# THE UPPER PERMIAN IN THE NETHERLANDS

by

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## Summary

The Upper Permian in the Netherlands, as known from borehole data, is deposited in a mainly evaporitic facies north of the Brabant and Rhenish Massifs. In the extreme south (Belgian Campine, de Peel) a near-shore facies of reef dolomites and clastics occurs. In the western and central Netherlands the Upper Permian is represented by a thin sequence of anhydrite and dolomite with some clastics (anhydrite facies). The rock salt facies, developed in the northeastern part of the country, is subdivided into 4 evaporation cycles. Each cycle, when complete, consists of a series of claystone, dolomite, anhydrite, rock salt, bitter salts, laid down under conditions of increasing basin salinity followed by a thin series of rocksalt and anhydrite, deposited under decreasing salinity.

The depositional rhythm of the deposits in the rock salt facies is caused by periodic northward shifts of the area of greatest subsidence. Owing to tectonic movements, initiating these shifts, changes occurred in the physiographic conditions relating to entrance channel and basin causing the basin salinity to decrease. Only during periods of relatively low salinity did euxinic conditions exist which gave rise to bituminous deposits.

From the distribution of dolomites and bituminous deposits the presence of an east-west striking swell, the Coevorden Swell, has been inferred, showing that this was a higher and more slowly subsiding tract in the Upper Permian basin.

The transition of marine Upper Permian to continental Bunter cannot be regarded as a time boundary; nor are time and rock units within the Upper Permian basin necessarily identical.

## 1. Introduction

Our knowledge of the Upper Permian in the Netherlands is derived exclusively from borehole data, since there is no place in the country where the formation comes to the surface. These subsurface data originate from several sources, i. e. the investigations by the "Rijksopsporing van Delfstoffen" as published in the R. O. v. D.'s Final Report and Supplement, the "Gelria" boreholes in the Winterswijk area, recently compiled, together with the R. O. v. D. boreholes, by A. J. PANNEKOEK (1952), and the deep drilling by the "Bataafsche Petroleum Maatschappij" (Royal Dutch/Shell Group) and their successors the "Nederlandsche Aardolie Maatschappij" [a 50/50 participation of B. P. M. and Standard Oil Co. (New Jersey)]. Since 1947 the N. A. M. has carried out an intensive exploration programme — gravity, seismic and deep drilling — in their search for oil and natural gas throughout the country.

Of the exploration wells, so far (October 1954) completed by N. A. M., 25 reached or penetrated the Upper Permian, 4 encountering natural gas in economic quantities (Coevorden 2 in Main Dolomite, 1949; Tubbergen 4 in

Platy Dolomite, 1951; Denekamp 1 in Platy Dolomite, 1952; De Wijk 6 in Main Dolomite and Basal Zechstein, 1953). A further 7 wells were drilled in the above-mentioned gasfields for evaluation purposes, of which only 2 are good producers, 2 yielded small quantities of gas only and 4 struck water. One of the smaller producers also found the Main Dolomite productive in Tubbergen.

The limited success in the Permian dolomites is due partly to the reservoir conditions, partly to the thick rock salt deposits. In many cases the rock encountered was too tight to produce gas, favourable cracks not having developed; in other cases, the rock salt being a strong absorber of seismic energy, the producing dolomites could not be mapped with sufficient accuracy.

## 2. The Upper Permian basin and facies

The Upper Permian basin in the Netherlands was situated north of the Brabant and Rhenish masses. In front of the former extended a shallow sub-marine platform on which a thin Upper Permian was deposited partly in evaporitic facies. Only in the northeastern part of the country do thick beds of rock salt occur; here stratigraphy and palaeogeography are comparable to NW Germany, where F. HEIDORN (1949) has recently discussed the Upper Permian in great detail. The German part of our map fig. 1 has been adopted from HEIDORN; the southern limit on the Upper Permian — greatly simplified — from L. U. DE SITTER (1949).

In Germany the Upper Permian is divided into four evaporation cycles, from old to young, called "Werra"-, "Stassfurth"-, "Leine"- and "Aller"-series, which for reasons of convenience, are here referred to as the 1st, 2nd, 3rd and 4th evaporation cycle respectively.

A complete cycle begins with clastic sediments, followed on account of increasing basin salinity by dolomite or dolomitic limestone, anhydrite, rock salt and bitter salts (in the Netherlands the latter consist of rock salt with an admixture of K and Mg salts to a maximum of about 10 %); each cycle is closed by a series laid down under conditions of decreasing salinity: thin rock salt, anhydrite. In the Netherlands, however, not only the area of salt deposition as a whole, but also the areas of deposition of the individual rock salt members are of limited horizontal extent.

Outside the area of rock salt deposition the Upper Permian consists of a series of anhydrite, dolomite and clastic, mainly argillaceous materials, quickly thinning to the west (about 100 m in western Holland). This partly evaporitic deposit passes towards the south into a near-shore or coastal facies of mainly reef-dolomites and limestones with marls and clayey beds of the Peel and the Belgian Campine (DE SITTER, 1949). It was not possible to establish any correlation between the three facies, the near-shore facies in the south, the anhydrite facies in the western and central part and the rock salt facies in the east and north, nor can the rhythm of the rock salt facies, as expressed in the evaporation cycles, be traced into the area of the anhydrite facies, except locally near its boundary.

The rock salt facies was deposited in an unstable, quickly subsiding area, whereas the more stable platform to the northeast of the Massif of Brabant did not follow its movements at the same rate. The near-shore and the greater part of the anhydrite facies may represent the lower part of the Upper Permian only. Hence in certain localities the marine Permian may have been replaced by the continental Bunter Sandstone at a relatively early date. This suggestion is supported by the stratigraphy of the rock salt facies.

Palaeogeography and stratigraphy of the Upper Permian, of which the

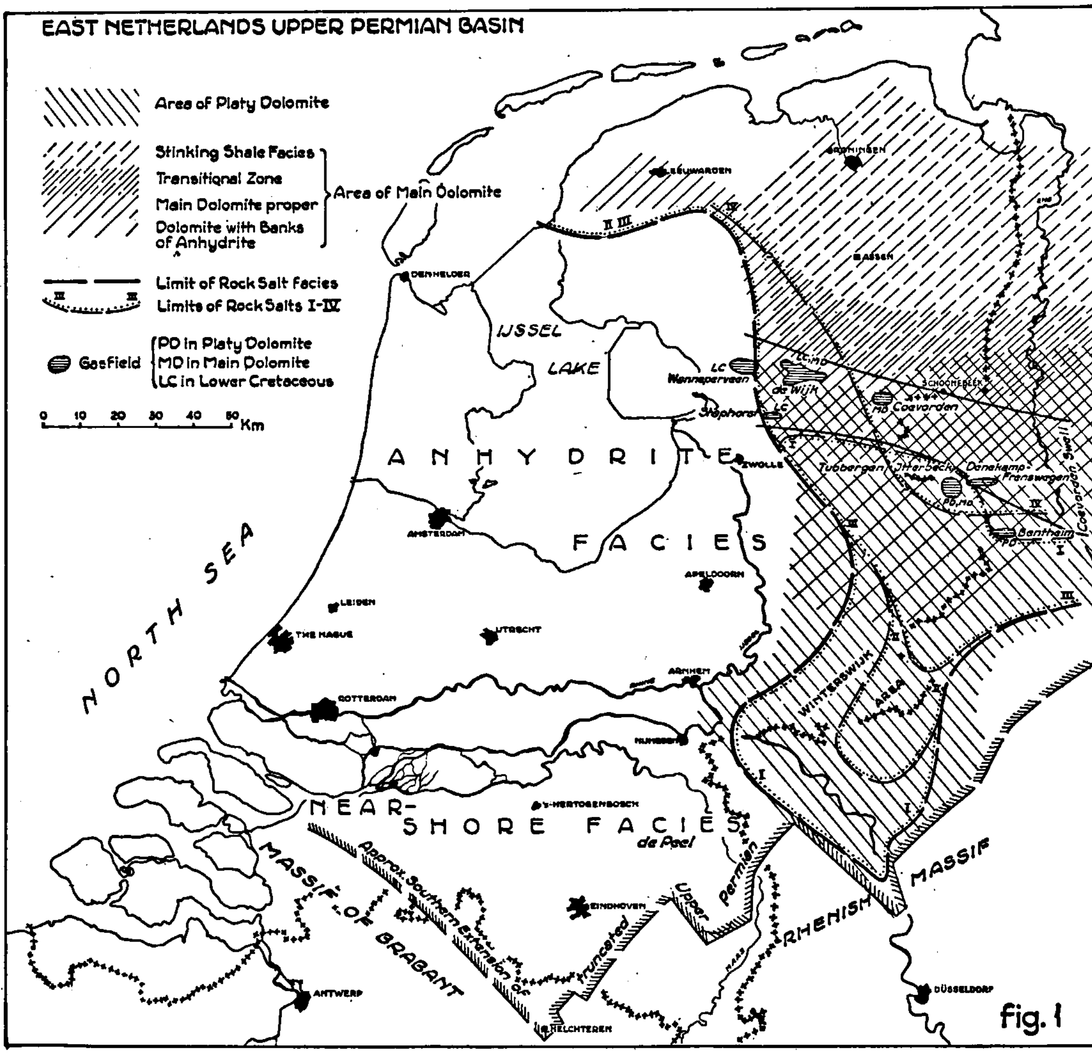


Fig. 1. East Netherlands Upper Permian basin.

rock salt facies forms economically the most important and most interesting part, are depicted on map fig. 1 and section fig. 2. As is the case in Germany, also in the northeastern Netherlands the deposits, which belong to the rock salt facies, are subdivided into four evaporation cycles. Here the development of the cycles is, however, less complete than in Germany.

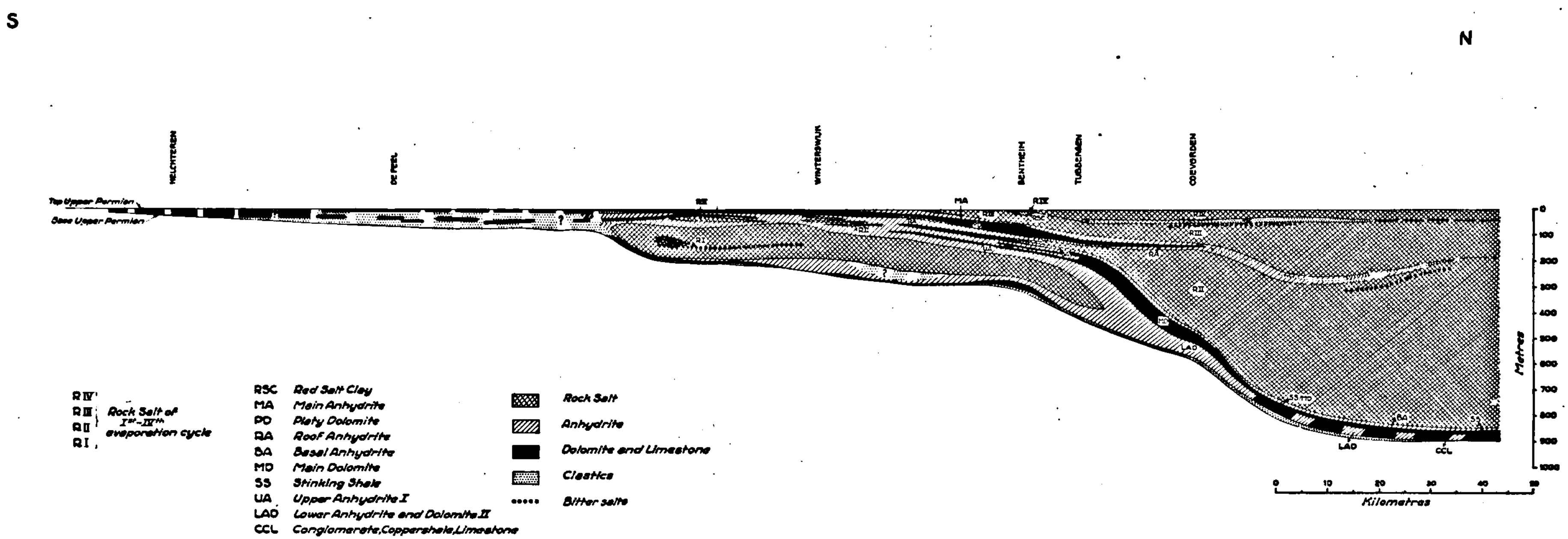


Fig. 2. Upper Permian stratigraphic section.

The *first evaporation cycle* from young to old is divided as follows:

| | | Maximum thickness in m |
|---|---|---|
| Upper Anhydrite I | | 70 |
| Upper Rock Salt I | abt. | 80 |
| Zone with bitter salts | abt. | 10 |
| Lower Rock Salt I | abt. | 60 |
| Lower Anhydrite I | | 90 |
| Dolomite I | | 30 |
| Limestone | | 4 |
| Coppershale | | 0,5 |
| Conglomerate | | 3 |

Rock Salt I is restricted to the southern part of the area of the rock salt facies. Each of the three lower members, which together form the classic Lower Zechstein, may be missing locally. Dolomite I, a massive dolomite often with nodules of fine-grained anhydrite, is not present in an area roughly coinciding with the area of deposition of Rock Salt I, where it is replaced by Lower Anhydrite I, generally a fine-grained mixture of anhydrite and some dolomite.

From the distribution of Rock Salt I and Dolomite I, it follows that during the deposition of the 1st evaporation cycle the area of greatest subsidence was situated in the area between the Rhine and Tubbergen, whence its eastern extension forms HEIDORN's "Osnabrücker Seestrasse" between Bentheim south flank and Rhenish Mass. The high area north of the area of greatest contemporary subsidence, the "Coevorden Swell", is an important feature in the Upper Permian rock salt basin.

During the deposition of the *second evaporation cycle*, which is divided as follows:

| | | Maximum thickness in m |
|---|---|---|
| Roof Anhydrite | | 15 |
| Rock Salt II, with a zone of bitter salts in its upper part | abt. | 800 |
| Basal Anhydrite | | 15 |
| Main Dolomite | | 55 |

the area of greatest subsidence had moved northward, which may be concluded from the southern "pinching" out of Rock Salt II and the facies change of the Main Dolomite.

In the Winterswijk area Rock Salt II is very thin and several intercalations of anhydrite and some clastic sediments occur; between Tubbergen and Coevorden the salt deposit quickly thickens and the intercalations mentioned have disappeared; the deposit attains its greatest thickness north of Coevorden.

The Main Dolomite proper was encountered at De Wijk and Coevorden, where it consists of a 40—55 m thick deposit of a dark-grey, sometimes finely interlaminated with dark-grey bituminous clay partings, but generally unbedded dolomite with subordinate limestone and often with anhydrite nodules or streaks. Northward its upper beds according to HEIDORN (no conclusive evidence for this statement is available in the Netherlands) gradually pass into the "Stinking Shale" ("Stinkschiefer" in Germany), this actually being not a shale but an alternation of bituminous paper-thin beds of anhydrite and limestone. In Groningen the deposit is 9 m thick. South of Coevorden banks of anhydrite become intercalated in the Main Dolomite (Tubbergen, Bentheim) and still further south, in the Winterswijk area, no further dolomite is present. Here Upper Anhydrite I and Basal Anhydrite (cycle II) form a single deposit with a maximum thickness of 17 m.

The southward facies change of dolomite into anhydrite indicates, that south of Coevorden the basin became deeper, as was also the case during deposition of the underlying Rock Salt I. The occurrence of anhydrite in the "Stinking Shale" may indicate, however, that towards the end of the deposition of the Main Dolomite the area north of Coevorden commenced to subside with respect of the Coevorden area, this subsidence continuing during the precipitation of Rock Salt II.

During the precipitation of the Main Dolomite, a period of movement and relatively low salinity, conditions seem to have been favourable for the development of bituminous deposits, viz. the bituminous "Stinking Shale" and the clay partings in the Main Dolomite. Owing to the downward current of heavy surface waters concentrated by evaporation, an evaporation basin is usually well aerated. As a result the occurrence of euxinic conditions is exceptional.

Primary bitumina only occur in the clay partings in Main and Platy Dolomites, in the argillaceous members (Coppershale, Grey Salt Clay, with the exception of the Red Salt Clay which is probably of continental origin) and in the Stinking Shale. Although it is known that in isolated continental salt pans black clays can accumulate under anaerobic conditions, the Upper Permian marine evaporitic basin must have been well aerated for the greater part of its history. Neither in the anhydrites nor in the rock salts have primary bitumina been observed. Whereas during deposition of the latter sediments conditions were stable, at the transition from one cycle to the next and at the beginning of a cycle, when tectonical conditions were changing and salinity was relatively low, according to P. C. Scruton (1953) fluctuations in physical conditions may have been such that the basin periodically or temporarily changed from an aerated to an euxinic one.

Similar conditions occurred in the North American Upper Permian, where in the Paradox and Castile formations a facies occurs comparable to the Stinking Shale in an otherwise non-bituminous sequence (Scruton, 1953, p. 2509).

The remnant of the Rock Salt I basin disappeared during the deposition of the *third evaporation cycle*, which is subdivided as follows:

| | Maximum thickness in m |
|---|---|
| Rock Salt III, with in its upper part a zone of bitter salts | 170 |
| Main Anhydrite | 15 |
| Platy Dolomite | 40 |
| Grey Salt Clay | 4 |

A similar facies change as in the Main Dolomite but in the opposite direction, occurs in the Platy Dolomite. In its optimum development in Bentheim and Tubbergen it consists of an about 40 m thick deposit of a dolomite, finely bedded by clay partings, with some limestone and an occasional nodule or streak of anhydrite. Southward the Platy Dolomite decreases in thickness to about 20 m in the Winterswijk area, where it has locally developed to a limestone; northward the anhydrite content quickly increases and in Coevorden 2 only a bed of anhydrite (Roof- and Main Anhydrites without an intervening dolomite) separates Rock Salts II and III. There is some evidence that still further north the anhydrite disappears too.

The Platy Dolomite only occurs in the shallow southern part of the basin, where, after the deposition of the Main Dolomite, subsidence was small as compared to the area north of Coevorden. In the latter area, where the maximum subsidence occurred, both during the deposition of Rock Salt II and of the far thinner 3rd evaporation cycle, the Platy Dolomite quickly pinches out and disappears.

In the Winterswijk area, after the precipitation of the Main Anhydrite, marine deposition was replaced by the continental Bunter. The southern limit of Rock Salt III lies north of Winterswijk, i. e. further north than the southern extension of Rock Salt II. Although it was not as drastic a change as the shift at the end of the precipitation of the Main Dolomite, the northward movement of the basin continued during the lower stages of the 3rd evaporation cycle.

During the period of lowest salinity at the beginning of the 3rd cycle, represented by the deposition of Grey Salt Clay and Platy Dolomite, conditions were again favourable for the development of an euxinic basin, as the frequent occurrence of bituminous clay-partings indicates.

The third evaporation cycle is not complete in the Netherlands. In northern Germany two zones with bitter salts, the "Riedel" and "Ronnenberg" zones, occur in the central part of the Upper Permian basin and are separated by anhydrite and rock salt.

In the northeastern Netherlands there is only one bitter salt zone, about 6 m thick, which is covered by a few metres of rock salt. The covering rock salt is in turn overlain, without intervening anhydrites, by the basal bed of the 4th evaporation cycle, the Red Salt Clay, indicating an abrupt end of the 3rd cycle. On the other hand, in the extreme north the beds separating Rock Salt III and IV seem to disappear as was the case with those separating Rock Salts II and III. It is suggested that here a continuous high salinity and precipitation of rock salt were maintained during the 2nd, 3rd and 4th evaporation cycles, whereas in the tectonically unquiet area to the south a rhythmic alternation of precipitates was formed.

The *fourth evaporation cycle*, which is subdivided as follows:

| | Maximum thickness in m |
|---|---|
| Rock Salt IV | 30 |
| Pegmatite Anhydrite equivalent | 4 |
| Red Salt Clay | 12 |

is also incomplete. In Germany it is topped by the Boundary Anhydrite, but the latter bed is missing here, as well as the "Zechstein-Letten", which in drill cuttings cannot be distinguished from the Bunter.

The Red Salt Clay may possible be a continental deposit. After its sedimentation, a renewed ingression of the sea caused the equivalent of the Pegmatite Anhydrite, here a generally fine-grained mixture of anhydrite and dolomite, to be deposited; otherwise no dolomite occurs in this cycle.

Rock Salt IV is only a thin deposit and no bitter salts occur, nor does it reach as far south as its pre-decessor Rock Salt III.

### 3. Development of the basin

In his *Principles of sedimentation* (1950, p. 503) W. H. TWENHOFEL lists at least eight variables which can influence character, thickness and succession of evaporites: rainfall; temperature; duration of the connection with the open ocean; shape, depth and size of the evaporitic basin; inflow of clastics, and tectonic movements. Some of these factors are climatic, others depend on crustal movements; the latter are obviously the cause of the sequence and extent of the various evaporation cycles in the Netherlands-North German Upper Permian basin.

P. C. SCRUTON (1953), after a discussion of the currents which will be set up in an evaporating sea with restricted entrance, has advanced a theory giving the relation between basin salinities and precipitates at different places and at successive stages in such a basin. To quote (p. 2510; 5, 6):

"Horizontal segregations of pure evaporite deposits are produced because of the development of a strong horizontal salinity gradient, salinities increasing from the entrance to the head of the evaporating pan, and by the different salinity ranges at which precipitation of different salts occurs.

The vertical sequence of beds which result from salinity changes can be predicted approximately from experiments on evaporation of sea water. The predicted sequence results from lateral migration of the horizontal salinity gradient and shows excellent agreement with natural sequences which have been described in detail. Salinity changes are produced principally by changes in precipitation or channel restriction and to lesser extent by variations of temperature, sea-level, or wind stress".

SCRUTON's model is well applicable to the basin under discussion, if a factor for the bottom configuration is introduced. As indicated by the facies changes and pinch-outs of the dolomites and simultaneously varying thickness of the rock salt deposits — on a smaller scale within the area of rock salt deposition, on a bigger scale in the differences between rock salt and anhydrite facies — the kinds of evaporite are to a great extent controlled by the depths (or varying rates of subsidence) in the basin. The factor to be introduced, viz. the bottom relief of the basin, is caused by differential rates of subsidence. Owing to density currents the densest waters, i. e. those of highest salinity at a particular stage, were concentrated in the deepest parts of the basin. Thus if dolomite is precipitated in a comparatively shallow tract, in an adjacent deeper tract anhydrite, and in the deepest pockets rock salt could be deposited simultaneously. Hence time and rock units are not necessarily identical.

In the rock salt facies the series dolomite — anhydrite — rock salt — bitter salts represent deposition in a subsiding basin where salinity increased owing to the greatly restricted circulation in a stable entrance channel. The overlying reversed series, rock salt — anhydrite, were precipitated in a subsiding basin, where salinity decreased. The cause of this decrease in salinity is to be found in the tectonical movements which initiated the northward shift of the basin at the transition to the next cycle and which possibly enhanced circulation in the entrance channel.

During the precipitation of the 1st evaporation cycle south of Tubbergen, the area of main subsidence at the time, Lower and Upper Anhydrite I and Rock Salt I were deposited, whereas on a shallow platform to the north of Tubbergen (Coevorden Swell and the northeast adjoining area) dolomite and subordinate anhydrite (Dolomite I) were formed. On the Swell of Coevorden Dolomite I grades into the Main Dolomite proper. The lower part of the latter is possibly contemporaneous with Dolomite I to the north, and Rock Salt I and Upper Anhydrite I to the south of the Coevorden Swell.

The subsidence of the area north of Coevorden commences with the deposition of the Stinking Shale facies of the Main Dolomite, whilst the precipitation of dolomite (Main Dolomite proper) was still in progress on the Swell of Coevorden itself and whilst continuous sedimentation of anhydrite (Upper Anhydrite I and Basal Anhydrite) was proceeding to the south of it in a still deeper part of the basin.

The Swell of Coevorden may still have received dolomite at a time when Basal Anhydrite and Rock Salt II were precipitated on its northern slope. No explanation can be given for its great thickness as compared to the adjoining anhydrites unless we assume a prolonged period of deposition of the Main Dolomite proper.

At a later stage of the 2nd evaporation cycle salinity had increased to such an extent that anhydrite and rock salt were deposited on both sides of, and even on the Swell. But by that time the main area of subsidence had already moved to the north of Coevorden.

The occurrence of primary bitumina in the Stinking Shale and the lack of it in contemporaneous deposits south of Coevorden gives a further indication of the co-existence of two sub-basins separated by the (sub-marine) Coevorden Swell. As discussed before, the generally well-aerated Upper Permian basin was not a favourable milieu for the development of euxinic conditions, the latter only occurring during certain periods of its history when salinity was relatively low and physiographic conditions were changing. The occurrence of an aerated part of the basin adjoining one with stagnant waters can hardly be explained without assuming a barrier between the two. During deposition of Stinking Shale, Main Dolomite proper and Basal Anhydrite an euxinic basin occurred north of the Swell, whilst non-euxinic conditions prevailled south of it.

Platy Dolomite, Main Anhydrite and Rock Salt III may be partly contemporaneous deposits, lithological character being governed by depth of deposition, so that the precipitation of the Platy Dolomite may have lasted well into the period of deposition of Main Anhydrite and Rock Salt III. Again, prolonged dolomitic deposition on and immediately south of the Coevorden Swell is assumed to explain its thickness. The occurrence of bituminous clay partings also reflects the existence of the Coevorden Swell. Non-bituminous anhydrites were deposited in the deep basin to the north, and dolomites with bituminous clay partings in the shallower basin to the south. With regard to circumstances during deposition of the Main Dolomite, conditions were reversed. Now an euxinic basin occurred to the south of the Swell, aerated waters to the north.

After the deposition of Platy Dolomite and Main Anhydrite no further influence of the Coevorden Swell can be discerned, as the southern sub-basin has disappeared.

In Germany the deposition of Rock Salt III with its associated bitter salts took place in two phases of high salinity separated by a stage of anhydrite and rock salt deposition; in the Netherlands only one zone of bitter salts occurs, overlain by a few metres of rock salt. Then the cycle is suddenly interrupted by the possibly continental Red Salt Clay, indicating an emergence of the basin, which was followed by quite sudden subsidence accompanied by rapid increase in salinity. No pure dolomite was precipitated, but only the Pegmatite Anhydrite equivalent. No bitter salts are known from the 4th cycle. After the deposition of Rock Salt IV a quick emergence to continental conditions of Bunter deposition must have taken place, so that, at least in the Netherlands, not even any covering anhydrite was formed.

The transition from marine evaporitic Upper Permian to continental wind-blown Bunter is not a time boundary, since it occurred at a comparatively early date in the southern part of the area of the Rock Salt facies and subsequently moved northward. As a result the near-shore facies of de Peel and the greater part of the anhydrite facies may represent only the lowest or lower stages of the Upper Permian. Moreover the Bryozoa reefs of the former can only have grown in waters of a salinity comparable to that of — or on account of the paucity of the fauna somewhat higher salinity than — normal oceanic water. Such waters can only have reached the southern coastal part of the basin at a time, when evaporation was still negligible. Since evaporation necessarily takes place at the surface of the sea, no layer of such water, floating on more concentrated brines and in which reefs could grow, can possibly occur.

Consequently reefs could only have been formed at periods of comparatively low salinity, i. e. at the beginning of the Upper Permian or perhaps at the beginning of the evaporation cycles. As the near-shore facies did not follow the northern shifts of the basin, the formation of the reefs can be dated as having occurred at the very beginning of the Upper Permian.

At that time circulation in the deeper part of the basin has been prevented, giving rise to the bituminous Copper Shale, its faunal content (exceptional in the Upper Permian clays) probably being derived from the overlying layer of aerated water.

When evaporation increased and as a consequence downward density currents (rendering the formation of reefs impossible), were set up, the evaporitic sequence commenced to be deposited. Then already in the extreme south marine deposition possibly has been replaced by the continental Bunter facies, whilst sub-marine precipitation in a shallow, stable, and slowly subsiding basin in the western and central part of the Netherlands gave rise to the anhydrite facies and whilst in a deep, unstable, quickly subsiding part in the NE the rock salt facies was deposited.

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