth position, and may indicate proximity to a reef (Taylor & Colter 1975). The grainstones are commonly bioclastic and the diverse fauna includes bivalves, brachiopods, crinoids, bryozoans and foraminifera.

Basinal sections typically consist of thin, dark grey to brown, argillaceous, pyritic, carbonaceous and locally sandy, laminated limestone and dolomite. Algal pisoliths have been described from the uppermost part of this basinal facies together with a marine fauna of foraminifera and sometimes crinoids (Taylor & Colter 1975). Vugs and veins in the Zechsteinalk Formation are commonly partially filled with anhydrite.

Upper boundary
In basal sections, the top of the Zechsteinalk Formation is normally defined by a downward change from white or yellow anhydrite of the Werraanhdyrit Formation to dark grey to brown argillaceous, laminated or thickly bedded fine grained limestone. It is typically marked on wireline logs by a sharp downward increase in gamma-ray values and a decrease in velocity (e.g. 49/21-1, fig. 35 in Cameron et al. 1992), but the key reference section 49/26-4 has no single-thickly bedded limestone. Some sections in the slope facies also show a marked downward change in gamma-ray values at this boundary (e.g. 48/30-5, not illustrated). In shelf sections, where the Werraanhydrit Formation is absent, the upper boundary of the Zechsteinalk Formation is commonly defined by a downward change from red-brown mudstones and sandstones with thin anhydrites and dolomites of the Blakeney Formation (e.g. 53/1-2) or white to grey anhydrite with interbedded red mudstones of the Basalanhdyrit Formation (e.g. 53/1-1, Panel 48), to pale grey-brown dolomite. These boundaries are generally marked by a downward decrease in gamma-ray values and an increase in velocity.

Lower boundary
Typically, the base of the Zechsteinalk Formation is taken at a sharp downward change from grey dolomitic limestone to dark grey or black, organic-rich, laminated mudstone of the Kupferschiefer Formation. This is marked on wireline logs by a sharp downward increase in gamma-ray values and a decrease in velocity (e.g. 49/26-4). In the Silverpit Basin a thin dark grey, bireumous mudstone unit with a high gamma-ray and low velocity log signature locally occurs within the condensed Zechsteinalk Formation (e.g. 44/22-1, p.81). Locally, the Kupferschiefer Formation appears to be absent and the Zechsteinalk Formation rests unconformably on pre-Zechstein rocks (e.g. 38/25-1, Upper Old Red Group Panel 1).

Lithostratigraphic subdivision
The Zechsteinalk Formation is not subdivided in this report. Two sub-cycles are recognized in equivalent strata in eastern England (e.g. Smith 1980) (see Regional correlation) and in Germany (Paul 1986).

Distribution and thickness
The Zechsteinalk Formation is present throughout most of the Southern North Sea Basin. It is, however, absent from the London-Brabant Platform (e.g. 53/16-1, not illustrated) and on parts of the Mid North Sea High (e.g. 38/16-1, Panel 1). The Zechsteinalk Formation shows considerable lateral thickness variation which reflects its depositional environment. In a 50km-wide marginal belt around the southern rim of the basin, a thick, prograding wedge of dolomite accumulated in shelf and slope environments. Here it reaches about 120 m (e.g. 48/28-1, not illustrated). Relatively thick shelf sections are also locally present on the southwestern flank of the Mid North Sea High (e.g. 38/25-1). In contrast, the basinal facies which extends beyond the break of slope at the foot of the shelf and covers most of the Southern North Sea Basin, is very thin and typically in the range 2-4m (e.g. 49/26-4). Locally, the basinal facies appears to be absent, with Werraanhdyrit Formation resting directly on the Kupferschiefer Formation (e.g. 38/24-1, Panel 1). In the northern parts of Quadrants 38 and 39, strata equivalent to the Zechsteinalk Formation are included in the Halibut Bank Formation (e.g. 39/1-1, Panel 1).

Regional correlation
Carbonate successions equivalent to the Zechsteinalk Formation occur throughout the Southern and Northern Permian Basins of western and northern Europe (Taylor 1990). In the UK Central and Northern North Sea, equivalent strata are included in the Halibut Carbonate Formation (Cameron 1993). In the Dutch sector, equivalent strata are included in the Z1 Carbonate Member and the Z1 Anhydrite-Carbonate Member of the Zechstein 1 Formation (NAM & RGD 1980). In the Yorkshire Province equivalent strata are included in the Cadby (Magnesian Limestone) Formation (Smith et al. 1986), which is divided into two members separated by the Hampole Discontinuity (Smith 1968). In the 'Durham Province', equivalent strata are included in the Ford (Magnesian Limestone) Formation and the underlying Raishy (Magnesian Limestone) Formation (Smith et al. 1986).

At the extreme southern margin of the Southern Permian Basin, the Zechsteinalk Formation passes southwards into interbedded dolomitic terrigenous sandstones and mudstones, which are left unmeasured in the Zechstein Group in this study (e.g. 54/11-1, Panel 48).

Genetic interpretation
The Zechsteinalk Formation represents a range of environments from sabkha and shelf to basin (Taylor & Colter 1975). The shelf carbonate mudstones and grainstones locally contain a diverse marine fauna and bryozoan-algal reefs may have developed locally at the shelf-edge in the upper part of the Zechsteinalk Formation (Taylor & Colter 1975; Clark 1986). Turbidites and slumped material are interpreted in the slope facies (Clark 1986). The basinal facies generally have an impoverished fauna and were mainly deposited under stagnant conditions (Smith 1980; Cameron et al. 1993). A widespread, thin, fossiliferous layer with oncoliths at the top of some basinal sections represents a brief return to normal marine conditions and may reflect a temporary fall in sea level of about 100 m (Taylor 1990). This unit is correlated with the Trow Point Bed in northeast England (Taylor 1990; Smith 1986).

Age
Late Permian
References
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ROTLIEGEND GROUP

Most of the Rotliegend Group consists of sandstones, mudstones and minor halites deposited in arid or semi-arid, tropical desert and playa lake environments. These sediments rest unconformably on strata ranging from Devonian to Westphalian in age. They are generally overlain by Upper Permian marine sediments and evaporites of the Zechstein Group as revised herein. Also included within the Rotliegend Group are the Lower Permian volcanics that have been drilled beneath desert sediments on the Mid North Sea High (Cameron 1993).

The Rotliegend Group of the UK Southern North Sea is divided here into the Leman Sandstone, Silverpit, Auk and Inge Volcanics formations. The first two of these formations were defined by Rhys (1974), the third by Deegan & Scull (1977) and the last by Cameron (1993). The Leman Sandstone Formation comprises up to 300m of aeolian and fluvial red-brown sandstones with localized conglomerates and relatively minor interbedded sabkha mudstones. Equivalent strata in the Dutch sector are known as the Slochteren Sandstone Formation (NAM & RGD 1980). The Silverpit Formation was deposited in a desert lake environment and comprises up to 350m of red-brown mudstones with localized interbedded halites. Equivalent strata in the Dutch sector are known as the Silverpit Claystone Formation (NAM & RGD 1980). The Auk Formation dominantly consists of red-brown aeolian and fluvial sandstones which are up to 500m thick in parts of the Central North Sea (Cameron 1993). The Inge Volcanics Formation, which is locally more than 350m thick, underlies the Auk Formation and consists of red, purple and green basalts, and weathered tuffs with interbedded mudstones and sandstones (Cameron 1993).

**References**


Cameron, T.D.J. 1993. Early to Late Permian. Summary descriptions only are given here.


**Name.** From the old German mining term for the Lower Permian red beds beneath the Zechstein Group.

**Age.** Early to Late Permian.

**Constituent formations (Southern North Sea)**

**AUK FORMATION**

**SILVERPIT FORMATION**

**LEMAN SANDSTONE FORMATION**

* denotes Central North Sea formations that extend into the northernmost part of the Southern North Sea. They are described in full in Cameron (1993). Summary descriptions only are given here.
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AUK FORMATION

The term Auk Formation was introduced by Deegan & Scull (1977) for a unit of Lower Permian sandstones resting unconformably on Devonian strata in the Central North Sea. In Part 4 of this revision (Cameron 1993), the Auk Formation was extended to include comparable sandstones in the Outer Moray Firth, South Viking Graben and Beryl Embayment. A brief account of the Auk Formation is included here since it extends into the north of Quadrants 38 and 39.

The Auk Formation consists dominantly of reddish brown, fine to coarse grained aeolian sandstones, but also includes units of waterlain sandstone, conglomerate and mudstone (Heward 1991). Normally the sandstones are cemented by hematite and authigenic clay, but dolomite, anhydrite and kaolinite are locally important cements.

In Quadrants 38 and 39, the Auk Formation rests unconformably on Devonian strata of comparable red-bed facies, and the boundary is consequently difficult to identify (e.g. 38/5-1, Panel N). In most sections, the top of the Auk Formation is marked by a downward change from highly radioactive mudstones of the Kupferschiefer Formation or carbonates of the Halibut Carbonate Formation, to sandstones.

In the Central North Sea, much of the Auk Formation comprises dune-bedded sandstones, deposited on a mainly dry desert surface by prevailing winds that blew towards the east or southeast (Deegan & Scull 1977; Glennie 1990). Waterlain sediments accumulated during wetter periods when the dunes became inactive. In parts of the Central North Sea, as in the Auk Field (Heward 1991), fluvial sands filled in some of the relief on the base-Permian unconformity before the onset of aeolian deposition.

References
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The term Inge Volcanics Formation was introduced in Part 4 of this revision (Cameron 1993) for a unit of Lower Permian basic lavas and tuffs with minor interbedded sediments that occur beneath the Auk Formation or subcrop Upper Permian sediments on the northeastern flank of the Mid North Sea High. A brief account of the Inge Volcanics Formation is included here since it extends into the extreme north of Quadrant 39. Equivalent Lower Permian volcanics are widespread beneath the Danish Central Graben and also occur locally at depth beneath the Norwegian-Danish Basin and Horn Graben (Sørensen & Martinsen 1987). They are referred to the Lower Rotliegend Group in the Dutch sector (NAM & RGD 1980), but are not differentiated within the Rotliegend Group in either the Norwegian or Danish sectors.

Much of the Inge Volcanics Formation comprises red and purple weathered tuffs and purple, reddish grey, and occasionally dark green basalts. The tuffs are hard and cindery, and contain feldspar laths and sporadic glassy shards. Grains of chlorite give the tuffs a speckled appearance. The basalts are locally amygdaloidal and contain pyroxene phenocrysts and possible serpentine pseudomorphs of olivine in a feldspar-pyroxene groundmass. The interbedded mudstones are dark reddish brown or reddish grey, tuffaceous, calcareous and anhydritic. Dark reddish brown very fine to fine grained, micaceous, argillaceous and non-calcareous sandstones form a relatively minor component of the formation.

In Quadrant 39, the Inge Volcanics Formation is unconformably overlain by Upper Permian sediments of the Zechstein Group (39/2-1, Panel 5N). Secondarily reddened sandstones and mudstones of possible Carboniferous age underlie the Inge Volcanics Formation in Quadrant 39. Lower Permian volcanics in the North Sea Basin, northern Germany and Poland largely consist of mildly alkaline basalts and associated silicic extrusives (Dixon et al. 1981). Their composition and their occurrence adjacent to major fault systems suggests that the volcanics were extruded during earliest post-Carboniferous transtensional movements (Glenne 1990).

References
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Leman Sandstone Formation

The term Leman Sandstone Formation was introduced by Rhys (1974) for a unit of Lower Permian sandstones with interbedded mudstones that lay between Carboniferous and Zechstein sediments in the Southern North Sea. These Lower Permian desert deposits have also been informally called the 'Leman Formation' (van Veen 1975), the 'Rotliegendes Formation' (Butler 1975), and the 'Rotliegendes Sandstone' (France 1975).

References


Name. After the Leman Field, where the formation is the principal reservoir.

Type section

49/26-4 (Rhys 1974, table 2, fig. 2): 2013-2289m (6604-7510ft) below KB.

Reference sections

44/21-1: 3863-3864.5m (12674-12678ft) and 4185-4202m (13730-13786ft)
48/6-25: 2905-3021m (9531-9911ft)
53/2-4: 1981.5-1983m (6518-6534ft)
Lithology

The Leman Sandstone Formation is characterized by red-brown, pink, and occasionally grey sandstones with interbedded conglomerates, breccias, and red mudstones. The sandstones are typically very fine to medium grained, although some coarse grained sandstones are also present. They are generally clean, massive or slightly laminated, and in fragmental coarse gravels. Locally, slightly argillaceous, micaceous, poorly sorted, commonly upward-fining sandstones with sporadic pebbles and rip-up clasts of mudstone are prevalently. Minerals in the sandstones are moderately mature quartz and feldspar with up to about 10-15 percent feldspar grains. Dolomitic cement is common in the argillaceous sandstones.

Core evidence indicates that sedimentary structures in the sandstones include planar and trough cross bedding and lamination, and typically there is an upward increase in the inclination of the laminae from sub-horizontal to an angular cross bedded truncate by the overlying set. Commonly, the lower few metres of each set is preserved, but locally the units are up to 40m thick. Massive-beded sandstone is widespread and locally grades into laminated sandstone and pebbly sandstone. Locally, adhesion ripples, mud cracks and sandstone dykes are common in interbedded sandstone and mudstone facies.

The conglomerates vary from orthoconglomerates with a moderate to well-sorted, matrix-filled framework, to polymodal, sandy paraconglomerates. They are generally non-stratified and typically fine upwards into sandstones. Generally they occur in units up to about 1.3m thick.

The interbedded mudstones are rare in the area of the Leman Field, but become more common to the north and east, as the Leman Sandstone Formation passes laterally into the coeval Silverpit Formation.

Upper boundary

The boundary between the Leman Sandstone Formation and the overlying Conybeare Group is typically a sharp downward passage from dark coloured sandstone to red-brown sandstone, corresponding to a marked downward decrease in gamma-ray values and an increase in velocity values. Where the Leman Sandstone Formation is split by interbedded mudstones of the Silverpit Formation, the upper boundary of the lower level (Leman Sandstone) is typically marked by a downward change from red-brown mudstone to red-brown sandstone. This is generally associated with a downward decrease in gamma-ray values. Locally, the downward passage from the Silverpit Formation to the Leman Sandstone Formation is gradational (e.g. 48-6-25).

Lower boundary

The lower boundary of the Leman Sandstone Formation with the Carboniferous is everywhere an unconformity surface. The lower boundary with the Conybeare Group is generally marked by a downward change from red-brown sandstones and local fluvial conglomerates (e.g. 53/2-4), to grey mudstones with interbedded mudstones and coals. It is marked on wireline logs by a significant downward increase in gamma-ray values. However, where the Leman Sandstone overlies reddish brown to purple mudstones and reddish brown to occasionally grey grey mudstones of the Ketch Member (Schooner Formation), the boundary is normally marked by a sharp downward decrease in velocity (e.g. 49/1-3, 23 in Cameron 1993). Locally, the Leman Sandstone Formation overlies white to cream coloured and grey, carbonaceous mudstones of the Millist-Grit Formation (Cameron 1993).

Where the Leman Sandstone Formation is split by mudstones of the Silverpit Formation, the base of the upper level (Upper Leman Sandstone) is marked by a downward change from sandstone to red-brown mudstone and this coincides with a downward increase in gamma-ray values.

Lithostratigraphic subdivision

In the north and east of Quadrants 48 and 49, interdigitation of the Silverpit Formation and the lower part of the Leman Sandstone into two leaves. These are informally designated here the Lower Leman Sandstone and Upper Leman Sandstone. Butler (1975) recognized equivalent informal Lower and Upper Leman Sandstone members of the ‘Rotliegendes Formation’. The base of the Lower Leman Sandstone coincides with the base of the Leman Sandstone Formation as described above. It is normally overlain by mudstones of the Silverpit Formation. Upper Leman Sandstone rests on the Silverpit Formation and its top coincides with the top of the Leman Sandstone as described above.

From detailed core examination and wireline log interpretation, George & Berry (1993) recognized a five-fold subdivision of the Lower Leman Sandstone.

The interbedded mudstones are rare in the area of the Leman Field, but are left undifferentiated within the Rotliegend Group. Some of the sandstones are most likely thickly developed in the upper unit characterized by interbedded mudstones and an upper unit of grey coloured, structureless strata, believed to be related to the new sedimentary facies in the Lower Permian of Germany. The term is not used in this report, because reworking of Lower Permian facies in the Leman Sandstone Formation has been informally designated ‘Weissliegend facies’ (Glenie & Buller 1983, Glenie 1990) on the basis of lithological similarity to the waterlaid Weissliegend facies in the Lower Permian of Germany. However, this term is not used in this report, because recognition of primary Weissliegend facies solely on the basis of grey colour can be misleading, as discolouration can also result from the upward migration of acidic waters from Coal Measures (Glenie 1990).

Distribution and thickness

The Leman Sandstone Formation extends throughout the Sole Pit Basin, South Leman Field, across the Cleaver Bank and Winterton highs to the boundary with the Dutch sector. It interdigitates with, and passes northwards into the laterally equivalent Silverpit Formation in the Silverpit Basin. It thins to the north towards the English coast and is most thickly developed in the Pot Trough, where it reaches about 290 m thick.

Successive units are developed on the Inde and South Hewett Shelves and on the Cleaver Bank and Winterton highs.

The Leman Sandstone Formation was not deposited on the North Pot Trough, where a thin and patchy veneer of sandstone and breccia is locally present (Cameron et al. 1992) (e.g. 36/26-1, 1487-1929m, Zechstein Panel 2; 41/8-1, 1129-1134m, Zechstein Panel 2). In this report, these deposits are not given formal status, but are left undifferentiated within the Rotliegend Group. They are probably equivalent to the Lower Permian residual pediment gravels and worked yellow dune sands in northern and central England (Smith et al. 1974).

Regional correlation

The Leman Sandstone Formation passes laterally into mudstones and evaporites of the Silverpit Formation. Laterally equivalent facies in the Dutch sector are known as the Schlesischen Sandsteinen Formation (NAM and RGD 1980). Equivalent strata in the Central and Northern North Sea are included in the Ass Formation (Deegan & Scull 1977, Cameron 1993).

In the Netherlands, where a thin veneer of sandstones and breccias with interbedded mudstones interbeds on the North Pot Trough (e.g. in wells 36/26-1, 39/11-1, 43/3-1 and 48/8-1, Zechstein Panel 2) are possibly laterally equivalent to the Lower Permian Brecchia and Yellow Sands of northern England (Smith et al. 1974), and in part to the Leman Sandstone Formation.

Genetic interpretation

The Leman Sandstone Formation was deposited in aeolian, fluvial and sabkha, tropical desert environments (Glenie 1972 & 1990). In general, the aeolian sandstones form the best reservoirs. Cross bedding suggests that most of the aeolian sands formed dunes in the Pot Trough and further east, but some dunes may have predominated around the margins of the basin (Glenie 1972). An easterly to northeasterly palaeowind direction is postulated (Glenie 1972, 1990). The fluvial sandstones were deposited on the alluvial plains of rivers flowing northwards from the London-Brabant Massif (Marie 1975). Poorly bedded sandstones and mudstones with mud cracks, adhesion ripples, sandstone dykes and anhydrite nodules are interpreted as sabkha deposits (e.g. Glenie 1972). George & Berry (1993) recognized five depositing-upwards cycles in the Leman Sandstone Formation. They suggested that these cycles can be traced throughout the basin in both the Leman Sandstone and Silverpit formations and reflect long-term climatic fluctuations with chronostratigraphic significance.

According to van Veen (1975) the so-called ‘Weissliegend facies’ represent reworking of aeolian sediments by the transgressive Zeekstein Sea. Some of the characteristics of ‘Weissliegend facies’ reported in the Southern North Sea have also been attributed to the rapid degassing of sandstones during the rapid Zeekstein transgression (Glenie & Buller 1983).

Age

Early to Late Permian.

References


SILVERPIT FORMATION

The term Silverpit Formation was introduced by Rhys (1974) for a unit of Lower Permian desert playa mudstones and interbedded halites, that lay between Carboniferous and Zechstein sediments in the Southern North Sea. Apart from minor revision to recognize an evaporitic unit of member status, this definition is followed in this report. Equivalent strata in the Dutch sector are known as the Silverpit Claystone Formation (NAM & RGD 1980).

**Name.** From the Outer Silver Pit, which is a sea-bed feature near the type section.

**Type section**
44/21-1 (Rhys 1974, table 2, fig. 2): 3864.5-4185m (12767-13750ft) below KB (metric conversion of upper boundary revised and depth of base revised)

**Reference section**
48/6-25: 2848.5-2905m (9343-9531ft)

**Formal subdivision**
Silverpit Evaporite Member

**Lithology**
The Silverpit Formation is characterized by reddish brown mudstones and siltstones, locally interbedded with units of halite and thin sandstones. The mudstones and siltstones are locally anhydritic and calcareous, and vary from soft to very hard and dense. The halites are translucent to off-white, pink and reddish brown, coarse crystaline, brittle and hard, with occasional white patches of hard, amorphous anhydrite. Generally, the halites are thicker and more numerous in the lower part of the formation. The sandstones are generally reddish brown and grey, very fine to medium grained and argillaceous.

**Upper boundary**
Where the Silverpit Formation is overlain by the Upper Leman Sandstone, its top is normally marked by a downward increase in the proportion of mudstone, corresponding to a downward increase in gamma-ray values. Where the Upper Leman Sandstone is absent and the Silverpit Formation is overlain directly by the Kupferschiefer Formation (e.g. 43/12-1, Panel 5N), the boundary is marked by a downward passage from black, organic-rich mudstone to red-brown mudstone. This is typically associated with a downward decrease in gamma-ray values and an increase in velocity. Where the Kupferschiefer Formation is locally absent, the Silverpit Formation is directly overlain by grey carbonate of the Zechsteinkalk Formation (e.g. 47/3-a, not illustrated).

**Lower boundary**
The lower boundary with the Lower Leman Sandstone is generally marked by a downward change from mudstone to sandstone, corresponding to a downward decrease in gamma-ray values (e.g. 48/6-25). Where the Lower Leman Sandstone is absent, mudstone or halite of the Silverpit Formation rests directly on the Coobybear Group (Cameron 1993) (e.g. 44C22-1, p.125). This boundary is typically associated with a downward increase in gamma-ray values.

**Lithostratigraphic subdivision**
The Silverpit Evaporite Member (NAM & RGD 1980) is formally extended into the UK sector. George & Berry (1993) recognized five drying-upward cycles within the Silverpit Formation, but these are not given either formal or informal lithostratigraphic status here.

**Distribution and thickness**
The Silverpit Formation is present across the northern parts of the Sole Pit Trough and Indefatigable Shelf, and extends across the Silverpit Basin and the Cleaver Bank High to the international boundary with the Dutch sector. It pinches out eastwards before reaching the English coast, and northwards against the North Dogger Shelf. To the south, the Silverpit Formation passes laterally into the coeval Leman Sandstone Formation. It is thickest in the southwestern part of the Silverpit Basin, where it reaches about 350 m.

**Regional correlation**
The Silverpit Formation is laterally equivalent to, and interdigitates with, the Leman Sandstone Formation. Laterally equivalent facies in the Dutch sector are known as the Silverpit Claystone Formation (NAM & RGD 1980).

**Genetic interpretation**
The Silverpit Formation accumulated in and at the margins of a desert lake which extended about 1200 km eastwards from the North Sea through Germany into Poland (Glenneis 1972, 1990). The mudstone and halite facies represent periods of high and low freshwater influx, respectively. George & Berry (1993) postulated that each of five prominent halites in the Silverpit Formation of the UK Southern North Sea represents the top of a drying-upwards cycle. They proposed that each drying-upwards cycle has chronostratigraphic significance and can be traced into coeval facies of the Leman Sandstone Formation.

**Age**
Early to Late Permian.

**References**


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The term Silverpit Evaporite Member was introduced by NAM & RGD (1980) for a unit of mudstones with interbedded halites within the Silverpit Claystone Formation of the Dutch sector. In this study the Silverpit Evaporite Member is formally recognized in the Silverpit Formation of the UK Southern North Sea. Cameron et al. (1992) informally applied the term ‘Silverpit Halite Member’ to these strata.

**Name.** From the characteristic evaporite lithology.

**Type section**
44/21-1: 4063.5-4185m (13331-13730ft) below KB.

**Reference section**
44/22-1: 3262.5-3453.5m (10703-11300ft)

**Lithology**
The Silverpit Evaporite Member is characterized by reddish brown mudstones and siltstones with beds of halite. The halite beds are up to about 25m thick and are typically massive and hard, brittle, coarsely crystalline and clear to translucent or white and reddish brown in colour. Locally, minor amounts of white to pink, amorphous anhydrite are associated with the halites (e.g. 3599.5-3609m in 43/25-1, not illustrated).

**Upper boundary**
The top of the Silverpit Evaporite Member is typically placed at the top of the highest, massive halite bed in the Silverpit Formation. This does not necessarily coincide with the highest occurrence of halite, but typically corresponds to a marked downward decrease in gamma-ray values and a sharp increase in resistivity. Locally, thin, ‘ratty halites’ are present above the top of the Silverpit Evaporite Member (e.g. 3226.5-3257m in 44/22-1). In the deposcentre of the Silverpit Formation, the halite beds are generally thicker, more numerous, and apparently range to higher stratigraphic levels (e.g. 44/22-1).

**Lower boundary**
The base of the Silverpit Evaporite Member is typically placed at the base of the lowest, massive halite bed in the Silverpit Formation. This is generally associated with a marked downward increase in gamma-ray values and a sharp decrease in resistivity. Locally, the Silverpit Evaporite Member lies unconformably on the Carboniferous Conybeare and Whitehurst groups (e.g. 44/22-1).

**Distribution and thickness**
The Silverpit Evaporite Member is present in the southern part of the Silver Pit Basin (i.e. the south of quadrants 43 and 44) and extends into the Dutch sector. It is absent near the northern, western and southern limits of the Silverpit Formation. However, an isolated patch of thick halites is recorded in the Silverpit Formation in well 48/7b-5 (not illustrated), to the west of the main development of the Silverpit Evaporite Member. The Silverpit Evaporite Member reaches up to about 200m thick.

**Regional correlation**
The Silverpit Evaporite Member extends into the Dutch sector of the Southern North Sea (NAM & RGD 1980).

**Genetic interpretation**
The mudstones and halites of the Silverpit Evaporite Member accumulated in, and at the margins of, a large desert lake which extended about 1200km eastwards from the North Sea into Poland (Glennie 1972, 1990). George & Berry (1993) postulated that each of five prominent halites in the Silverpit Formation of the UK Southern North Sea represents the top of a drying-upward cycle. They proposed that each drying-upward cycle has chronostratigraphic significance and can be traced into coeval facies of the Leman Sandstone Formation.

**Age**
Early to Late Permian.

**References**


CORRELATION PANELS
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<td>Z21</td>
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</table>

**Note:** The table above represents the stratigraphic column for the Southern North Sea, showing the sequence of geological formations and members from the Triassic to the Cretaceous periods. The column includes various formations such as the Shearwater Salt Formation, Turbot Formation, Anhydrite Formation, and others, each with specific members and depths. The age and group correspond to the Permian and Cretaceous periods, respectively.
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APPENDIX

Permio-Trias biostratigraphic markers
by G. Warrington

Biostratigraphic markers of use in the Permio-Trias of the Southern North Sea are mainly palynomorphs but include a foraminifer and a calcareous alga, they are defined below.

1) Retiolitinae tuberculatae Definition. The FDO of Retiolitinae tuberculatae Lund, 1934. Age. Late Triassic (Late Anisian).


Remarks. This biomarker signifies the top of the Anisian Stage (van der Zwan & Spaak 1992) and is higher than the FDO of Protovolvites minor Antonescu & Tausgradedt Lantzi 1975 which is at the top of the Lower Muschelkalk (Weltkenkalk) in the Southern North Sea (Geiger & Hopping 1968).

3) Densoisporites nejburgii Definition. The FDO of Densoisporites nejburgii (Schulz) Balme 1970.

Age. Mid-Triassic (Early Anisian).

Remarks. This shallow water, euryhaline biomarker signifies the top of the Z1 cycle in Zechstein carbonate facies in eastern England and contiguous offshore areas; it is important eastwards into the basin (Tayl. & Colter 1975).

FORAMINIFERA

Agathammina pusilla Definition. The FDO of Agathammina pusilla (Geinitz) Cushman 1948. Age. Late Permian (Kazanian).

Remarks. This shallow water, euryhaline biomarker signifies the top of the Z1 cycle in Zechstein carbonate facies in eastern England and contiguous offshore areas; it is important eastwards into the basin (Tayl. & Colter 1975).

References


References


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