SEDIMENTARY HISTORY OF THE PALEOZOIC WAJID GROUP (SAUDI ARABIA) AND IMPLICATIONS FOR THE TECTONO-STRATIGRAPHIC EVOLUTION OF THE SOUTHWESTERN ARABIAN PLATFORM

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In the Kingdom of Saudi Arabia, Lower Paleozoic rocks crop out extensively in many areas and are well known from the subsurface (Konert et al., 2001). In the southern part of the country, the Paleozoic deposits are known as the Wajid Group, which is composed of five formations: The Dibsiyah, Sanamah, upper Sanamah or Qusaiba, Khusayyayn, and Juwayl formations.

The strata crop out in the area between Wadi Ad Dawasir and Najran in the south. They unconformably onlap the basement of the Arabian Shield to the west. Mapping has revealed that the general dip of the strata invariably is 1° to 2° to the east where they disappear beneath the Tuwaiq Escarpment.

The plate tectonic background of sedimentation on the Arabian Platform and the main sequence-stratigraphic aspects has been described by Sharland et al., 2001). For the Paleozoic 4 main units are recognized. Arabian Plate-Tectonic Megasequence (TMS AP) 2, of Early Cambrian through Late Ordovician age, is characterized by stable platform conditions related to a passive margin setting of the Arabian Plate at the northeastern edge of Gondwana. The main triggering factors of sedimentation were sea-level changes in a combination of eustacy and variable subsidence. The upper bounding surface is an erosional surface interpreted to have been formed prior to the deposition of the Hirnantian glacial deposits. TMS AP 3 comprises the Upper Ordovician through Devonian sediments that were laid down essentially in an intra-cratonic setting. In Oman, however, the Huqf Arch became active as evidenced by regional uplift and the intrusion of basalts. The upper bounding surface of probably Famennian age seems to mark the onset of back-arc rifting along the northern margin of the Arabian Plate. TMS AP 4 was formed during the Late Devonian through Late Carboniferous, a time of major tectonic readjustments. The Arabian Plate was in an intra-cratonic back-arc setting caused by subduction beneath the plate at its northern margins. In its interior, block faulting led to uplift along pre-existing basement faults. Consequently, across much of the plate, accommodation was limited and the sedimentary record is sketchy. TMS AP 5 starts with the Late Carboniferous rifting that eventually led to the separation of the Cimmerian Terranes from Gondwana. In Saudi Arabia, the upper limit of TMS AP 5 is marked by the pre-Khuff unconformity, which is the upper bounding unconformity of the Wajid Group. In the Wajid Group, the 5 units recognized can relatively easily be attributed to these megasequences. Their position within these sequences however remains speculative, because there are almost no biostratigraphic ages for the formations.

The Dibsiyah Formation of presumably Cambrian to Ordovician age is a marine unit. In its lower part it shows an alternation of conglomeratic sandstones and coarse-grained sandstones with some bioturbation. Large-scale, 2D-trough cross bedding is very prominent. The upper part consists of medium- to coarse-grained sandstones. In this part, Skolithos sp. and Bergaueria sp. abound. Individual horizons, totally bioturbated, are up to 13 m thick. The sedimentary structures and the bioturbation indicate that the unit was deposited in a (meso-) tidal environment. In the Wajid outcrop belt, the Dibsiyah Formation represents TMS AP 2. To date, no more precise attribution to the Cambrian or Ordovician equivalents in northern Saudi Arabia can be made because of the lack of age-diagnostic fossils.

The Sanamah Formation was deposited across a major unconformity that is correlated to the sequence boundary between TMS AP 2 and TMS AP 3. The Sanamah Formation consists of a basal succession of red conglomerates and coarse-grained sandstones. Most of the clasts are rounded to well rounded, sorting is moderate to poor. Sedimentary structures include large-
scale trough cross bedding and lateral accretion complexes. The second unit is composed of massive yellow to beige coarse-grained sandstones. There is hardly any cross bedding visible, and only a few reactivation surfaces have been found. The third unit is a succession of sandstone that shows repeated horizons of slumping. The sediments are well bedded; grain size is medium to coarse sand. The fourth unit is a conglomerate that shows trough cross bedding, a bad sorting, and clasts that are subangular to subrounded. In these sediments, a few striated clasts have been found. According to its position above a major unconformity and the indicators of glacial to proglacial origin, the Sanamah Formation is interpreted to represent the basal TMS AP 3, the glacial episode (see also Hinderer, this volume).

The Upper Sanamah or Qusaiba Formation is a fine-grained unit of presumably Silurian age. It is interpreted to reflect the sea-level rise that followed the Late Ordovician glaciation and consequently also belongs to TMS AP 3.

The Khusayyayn Formation is a thick Devonian unit, composed almost entirely of medium- to coarse-grained quartz sand. This sand was deposited in spectacular large tabular cross beds, which often can be traced laterally over hundreds of meters. Individual beds are up to two meters thick. These deposits are interpreted to have been formed in a marine, meso- to macrotidal environment. The confining unconformities indicate that the Khusayyayn Formation represents AP 4 in the Wajid outcrop belt.

The Juwayl Formation represents the Late Paleozoic glaciation. It is a complex arrangement of different lithofacies of glacial, proglacial and periglacial facies and is the representative of TMS AP 5 in southern Saudi Arabia. In the Wajid outcrop area, the sediments were deposited in two major channels, each several kilometers wide and presumably a couple of hundred meters deep. These channels apparently fed a giant glacial lake in the present day Rub' Al Khali basin where Hinderer et al. (this volume) interpreted them as fluvial channels carved into the sediments in front of the glaciers. The valley fill consists of massively bedded sandstones or conglomerates, often with no visible internal structure. Where individual sand bodies were identified, their erosional bases indicate permafrost conditions (vertical or overhanging walls). Varve sediments occur in different positions, often associated with dropstones of basement origin, but sediments of the underlying strata have also been observed.

The contacts between all individual units described above are unconformities. Previous workers have repeatedly argued that these are angular unconformities and have related these unconformities mainly to different orogenic movements ((Powers et al., 1966); (Stump & Van Der Eem, 1996)).

The Dibsiyah – Sanamah contact is an erosional unconformity. The Sanamah is present in major valleys incised into the Dibsiyah Formation. The origin of these valleys is not known; they may represent fluvial channels or ice tunnel valleys. These valleys were filled with the majority of the Sanamah Formation, only locally are very thin sediments observed that onlap and transgress the valleys. The overlying Upper Sanamah or Qusaiba Formation was deposited over a major transgressive surface. The corresponding sea-level rise is presumably caused by post-Hirnantian deglaciation. The Khusayyayn Formation again covers an erosional relief. The geometry of the unconformity indicates that sea-level change alone cannot be responsible for the formation of the unconformity: Near Hima, north of Najran, the Khusayyayn rests on Precambrian granites. In this area, the unconformity resembles a high-energy shoreline with bays and well-washed cliffs. Ina recently drilled well some 10 km away, however, the Qusaiba and underlying siliciclastics of either the Sanamah or the Dibsiyah have been observed. In other areas, the Khusayyayn rests on Qusaiba and in several places, on Sanamah. In the central study area, large-scale erosional channels can be observed in the outcrops cutting down through the Qusaiba into the Sanamah.
The majority of the Juwayl Formation was deposited in two major, NW – SE running channels that have already been mapped by Kellogg et al., 1986. The lake deposits however, extend over much larger areas (Pollastro, 2003).

The angular unconformities between the Dibsiyah – Sanamah and the Khusayyayn – Juwayl are erosional. The pre-Khusayyayn unconformity is also an erosional unconformity, although this becomes apparent only from detailed mapping. The interpretation of all these unconformities being angular unconformities stems from individual outcrops in which large-scale erosional channels that extend over 100s of meters or more are stacked and superimposed onto one another. The situation is comparable to a braided-river system where the individual channels cross cut each other with inclined foresets and pretend an angular relationship between the sedimentary bodies.

The basal unconformity of the Wajid Group onto the basement is of presumed Precambrian or Cambrian age. The basal Dibsiyah sediments yet contain abundant bioturbation and trilobites that indicate that the transgression onto the peneplain is of Cambrian or Ordovician age. A more precise time attribution hitherto is not possible. In comparison with the deposits of the northern Kingdom it seems that the Dibsiyah Formation is a thinner, more amalgamated succession, which is probably due to more cratonward position of the Wajid basin. In addition, it cannot be excluded that there are some as yet undetected unconformities within the Dibsiyah Formation.

The Dibsiyah – Sanamah unconformity can relatively confidently be attributed to the eustatic sea-level changes induced by the Upper Ordovician glaciations. In combination with the subsurface data from northern Saudi Arabia, glacier flow away from the Arabian Shield has to be assumed. At that time, the Arabian Shield acted as a slightly elevated positive area. As post-glacial sea-level rise accelerated, the Qusaiba fine-grained siliciclastics were deposited across the entire area. Although their distribution in outcrop is sketchy, they were found in several newly drilled wells. This findings point to an erosional removal of the Qusaiba Formation beneath the Khusayyayn unconformity. As the latter irregularly overlies all strata from the basement to the Qusaiba Formation, it is here assumed that the pre-Khusayyayn unconformity was caused by differential uplift, either in the form of block faulting or folding. As there is little evidence of folds or thrusts older than the Khusayyayn, we interpret these movements as a long distant effect of crustal stretching in Oman which led to uplift of the Huqf Arch. Apparently, these crustal movements affected larger areas than hitherto assumed.

The pre-Juwayl unconformity, finally, is a combination of eustatic effects and tectonic movements. Compressional movements attributed to “Hercynian” tectonics caused block faulting and uplift. Coeasily, the Late Paleozoic glaciation led to sea-level draw down. In this combination, the valleys of the Juwayl were carved into the underlying sediments. The valleys apparently originated close to the ice shield; probably only the best-developed valleys were filled and preserved as the preservation potential of glacial features in a system of repeatedly advancing and retreating ice shields is relatively low.

In conclusion, the sedimentary patterns and the unconformities within the Wajid Group record a variety of factors that acted alone or in unison. Tectonic uplift and peneplanation caused the pre-Dibsiyah unconformity; uplift is responsible for the pre-Khusayyayn unconformity and is a part in the formation of the pre-Juwayl unconformity; eustatic sea-level changes are reflected in the pre-Sanamah unconformity, in the flooding event that led to the deposition of the Qusaiba Shale, and partly attributed to the formation of the Juwayl channels.
Plate 1: above, one of the large channels is visible that cuts down from the base of the Khusayyayn Formation into the Qusaiba Formation. The channel, observed in the Jibal al Qahr, is approximately 800 m wide. In the lower photo, a similar channel is visible, this time eroding Dibsiyah strata beneath the Ordovician Sanamah Formation. Outcrop in thevicinity of Jabal Sanamah is approximately 1 km wide.

References