GEOLOGY OF OMAN CONFERENCE

The International Conference on the Geology of Oman was held on January 12–16, 2001, at Sultan Qaboos University, Muscat, Sultanate of Oman. It was organized by the Oman Ministry of Commerce and Industry, together with Sultan Qaboos University and UNESCO, and was attended by more that 600 delegates. The Conference was opened by HH Sayyed Faisal bin Ali, Minister of National Heritage and Culture accompanied by HE Maqbool bin Ali Sultan, Minister of Commerce and Industry, and attended by many dignitaries.

The Chairman of the Organising Committee was HE Mr. Masoud Al-Sunaidy, Under Secretary of Commerce and Industry. The Vice Chairman was Dr. Hilal bin Mohammed Al-Azri, Director General of Minerals; and the Secretary, Mr. Harib bin Hamad Al-Hashmi, Head of the Geographic Information System. The Organising Committee also included 19 members representing Sultan Qaboos University, Muscat Municipality, Ministry of Defence, Royal Oman Police, Ministry of Water Resources, Ministry of Information, Ministry of Oil and Gas and Ministry of Commerce and Industry. In addition, the Organising Committee, was assisted by a Local Committee that was chaired by Dr. Hilal bin Mohammed Al-Azri and assisted by 22 members representing the above ministries and institutions.

The Chairman of the Scientific Committee was Prof. Tjerk Peters, University of Bern; and the Vice Chairmen: Dr. Hilal bin Mohammed Al-Azri, Ministry of Commerce and Industry, Oman, and Prof. Max Dobson, Sultan Qaboos University. The members of the Scientific Committee were: Mr. Zaher Al-Sulimani, Ministry of Water Resources; Dr. Aymond Baud, Geological Museum Lausanne, Switzerland; Prof. Francoise Boudier, Montpellier University; Prof. R. Coleman, Stanford University; Dr. Samir Hanna, Sultan Qaboos University; Prof. Peter Kelemen, Woods Hole Oceanographic Institution, USA; Dr. Joel Le Métour, BRGM; Prof. Albert Matter, Bern University; Dr. Sumio Miyashita, Niigata University, Japan; Dr. Masatsugu Ogasawara, Geological Survey of Japan; Dr. Jeroen Peters, Petroleum Development Oman; Prof. Alastair Robertson, Edinburgh University; and Dr. Mike Searle, Oxford University.

More than 300 studies were presented during the five days, and these covered the full spectrum of the Earth Sciences. Numerous studies described ophiolites from many regions of the world, particularly the unique ophiolites of Oman. The conference also covered the evolution of the southern Tethys margin and Pangea; tectonics of the Arabian Plate, Red Sea and the Gulf of Aden; the hydrocarbon habitat of the Arabian Peninsula; hydrogeology of arid regions; environmental geology; and industrial minerals.

The four keynote presentations were: (1) Introduction to the Geology of Oman, by Dr. S. Hanna, Sultan Qaboos University; (2) Overview of the tectonic setting of northern Oman and the evolution of the Tethys realm, by Prof. A. Robertson, Edinburgh University; (3) Arabian Plate Sequence Stratigraphy by Mr. P. Sharland, LASMO; and (4) Introduction to the Symposium on Ophiolites by Prof. A. Nicolas, Montpellier University.

In addition to the technical sessions, field excursions covered many subjects in the spectacular countryside of Oman. These included: (1) Permo-Triassic deposits of the Tethys Platform; (2) Lower to Middle Permian sedimentation on the Arabian Platform; (3) Sedimentary and structural evolution of the Mesozoic of the Central Oman continental margin and slope basin; (4), Stratigraphic evolution of the Batain Embayment of the southern Tethys; (5) Structural geology of the Oman Mountains; (6) Northern Semail Ophiolite and related metamorphic and granitic rocks; (7) Geology of the Northern Oman Ophiolites; (8) Mineralisation styles in northern Oman unrelated to the ophiolite; (9) Geology of Masirah Island; and (10) Sequence stratigraphy and reservoir geology of the Cretaceous carbonates. These excursion were accompanied by detailed field guides.

An evening official dinner and Omani night at the Al Bustan Palace Hotel was one of the highlights of the conference social events. Tourist visits were also organised to the famous traditional souq of Nizwa town. The organisers of the conference are congratulated on this well-organized and truly international meeting.

Juma Al-Belushi
Petroleum Development Oman, Muscat

Selected Petroleum Geoscience Abstracts

Due to page limitations, and the petroleum specialization of *GeoArabia*, all the abstracts of the Geology of Oman Conference cannot be published here. Instead, a selection of nearly 100 abstracts was made by several members of the Editorial Board of *GeoArabia*.

These abstracts describe subjects that are considered to be of interest to Middle East petroleum geoscientists. Specifically, they discuss the stratigraphy of Oman and adjacent regions (lithostratigraphy, biostratigraphy and sequence stratigraphy), petroleum systems and hydrocarbon habitats, mapping projects in Oman, the evolution of the basement in relation to the sedimentary cover rock, and the regional tectonics of Oman and adjacent regions. A few *GEO 2000* abstracts that appeared earlier in *GeoArabia* (Volume 5, Number 1, 2000) are not republished.

Moujahed Al-Husseini
Editor-in-Chief, *GeoArabia*

Abstracts

#54 The hydrocarbon habitat of the Upper Cretaceous Natih Formation of North Oman

Al Habsi, A., Al Siyabi, H., Partington, M., PDO, Oman

The middle Albian to early Turonian Natih Formation represents a carbonate ramp depositional system, in which back shoal, shoal complex, fore shoal slope and open shelf depositional environments are recognised. The formation, which consists of four 3rd order depositional sequences, is lithologically divided into 7 members (A through G).

To date, all commercial Natih hydrocarbon accumulations are found in structural traps. These traps are in the form of four-way dip closures or fault-dependent closures. The main reservoir intervals are the Natih A and E. While Natih A reservoirs are sealed by the overlying Upper Cretaceous Fiqa shales, intra-formational lime mudstones act as seals for Natih E reservoirs. Contributing source rocks to Natih hydrocarbon accumulations include the Natih, Tuwaiq, Huqf and Q. The amount of contribution from each source rock is geographically variable.

The remaining undiscovered hydrocarbons in the Natih occur in more subtle stratigraphic traps. Channel-bounded closures and truncation traps are stratigraphic opportunites associated with the early Turonian to early Campanian emergence of the Natih platform. Fiqa channels that eroded into the platform were subsequently filled with transgressive mudstone. These channels are recognized as potential lateral and/or updip seals to hydrocarbon accumulations within the upper part of the Natih. In places that experienced maximum uplift, such as Lekhwair/Dhulaima area, total erosion of the Natih platform took place. In this setting, potential Natih reservoirs occur as low angle truncation traps sandwiched between intra-Natih lime mudstone intervals and base Tertiary Shammar Shale Other stratigraphic traps, in the form of amalgamated carbonate mounds, are recognised with the the intra-shelf basin that developed during the deposition of the Natih E.

#75 The sedimentation of the strike-slip basin of Jabal Ja'alan area

Al Harthy, A., Sultan Qaboos U., Oman

A near continuous Palaeogene succession with 2,000 m of rock was logged in Wadi Musawa of Jabal Ja'alan area. The studied basin is narrow (less than few tens of kilometre) filled by a triangular-shaped wedge of sediment that thickens southwards towards a major NW-trending fault known as the North Ja'alan Fault (NJF). The basin is bounded from the East by a flexural fault (FF) east of which the sedimentary sequence does not match with sediments accumulated in the main basin. The post-depositional structural grain is dominated by strike-slip tectonics which displays en echelon array of faults, positive flower structure and left-lateral displacement of about 2,000 m. Through detailed facies studies of the Jabal Ja'alan basin the following was observed: (1) basin asymmetry; (2) evidence for episodic subsidence; (3) local facies changes; and (4) contrast between adjacent basins.

From these observations it was concluded that the Palaeogene basin of Jabal Ja'alan area was deposited in a strike-slip basin and two tectonostratigraphic models have been suggested. The first model involves an E-W fault facilitating a net left-lateral movement along the NJF with an extensional component along both the NJF and the FF resulting in a strike-slip basin with a maximum accommodation space against the NJF, which becomes shallower northwards. The second model involves an original right-lateral movement inferred from the current geometry of the NJF, and the FF with its extension northwards along the Qalhat Fault, resulting in a pull-apart basin. In the first model field evidence of left-lateral movement can be illustrated from the fault and fold patterns which are clearly the result of a net left-lateral movement, while there is no field evidence to support the original right-lateral sense of movement invoked for the second model, although the fault geometry necessitates it.

The movement along the NJF, proposed in the first model, is a NW direction and may result in another opening (basin) parallel to the coastal line north of Ras Al-Had. This basin may lie offshore and only geophysical investigation will confirm or refute its existence.

#290 Lithostratigraphy of the Tertiary Formations in the Batain plain, Sur area

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The Sur map area (Batain coast area) lies in the Sharqiah area, northeast part of Oman Mountains, about 180 km southeast of Muscat.

The map area is dominated by allochthonous Permian to Late Maastrichtian sedimentary and volcanic rocks (Batain Group), which are unconformably overlain by Tertiary Paleogene-Neogene sediments. The Tertiary sequence in the study area is represented by six formations: Jafnayn (Ejf), Abat (Eab), Seeb (Ese), Shamah (Eosa), Sur (Msr) and Salmiyah (Msl).

The Jafnayn Formation is built up mainly of reef building organisms such as corals and coralline algae indicating a fore-reef or deep ramp depositional environment, of late Thanetian to early Ilerdian age. The Abat Formation which is coeval in age with the Jafnayn Formation, consists of a fining-upward cycles of packstones of open shelf, deep ramp environment. The Seeb Formation is divided into three informal members: (1) a lower member is represented by a well bedded limestone with an assemblage of large benthic Foraminifera dominated by Nummulites; (2) the middle member is a bryozoan-gastropod limestone; (3) and the upper member is a highly bioturbated, *Ophiomorpha-Kufus* bearing limestone. This formation of Lutetian to Biarritzian age with upper ramp to shelf lagoon environments. The Shamah Formation consists of well-bedded to more massive limestone with gypsum-bearing marl at the base of a peritidal to shelf lagoon environment, of Priabonian to Oligocene age. The Sur Formation consists mainly of boulders of dolomitized limestone of shelf lagoon to deep ramp environment, is Early Miocene. The Salmiyah Formation of Middle? Miocene consists of conglomerate limestone of near shore to continental depositional environment.

The rest of the map area is covered by the Batain Group which consists of the Qarari Unit (Late Permian to Triassic), Al Jil Formation (Late Permian to Pliensbachian/Toacian), Matbat Formation (Ladinian/Carnian to upper Pliensbachian/lower Toarcian), Ruwaydah Unit (mid-Jurassic to probably lowermost Cretaceous), Guwayza Formation (Early Jurassic to Oxfordian), Wahrah Formation (Pliensbachtian/Toarcian to Conician/Santonian) and Fayah Formation (Santonian to latest Maastrichtian).

The Paleogeographic evolution of the Tertiary sequence within the study area is reconstructed based on five time slices: Late Paleocene to early Eocene, Early- to middle Eocene, Late Eocene to Oligocene, Early-to middle Miocene and Middle to Late Miocene.

The area is dominated by three major tectonostratigraphic units, these are: crystalline basement complex (Ja'alan complex), Allochthonous Batain Group and Tertiary neo-autochthonous sequence.

#151 Regional time-depth conversion of the Natih E horizon in Northern Oman using seismic stacking velocities

Al Rawahy, M., PDO, Oman, **Veeken, P.**, CGG/PDO, **Filbrandt, J.**, PDO, Oman

A single layer vertical time-depth conversion method, using seismically-derived interval velocities, has been applied to the Natih E marker belonging to the Cretaceous Wasia Group in Northern Oman.

The average error for the uncalibrated Natih E depth grid at the 255 wells is 50 m, i.e. a difference of 4% at a depth of about 1,300 m. The application of a residual depth correction removes the depth error at the wells. Wells located in zones of inversion (e.g. Maradi fault zone, salt diapirs) are excluded from this depth conversion scheme as they show an anomalous velocity behaviour. Geostatistical modelling demonstrates that the expected depth uncertainty after application of the residual depth correction is less than 35 m within a 5 km distance from the well control.

Several untested closures on the final Natih E depth map have been identified. On the base case map these closures show a column height slightly in excess of 25 m. Velocity anomalies in the shallow overburden (Rus and Simsima formations) can cause significant local pull-ups and/or push-downs on the time sections. Uphole surveys, refraction data and detailed mapping of overburden geology are needed to resolve some of these problems. Horizon-consistent velocity picking (i.e. reprocessing) and map migration is recommended to mature the newly identified leads.

Once a velocity cube has been created from the various 2-D or 3-D surveys, it is relatively simple to generate depth maps for other time horizons. Thus, it is feasible to obtain a rapid inventory of leads and prospects. However, the magnitude of the depth uncertainty increases with depth. Applying a multi-layer depth conversion has the disadvantage that several error maps have to be compiled to ensure a correct fit in the wells. These errors might not always cancel each other out and hence the depth of the target can be incorrect by a large percentage, especially in the uncalibrated areas.

The seismic depth conversion provides a base-case depth grid. Quantification of depth (or time and velocity) uncertainties forms the basis for subsequent volumetric probabilistic simulations. These simulations give an assessment of probable shape, the stability of the structures and closures, the position of the most likely spill points and associated volumetrics of the realisations.

#247 Heavy oils in South Oman: API variations, Biodegredation, water washing

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A geochemistry study was undertaken as part of an integrated study and carried out to predict API gravity, and thus the producibility of the oils on the Eastern Flank (South Oman).

Several trends have been recognized using this and completion logs data from the well site. A trend of API vs. depth was looked at in detail using cross-plots of several geochemical components. A trend of increasing API gravity with depth was recognized in the Huqf Supergroup. No trend was recognized with oil type.

The overall trend of heavy biodegraded oils increasing furthest away to the East of the Eastern Flank was recognized. The API gravity maps and cross-plots gave several clues that the distribution of API along the Eastern Flank was strongly influenced by transformation factors (biodegradation and water washing).

The Eastern Flank oils have been analyzed for degree of biodegradation and/or water washing. It was observed that biodegradation did not occur deeper than 2,000 m. Using a plot of $\%C_7$ vs. Pristane/nC_{17} in which the cut-off value was set to 56%, biodegraded oils could be separated from non-degraded oils. An additional method of identifying biodegradation is using the value of Alkane distribution: polybranched alkanes, normal C_7 and monobranched alkanes.

The re-analyses of 19 oils from the South Oman Eastern Flank for Triaromatic biomarkers added information of the source of the oils in the Eastern Flank.

Twenty oils were analyzed by Shell Services Holland for aromatic steroids in order to arrive at a better subdivision within the various Huqf sources rock formations. The results were analysed using cluster analyses. These resulted in trends showing the oil types were geographically distributed.

#76 Biostratigraphy of the Lower Tertiary sequence of Wadi Musawa section, Jabal Ja'alan area

Al Sayigh, Abdul, Sultan Qaboos U., Oman

Biostratigraphical observations lead to the recognition of eleven planktonic foraminiferal zones which have been correlated with the standard zones of Blow (1969, 1979). Two zones from Upper Palaeocene and nine from the Lower to Middle Eocene were recognised. They were used to redefine the ages of the Abat and Musawa formations. These are shown to be significantly older than previously published. Biostratigraphical and palaeoenvironmental data from both the planktonic and the larger Foraminifera has been used in conjuction with the lithostratigraphy to construct a sequence stratigraphy, in which several cycles have been recognised. Some of these cycles may possibly correlate with the global sea-level cycles of Haq et al. (1989).

The palaeoenvironment of the Palaeogene in Oman was reinterpreted using information from the Foraminifera, radiolaria, ostracods as well as molluscs. Parts of the early and middle Eocene contain in-situ larger Foraminifera including deposition in a shelf (dominantly mid to outer) setting. The late Palaeocene, most of the early Eocene, part of the middle Eocene, and the whole of the late Eocene and early Oligocene contain mixed assemblages of planktonics and shallow water benthonics.

A number of new larger and smaller benthonics are described and one planktonic foraminifer renamed.

#355 Structural evolution of Foreland Fold and Thrust belt, Hamrat ed Duru, Northern Oman

Al Wardi, M., Sultan Qaboos U., Oman

The Hamrat ad Duru Group consists of deformed slope to basinal sedimentary rocks of Mesozoic age, emplaced on the Arabian continental margin during the ophiolite obduction in Late Cretaceous time. Their emplacement took the form of a series of thrust imbricate stacks.

Surface structures from field observation were correlated with the sub-surface structures interpreted from seismic data in order to understand the influence of the autochthonous structures in the thrust and fold system.

The Hamrat ad Duru imbricate stacks comprise deep-water turbidity sediment obducted over a carbonate platform during the Late Cretaceous. The obduction led to the development of a series of extensional faults and partial erosion of Natih Formation in the upper part of the platform in response to a flexure bulge, while the syn-tectonic deposits of the Aruma Group were deposited in a foreland basin.

The sequence of thrusting in the study area can be ordered as follows. The initial imbrications took place far from the continental margin as a foreland directed piggy-back thrusting before the ophiolite emplacement. The second stage, which can be called the emplacement stage, gave rise to the major displacement of the Hawasina units and their emplacement onto the Arabian platform during the Late Cretaceous. The extensional faults within the carbonate platform influenced the fold and thrust structures by forming irregularities over which ramp folds were formed. The third stage is a deeper Alpine out-of-sequence thrusting that led to folding of the allochthonous imbricate stacks and their decollement. The burial history indicates a regional uplift, which could probably have occurred during this stage as well. There is a potential for sweet gas in the Mesozoic structural carbonates, but deeper reservoirs should also be considered.

#36 Petroleum systems of North Oman: thermal, charge and migration modelling

Al Belushi, J., Frewin, N., PDO, Oman

During the past ten years, the petroleum systems of Oman have been identified and described. These are the Huqf, 'Q', Tuwaiq/Shu'aiba, Safiq and the Natih petroleum systems. The systems have been identified using detailed geochemical techniques and their extent mapped using 1-D and pseudo-2-D modelling techniques. More recently, advances in 3-D charge modelling software has enabled us to further define the identified petroleum systems from basin to prospect scale. Furthermore, the addition of migration modelling to the tool box of the charge modeller has added a new dimension to prospect identification.

The use of Shell's proprietary 3-D basin modelling package (IBS+) in North Oman is detailed here. The main objectives of this study were to: (1) further investigate the late generation potential of the Cretaceous Natih Source rock in an area that forms the eastern extension of the Foreland Basin to the Oman Mountains; and (2) to map the migration routes of the 'Q' petroleum system in detail.

Results show that in the Afar and eastern Ghaba maturation is early (Palaeozoic) for all source rock levels, with Mesozoic hydrocarbon generation only occurring in the north (Afar). This is a consequence of the assumed early maximum paleotemperatures. Early generation means that, unless evidence for an alternative temperature history can be found, charge to the eastern Ghaba area is dependent on one of the following: long term retention by clastic Haima or salt seals; salt dissolution/movement; long distance migration; regional tilting allowing remigration; or in the Afar area possible late charge may be derived from burial in the foreland basin area. For the Ghaba Salt Basin, migration was modelled from the Dhahaban (Q) kitchens at the top Amin level. Results show two migration routes (later merging) from the Rim Basin towards the area between Fushaigah and Habiba (Kauther cluster area). Another migration route starts from the Rim Basin towards the Makarem High. An improved charge risk map could be obtained by using the predicted migration routes. In terms of calibration, there is a good correlation between oil shows and their position on a migration route.

South of the Salakh Arch, the generation and expulsion history of the Cretaceous Natih source rock at four different locations have been modelled. This work has illustrated that for various combinations of burial and uplift/erosion, charge from the Natih B and E is likely, with predicted oil of 26 API gravity. The Natih Formation. reaches its greatest depth in Block 6 East of the Maradi Fault Zone but, in both scenarios, did not enter the gas kitchen. A considerable kitchen area extended to the North of Sulan West kitchen area between 60 to 80 Ma. Rapid burial at about 70 Ma enabled the Natih source rocks to enter the oil maturity window. Minor subsidence during the Tertiary allowed the source rock to continue to generate hydrocarbons. From about 35 to 20 Ma ago, the kitchen area became substantially smaller and therefore the contribution from the Natih source rock was limited.

Because of the complexity of Oman's petroleum systems, charge remains a key risk in assessing prospectivity. The careful application of increasingly complex charge models can mitigate the risk considerably.

#37 Regional setting and sedimentology of the Late Palaeozoic Al Khlata Formation outcrops, Southern Huqf, Oman

Al Belushi, J., PDO, Oman

The late Palaeozoic Gondwanan glaciation has affected at least some parts of the Arabian Peninsula. Glacial and peri-glacial sediments have been confirmed in Oman, Yemen and Saudi Arabia to some extents. The glaciogenic, glacio-fluvial and glacio-deltaic sediments of the Al Khlata Formation in South and Central Oman pass laterally into more peri-glacial (both fluvial and aeolian?) sediments of the Unayzah in Saudi Arabia. This palaeogeography fits well with a northeasterly site of continental glaciation during that time.

In Oman, the Permo-Carboniferous Al Khlata Formation reservoir produces significant quantities of "heavy" (c. 18 - 28 °API) oil mainly from the southern fields of Oman. The complexity of these sediments is attributed to their deposition in glacial to peri-glacial environments strongly influenced by halokinesis within the underlying Huqf Supergroup. Hence correlation of these reservoirs is often problematical. The application of techniques such as heavy minerals, chemostratigraphy and isotopic analyses has had limited success to date with glacigenic sediments.

The latest Carboniferous/Early Permian period was one of extensive ice action, as evidenced by glaciogenics throughout the region. This was a time of significant base (sea)-level lowstand, with water locked up in substantial bodies of ice. Both polar and rift shoulder related, high altitude ice were presumably influential in Oman. A number of ice pulses (advance/retreats) from northerly (and north-easterly) sources define this major phase in glaciation: erosion (missing sections) and sediment cannibalisation were widespread, with deposition highly limited (phases of lowstand ice sheet expansion are typically erosive events, with hardly any sediment deposited).

One of the key, historical challenges with the Al Khlata has been accurate lateral and stratigraphic prediction of both reservoirs and seals: poor seismic definition and imaging have compounded these problems. The present study involved the identification and mapping of the sedimentary facies of the Al Khlata outcrops in the Huqf area where the formation is exposed in four wadi sections. The valuable information gathered from the outcrops have helped in establishing some regional setting of the formation in terms of its sedimentary facies, palaeoflow direction therefore addressing some of the more important, regional stratigraphic elements from an explorationist's perspective, suggesting new approaches for interpreting and understanding the Al Khlata.

#282 Structural analysis of Precambrian rocks near Hadbin, Oman

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The Precambrian basement exposed to the east of Salalah in southern Oman is composed of plutonic and metamorphic complexes-Juffa, Sadh, Mahall, Fusht and Hadbin. Extensive earlier studies by the Swiss geologists essentially concentrated on the petrological, geochemical and radiometric aspects of these complexes. This study concerns mainly with detailed structural analysis of smaller part of the basement exposed near the village Hadbin, where only the Sadh, Fusht and Hadbin complexes are exposed.

In the Hadbin area, four phases of folding (F1 to F4), and two events of shearing (Sh1,Sh2) are recognized from interfering fold patterns and cross-cutting foliations and shear zones. F1 folding produced a pervasive transposed foliation enclosing detached isoclinal folds or fold hinges that are generally composed of quartz veins or quartzo-feldspathic veins. A rodding lineation is represented by the hinge-lines of these detached fold hinges. F2 folds have tight to isoclinal profiles, and a new schistosity that is parallel to the axial planes of these folds, is often generated, resulting in the development of an intersection lineation in the rock. Generally open in their profiles and associated with axial-planar fracture cleavage (instead of schistosity), F3 folds indicate a milder phase compared to F1 and F2 phases of folding. F4 folds have gentle profiles with no new foliation devoloped.

The Sadh complex, bordered on the west by the Fusht complex and on the east by the Hadbin complex, exhibits different generations of structures (folds, foliations, lineations, shear zones) that indicate that it has been affected by all the phases of deformation. However in the Fusht complex, structures related to the F1 phase of folding are absent, suggesting post-F1 timing of intrusion of this complex into the Sadh complex. The Hadbin complex is essentially a massive body except along its margins and is considered to have intruded at the earliest after F2 folding, if not later.

#348 Geology of the Crystalline Basement of the Hasik Region (Dhofar, Sultanate of Oman)

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The main lithology of the Precambrian crystalline basement of the Hasik area is composed of: (1) the Sadh group which consists of the Banded Migmatite Complex (the oldest rocks in the area), amphibolites, and the leucocratic biotite gneiss; (2) the Hasik Complex which consists mainly of biotite hornblende gneiss and few metadioritic and metagabbroic lenses. This complex intruded into the Banded Migmatite Complex with sharp and straight contacts; (3) the Wadi Raykhut Gabbroic Complex which intruded into the biotite hornblende gneiss of the Hasik Complex; and (4) the Ras Hasik Gabbroic Complex which intruded into the rocks of the Sadh Group.

This work concentrates on the two gabbroic complexes and the Hasik Complex. The Hasik Complex is a homogenous large body about 10 km wide composed of biotite hornblende gneiss with some elongated basic enclaves. The Hasik Complex rocks are monometamorphic showing a steep and constantly trending foliation of NW-SE orientation. The foliation is weak in the area where the metagabbroic and metadioritic lenses occur and near the contact to the Wadi Raykhut gabbroic complex.

The two gabbroic complexes consist mainly of a layered gabbro, olivine gabbro, hornblende gabbro, and melanotroctolite. It is believed that the melanotroctolites are intrusive into the gabbros of the two complexes during their early history of evolution. During a process related to the gabbroic magmatism, the Wadi Raykhut Gabbroic Complex was intruded by a acicular hornblende gabbro, numerous subvertical pegmatitic hornblende dykes and bodies generally striking N-S, and numerous thin gabbroic dykes generally striking NE-SW. The Ras Hasik Gabbroic Complex was strongly deformed during subsolidus stage through numerous shear zones which initially start from the acid aplitic dykes and branch into the gabbro, causing deformation under amphibolite facies conditions. Later during solidus stage the

Ras Hasik Gabbroic Complex was strongly altered due to hydrothermal metamorphism of green schist facies. The Wadi Raykhut Gabbroic Complex is not deformed and seldom altered.

The geochemical analysis showed that there are no significant differences in composition between rock types in both complexes, and between the olivine gabbro and the hornblende gabbro. This indicates that the two gabbroic complexes evolved from magmas with similar composition and similar process of differentiation, and the segregation of hornblende gabbro and olivine gabbro resulted only from the characteristic continuous change in modal composition mainly olivine-plagioclase and hornblende of the gabbro.

The geochemical analyses could indicate that the melanotroctolites were not produced during same fractionation episode as the gabbros and through the same mechanisms. The field cross cutting relationships (melanotroctolites intruding discordantly the layered gabbro) are a further argument in this direction. Nevertheless, the composition of the melanotroctolites is in some way linked to the other gabbros and to olivine accumulation from a common primitive melt.

Also the geochemical analyses show that the composition of the tonalitic gneisses of the Hasik Complex plots coherently along a line connecting the tonalites, basaltic compositions from the literature (MORB mean after Hofmann, 1988 and the mean of the Andean basalts, Wilson, 1989) and the gabbros. This correlation demonstrates that the gabbros could be produced by the accumulation of olivine and plagioclase fractionating from a basaltic melt, producing tonalitic residual melts.

The study area is cross cut by different types of acid and basic dykes. The acid dykes show general trending of NW-SE, whereas the basic dykes have a scattered trending phenomena indicating different magmatic processes.

#303 Geology and geochemistry of the Al-Bayda supracrustal belt: Evidence for an ophiolitic island arc setting

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The Al-Bayda supracrustal belt is exposed as elongated NE-trending terrain and separated from the adjacent Archean – mid Proterozoic Al-Swadia gneissic terrain by a nearly vertical, NE-trending highly deformed zone of ophiolitic and island arc assemblage (suture zone).

The Al-Bayda belt is composed of late Proterozoic highly tectonized sequence of low grade metamorphosed metavolcanics. These metavolcanics consists of deformed pillowed spilitic metabasalts, metaandesites, metadacites and metatuffs blocks, in addition to highly disrupted metagabbros and serpentinites blocks. Generally, these blocks are intercalated with carbonate pelagic sediments, metamudstone, biotite and graphite phyllites and sometimes associated with marble and/or iron ore bands.

The geochemistry of the mafic pillowed lavas shows that they are tholeiitic basalts compatible with an ocean-floor or back-arc basin origin, while the metaandesites, metadacites and metatuffs show sub-alkaline affinities that are related to volcanic arc environment.

The actual documentation of Precambrian ophiolitic, island arc assemblage, and suture zones in Yemen remains incomplete and further research is essential to understand the mechanism of crustal accretion and models of arc-gneiss collage for the evolution of the Yemeni Precambrian terranes in particular and the Arabian-Nubian shield in general.

#251 Seawater dolomitization of Permian and Triassic shelf carbonates, Oman Mountains

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This study is based on field, pertographic and geochemical investigations of Hajar Supergroup autochthonous rocks: Ruus Al Jibal Group, Musandam Peninsula, and Akhdar Group, Jebel Akhdar, Oman. The petrographic investigations were carried out by using transmission light microscope, scanning electron microscope, especially back-scattered images, and cathodoluminesence. They were supplemented by geochemical methods, using microprobe, X-ray diffraction, ion chromatography, atomic absorption, and quantitative analysis by the scanning electron microscope.

Petrographic evidence indicates that the rocks were deposited in a shallow marine shelf environment, particularly tidal flat, lagoon, reef, back-reef and shoal environments that were part of the Arabian Platform during Permian and Triassic times. However, they are almost entirely dolomitized and the rocks show different petrographic features ranging from perfect preservation of original texture by mimetic dolomitization to complete obliteration and destruction of the original limestones giving rise to inequicrystalline and equicrystalline fabrics.

Dolomites analyzed by geochemical methods were categorized on the basis of textural variations; crystal size, shape and impurity or inclusion distribution within crystals, and whether these crystals are found as rock forming (replacive) or cements. The dolomites display variations in stoichiometry, ordering and trace element concentrations indicating differences in dolomitizing fluid chemistry and recrystallization stages that prevailed through time. It indicates also that although dolomitization is pervasive, dolomites are petrographically and chemically immature.

All the petrographic and geochemical evidence strongly indicates seawater and/or mixing zone dolomitization which may have been initiated soon after deposition of the host sediments. Rocks showing preservation of allochems as well as the marine cements by mimetic dolomite crystals, suggest that dolomitization was early (at shallow depths) with very active marine-water circulation and occurred in a relatively short time. In some cases, there is evidence of meteoric water diagenesis before dolomitization which is clearly visible within dolomitized bioclasts and ooids that underwent a dissolution event and cementation prior to dolomitization. Evidence from crystalline dolomites indicates several crystallization events at shallow burial depths, under marine waters modified by increased temperature and mixing probably with evaporitic brines.

The only fluid capable of early dolomitization in the case of the Oman Mountains dolomites was warm seawater from the Tethys Ocean which was circulating in the subsurface.

#168 Hydrocarbon exploration of salt diapirs in North Oman

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Salt diapirs continue to provide attractive exploration targets worldwide in hydrocarbon provinces such as the North Sea, Gulf of Mexico. In North Oman 21 salt diapirs are recognized. There are 6 surface and 15 subsurface diapirs with varying shapes and sizes. Reserves in culmination overlying the crests of diapirs and salt pillows (e.g. Ghaba, Ghaba North, Habur, Qarn Alam) have been successfully exploited. However, traps in upturned strata abutting against the flanks of diapirs have remained greatly under explored.

In a recent drive to open up new frontier exploration plays, PDO's exploration unit started to assess the hydrocarbon potential of the unexplored flanks of salt domes in the Ghaba Salt Basin. Technical challenges include a combination of poor seismic imaging of the steep salt-sediment interfaces and drilling problems such as real time steering of deviated wells, overpressures and borehole stability. Although still surrounded by major technical challenges, it is considered timely to actively pursue salt diapir flank traps in Oman.

This presentation will provide an overview of the Salt diapirs, history and technical problems associated with salt diapir flank exploration.

#235 New geochemical and structural evidence for the tectonic setting and emplacement of the Late Cretaceous Baer-Bassit Ophiolite (NW Syria)

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Many ophiolites along the South-Tethyan continental margin show similarities to the Oman ophiolite and associated units, including the Baer-Bassit ophiolite in northwest Syria, discussed here. The Baer-Bassit region of northwest Syria exemplfies the evolution of Neo-Tethys at the west end of the "ophiolitic crescent". The stratigraphy of the Baer-Bassit is divisible into four main units: (1) At the base, there is a relatively autochthonous Mesozoic Arabian carbonate platform (1,500-1,800 m thick), of mid-Jurassic-Early Cretaceous age; (2) The Mesozoic carbonate platform is overthrust by deformed Mesozoic rocks of continental margin and oceanic affinities. These include highly deformed volcanic-sedimentary lithologies, c. 450 m thick (Baer-Bassit Melange); and (3) Structurally above is a complete, but thrust deformed, Upper Cretaceous ophiolitic suite (c. 2-3 km thick), of harzburgitic tectonites, peridotitic cumulates and mafic rocks, including layered and massive gabros (with some cross-cutting dykes), sheeted dykes and pillow lavas. The ultramafic and mafic units are mainly exposed as two main massifs, Baer and Bassit. The ophiolitic units are very tectonically dismembered, such that complete successions can not be observed within any single tectonic unit. Previously, pillow lavas in the Baer-Bassit region were divided into two units the Lower Pillow Lavas and the Upper Pillow Lavas, similar to the Troodos, Cyprus.

In this study only one unit of lavas was identified, based on field and geochemical (major- and trace-elements) data. These lavas show a range of compositions from mid ocean ridge, island arc tholeiite and high-Mg boninite type. The Baer-Bassit ophiolite is inferred to have formed in an above subduction zone setting, where near-MORB and SSZ magma types could coexist, spatially or temporally. Locally, the uppermost extrusives are overlain by Fe-Mn sediments, comparable with the hydrothermal umbers of the Troodos and Semail ophiolite. The plutonics are structurally underlain by a well-developed metamorphic sole, 200-300 m thick, for which the protoliths were mainly alkaline extrusives and associated sediments similar to those within the Baer-Bassit Melange. The entire assemblage of marginal and ophiolitic units was emplaced onto the Arabian margin in Middle Maastrichtian time. Finally, (4) the Mesozoic allochthon is unconformably overlain by an intact sedimentary cover ("Neo-autochthonous succession"). Detailed structural mapping of both the ophiolite and melange (e.g. duplexes), and the metamorphic sole (e.g. stretching lineations) indicate emplacement mainly towards the Southeast. Regional evidence (e.g. Southeast Turkey, Oman) indicates that latest Cretaceous ophiolite obduction predated continental collision in Late Eocene-Oligocene time when updoming and regional folding took place. Neotectonic structures in Baer-Bassit relate to the effects of extensive strike-slip (mainly left-lateral) and normal faulting at the eastern end of the Cyprus active margin (i.e. Africa-Eurasia plate boundary) where it comes onshore to link with the left-lateral Dead Sea Fault system. The new results in Baer-Bassit region strengthen the interpretation of a Late Cretaceous subduction-related origin of the ophiolites along the African/Arabian margin stretching from Oman to Cyprus.

#107 Geochemical interpretive tools for solving stratigraphic problems in "Mesozoic Clastics", Oman

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The Cretaceous Kahmah-Mafraq formations in the south Oman has been a problem to interpret for a long time (1981-2000). These sediments were deposited in marine, wetland, and estuary environments (evidence from marine and terrestrial fauna and flora). The 'Mesozoic Clastics' are important reservoirs in South Oman, and the estimated reserves (if assumed by area of distribution) is immense (total thickness and area). Many fields have already been discovered in Oman including the main ones: Al Burj, Amal, Amal South, Ihsaan, Marmul, and Qaharir. However, the stratigraphy and seismic resolution is still unclear. The variations in oils types and viscosity are quite varied and biodegradation and water washing of oils have influenced the recovery, production and development of fields. These problems have been tentatively solved using an integrated approach involving geochemistry, Palynology, and Sequence stratigraphical tools. Further to these approaches, recent developments in basin modelling can help solve these problems and give directions for future developments of this yet untapped play area.

#55 Stratigraphy and hydrocarbon potential of the Devonian Misfar Formation of South Oman

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The continental to shallow marine Misfar Formation occurs as clastic pods, along the Eastern Margin of the South Oman Salt Basin (SOSB), preferentially preserved within salt-withdrawal synclines. The formation is assigned an early Eifelian to late Emsian age on the basis of *in situ* palynofloras. The Misfar can be informally subdivided into Lower Misfar Mudstone, Lower Misfar Sandstone, Middle Misfar Mudstone, Middle Misfar Sandstone, and Upper Misfar Mudstone Members.

At present 5 prospects, with an estimated 9 mm^3 of expected oil and an additional 12 leads (138 mm^3 expectation) are recognised within the Misfar play portfolio. The Misfar play concept is recognised along a broad 120 km belt running along the Eastern Flank of the SOSB, with structures mainly provided by salt pillows and rotated fault blocks. The play is largely dependent on the development of differential accommodation space during the Middle Devonian and Late Carboniferous.

The Lower and Middle Misfar Sandstone members are the main reservoir intervals. The Lower Misfar Sandstone is characterised by high net to gross, stacked aggradational, clean, well-sorted, quartz rich sandstones that pass vertically into the Middle Misfar claystone member. The Middle Misfar Sandstone member comprises two distinct sandstone units; (1) medium to coarse-grained conglomeratic sandstones with common chert, limestone, dolomite and igneous clasts. These sandstones are locally calcareous with typical low gamma-ray readings; (2) The second unit consists of subordinate poorly-sorted, highly-calcareous argillaceous, very fine to medium grained sandstones with a high gamma ray response. These finer grained sandstones exhibit lower porosities with pore filling clays occluding permeability resulting in a poorer quality reservoir. The Misfar porosity depth trend suggests porosities varying from 15-25% and permeabilities of 0.1-3,070 mD with an average of 479 mD. Primary mechanism of porosity destruction is calcite cementation and to a lesser extent quartz overgrowth cementation.

Misfar reservoirs are sealed by Al Khlata glaciolacustrine mudstones. The Upper Misfar mudstone member can act as a local seal, but is not regionally present due to truncation by the Al Khlata Unconformity. Excellent quality source rocks, rich in amorphous kerogen, are recorded in the Upper Misfar shallow marine mudstone member. However, these sediments have not been buried deep enough to generate hydrocarbons. Primary charge is via vertical migration of Huqf oil along the salt edge, with secondary re-migration owing to later phases of salt withdrawal, tilting and faulting.

#270 Petroleum source rock evaluation of Kazhdumi Shale formation, Southwest Iran

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The shales of the Kazhdumi Formation were deposited in the great and calm Dezful Embayment in anoxic environment during the Early Cretaceous. The equivalent of this formation in the other countries of the region are the Burgan Sands of Kuwait and Saudi Arabia, and the Nahr Umr in SE Iraq. The Kazdumi Formation consists of more than 300 m of dark gray shales, bituminous marl, and very rich clay limestone in the deeper parts of the basin that makes Rag Safid oil field in Southwest Iran.

In order to evaluate the source rock potential of the formation geochemical analyses were carried out. The result indicates that the TOC are close to the threshold value and range from 3-11%. The hydrogen index ranges between 300-450.

Based on this study it is concluded that the source rock of huge Asmari and Bangestan oil fields of Southwest Iran is the organic rich Kazhdumi Formation and hence could be of importance to the whole Middle East. Therefore, the author suggests a detail study of the source rock evaluation in the region.

#321 A great inland sabkha environment of Oman, Arabian Gulf

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The satellite data including optical sensor data of Landsat Thematic Mapper TM (30 m pixel) and Spot XS (20 m) and microwave shuttle imaging radar (SIR-A) data have been used in evaluating the characteristics of a great inland sabkha environment of Umm as-Samim in Oman, Arabian Gulf. The study area covers about 4,500 sq km in the eastern margin of the Empty Quarter (Rub' Al-Khali) sand desert. It is located in the south of the Oman Mountains piedmont and is the inland drainage area for the Jabel Akhdar (>2,000 m high). The southern alluvial fan wadis drain southwest from the Al-Hajar Mountains flowing into the Umm as-Samim Sabkha, where low rocks project above the salt to create small islands. On the western side, the salt flats (playa lake) merge into the patterned sand dunes of the Rub' Al-Khali desert. The region is characterised by an extremely arid climate, with low and highly erratic precipitation. However, water during the rain season picks up salts and sediments from rocks, as it passes through on its way from the Oman Mountains. As the water evaporates, the salt forms as polygonal-ridge crust of about 1 m. In general the basin was found to be devoid of vegetation cover owing to the arid climatic conditions and high concentrations of gybcrete as surface cement. The water table was found to be fluctuating seasonally, but it was generally near the surface.

The sequential satellite and radar images and field study of the area have revealed the nature of the largest closed inland sabkha drainage basin in the Arabian Peninsula. The images also clearly show sabkha sub-environments, development of a variety of aeolian forms, alluvial fans and evaporite mineral deposits.

#250 Neoproterozoic basin development in Oman: an Afro-Arabian Perspective

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The Huqf Supergroup comprises the oldest sediments in Oman, ranging in age from Neoproterozoic to Early Cambrian. The Supergroup consists of a lower group (Abu Mahara) of marine, diamictite-bearing sediments in structurally confined extensional basins, well-imaged on seismic and excellently exposed in the Jebel Akhdar of the Central Oman Mountains. Recent U-Pb dates suggest that the Abu Mahara Group in the Jebel Akhdar may be in excess of 723 Ma. The middle group comprises an extensive carbonate-dominated succession (Nafun) that onlaps the basin margin in the east and deepens down dip into the Oman salt basins. No radiometric dates are available from the Nafun Group. The upper group (Ara) records a phase of structural partitioning of the Huqf basin, volcanism, evaporite deposition and eventually the eastward shedding of coarse siliclastics. Well-developed ignimbritic ashes yield dates around the Precambrian-Cambrian boundary.

The Huqf basins developed to the east or southeast of a major zone of oceanic arc accretion in eastern Egypt and Saudi. It is envisaged that in Oman a period of continental extension (c. 750 - 590 Ma) was followed by convergence and collision, with an orogenic arc located in the west flexing down the Arabian lithosphere in the region of the Omani basins (c. 590 - 540 Ma). Late orogenic events may have been dominated by oblique slip tectonics and volcanism. This scenario of early stretching followed by convergence and flexure is recognized in other Neoproterozoic successions in Africa, such as the Nama Basin south of the Damara orogenic belt in Namibia.

By correlating diamictites, we recognize a coherent theme in the plate tectonics of the 'Gondwanan' assembly during the Neoproterozoic, suggesting that relative motion of continental fragments occurred in concert as Rodinia split and reassembled.

#268 Petroleum system and future petroleum potential in the Middle East

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More than 500 commercially significant oil and gas fields have been discovered in the Middle East since the beginning of the 20th century. The published recoverable petroleum reserves at the beginning of 1999 were estimated 677 billion barrels and 1,726 TCF, which represents almost 65.2% and 33.7% of the world's oil and gas reserves, respectively. Most of the fields have more than one pay zone producing from shallow water carbonates and clastics with pay zones ranging in age from Infracambrian to Oligo-Miocene. The most prolific oil-producing zones are the fracture and reefal carbonates of the Asmari and its equivalent formation (Oligo-Miocene) of southwest Iran and northern Iraq; the shallow water carbonates of the Arab Formation (Upper Jurassic) and the Thamama Group (Lower Cretaceous) of Eastern Arabia; the rudist and associated facies in the Shu'aiba, Mishrif, Simsima (Aptian, Cenomanian and Maastrichtian) in the southern Arabian Gulf; the shallow water clastics of the Zubair (Barremian) and Burgan/Nahr Umr (Albian) in Kuwait, south Iraq and northeast offshore Saudi Arabia; the shallow shelf limestones and dolomitic limestones of the Khuff/Kangan Formation (Permian) in the Arabian Gulf; the carbonate and clastic sediments of the Huqf Group (Infracambrian-Early Cambrian) in Oman and the clastics of the Permian Unayzah/Haushi in Arabia.

The most prolific source rocks are the shales of the Kazdhumi Formation (Albian) in southwest Iran; the laminated argillaceous limestones Hanifa Formation (Kimmeridgian) or its equivalent Sargelu Formation in the Arabian Gulf; the argillaceous bituminous limestones Shilaif/Khatiyah Formation (Albian-early Cenomanian) in the Arabian Gulf; the Upper Cretaceous marly limestones in northern Iraq, the Silurian shales in Arabia and Iran and the Infracambrian carbonates in Oman. The major sealing rocks are the anhydrite of the Hith Formation (Tithonian); the shales of the Nahr Umr (Albian); the shales of the Laffan Formation (Coniacian) and the anhydrite of the Gachsaran (Miocene). The structure forming mechanisms that have operated in various parts of the Middle East include several types such as salt-cored structure, and/or halokinesis movements; deep seated basement faulting; compressional folding, and transtensional/transpressional structures. The depositional pattern of the sedimentary rocks through geologic time resulting from the interplay of many factors such as sea-level changes, climatic variations, epeirogentic movements and rejuvenation of relief. These factors have a direct influence on the regional distribution and occurrences of hydrocarbons in the region.

Future exploration is expected to focus on: (1) discovery of smaller structures, and the search for subtle traps revealed by analysis of geologic data and special seismic processing and interpretation. Although the long lived stability of the shelf has influenced the development of the giant oil pools, and reduced to some extent, the potential for stratigraphic traps, it has not eliminated the potential for smaller structures; (2) Exploration for new oil and gas reserves in the offshore of the Arabian Gulf, Gulf of Oman, Red Sea and Indian Ocean (an offshore area of the Arabian Peninsula); (3) exploration in the vast areas of the Arabian Basin that have not been extensively drilled including the southeastern Rub' Al-Khali basin, western and southwestern Iraq, eastern Jordan and northern United Arab Emirates. This will involve extensive regional and local geologic-sedimentologic studies, 3-D or 4-D seismic surveys and drilling programs.

#320 Tectono-eustatic controls on the diagenetic evolution of the Middle East platform carbonates

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Abundant surface-subsurface data for the Paleozoic, Mesozoic and Cenozoic sections of the Middle East make it possible to trace the relationship of shelf carbonate and evaporite sequences and parasequences to the tectono-eustatic and Milankovitch low to high amplitude eustatic sea level change. Deposition in this part of the world was in part controlled by gentle tectonic subsidence punctuated by eustatic variations. The major cycles of the reservoirs and seals and their early diagenesis, can be related to sea-level behavior at the time of deposition. Climate was also a controlling factor that influenced the depositional and diagenetic settings of these sediments. For the purpose of this scheme, it is suggested that the early diagenesis of these sediments can be investigated in terms of six major settings exemplified by case studies from the region. These include early diagenesis associated with either arid or humid climate and related to either low, medium or high amplitude sea level changes. Arid climate and low amplitude sea level changes can be traced in the Triassic carbonate cycles of northeast Syria and northern Iraq, the Upper Jurassic Arab Formation of Arabia and the second Eocene dolomite of Kuwait-Saudi Arabia Neutral Zone, whereas the high amplitude changes are characteristic of the Miocene carbonate cycles of Iraq and Syria. Humid climatic conditions associated with high or medium amplitude changes can be found in the Khuff Formation of Arabia, the low amplitude changes, however, are probably found in the Yamama Formation of southern Iraq and Kuwait. Tectonically induced pedogenesis and paleokarst, and unconformities-related diagenesis associated with diffuse flow aquifers are some of the regional diagenetic features that can be attributed to these tectono-eustatic changes.

#224 Biogeochemical significance of the Precambrian-Cambrian boundary carbon isotope anomaly: constraints from Oman

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Globally significant events of faunal turnover, tectonic reorganization, and biogeochemical change are now widely regarded to have closely coincided with the Precambrian-Cambrian boundary. Over the past decade, numerous studies have provided constraints on the age and duration of these events, the possible phylogenetic relationships between faunal assemblages, and the magnitude and significance of contemporaneous shifts in the trace element composition and isotopic composition of C, O, S and Sr in the oceans. The Ara Group (Huqf Supergroup) of the South Oman Salt Basin (SOSB) presents an excellent succession with which to address this problem. At least six evaporite-carbonate sequences (A1 to A6) are observed in the SOSB. The carbonate rocks are tightly enclosed in a protective envelope of impermeable halite, and therefore these rocks have likely never exchanged isotopes with younger fluids.

New lithologic, chemostratigraphic, biostratigraphic, and geochronologic data help to constrain the timing and significance of key events at the Precambrian-Cambrian boundary. The A4 carbonate within the Ara Group contains a prominent shift in carbon isotope values from +2 to -5 permil (PDB) and a coincident enrichment in uranium (up to 4 ppm) as revealed by spectral gamma ray logs and chemical analyses. A volcanic ash bed in the A4 carbonate yields an age of 542 ± 1 Ma, indicating that this excursion is the same as that which occurs on other continents at this time. The A2, A3, A4, and A5 carbonates all contain *Cloudina* fossils, and *Namacalathus* has been discovered in the A5 carbonate. This carbon isotopic depletion and uranium enrichment of surface seawater was coincident with deposition of over 400 m of silica (Athel Formation "silicilyte") in the contemporaneous basin. Together, these geochemical responses and facies assemblages suggest that surface seawater in the SOSB, and perhaps the global ocean, may have become oxygen depleted at this time.

#93 The Gondwanan deglaciation in Central Oman: paleontological and sedimentological evidence

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The bioclastic bed at the base of the Saiwan Formation at Saiwan (Central Oman) represents a key-interval in the reconstruction of the Neo-Tethys opening and the Gondwana deglaciation. Palaeontological and sedimentological evidence points out that this 40-cm thick bed of hybrid arenites finally sutures, during mid Sakmarian, the irregular topography of the syn-rift sequence and the diamictite of the Gondwanan glaciation, in the rim-basin of Interior Oman.

The faunal assemblage of this bed consists of the dominant

Cyrtella-like spiriferid - representing up to 90% of the total assemblage -, the brachiopod *Heterilosia* sp., two species of bivalves and gastropods, conularids, bryozoans, crinoids, barnacles, and few ammonoids. The distribution of this basal palaeocommunity is casual patchy, with clustering being controlled by reproduction constraints, the distribution of sheltered niches and possibly the dynamics of the sandy bottom.

The palaeocommunity shares all of the characters of a pioneer community, being characterised by suspension feeders with low density, low variety and very low evenness, large production, high resiliency, and negative biotic interactions such as exploitive competition and parasitism. Furthermore, the *Cyrtella*-like spiriferid shows the features of a typical palaeo-opportunist species: random distribution pattern over a limited area, clustering in groups, numerical dominance (> 85%), suspension feeding, rapid rates of reproduction and growth (r-strategy), early maturity, low mortality of juveniles and mortality rates in the adults which are independent from the density and from the size of the individuals.

The basal bed of the Saiwan Formation contains at least four settlements of this early successional palaeocommunity, which - taking into account the approximate life-span of the *Cyrtella*-like spiriferid - suggests a time-span of about 80 years for the entire bed, non considering the possible presence of hiatus.

The mid Sakmarian transgression above the sandstones of the Raab Formation provides a new habitat, a free but cool and inorganic nutrient-rich environment, which is colonised by the Saiwan pioneer palaeocommunity showing several morphological adaptations enabling its successful exploitation.

The great significance of the basal bed of the Saiwan Formation is enhanced by the petrographic analysis of the Al-Khlata Formation and overlying Raab and Saiwan formations.

Sandstone composition, along with available knowledge of the Al-Khlata-Raab basin, points to provenance from Precambrian crystalline basement and overlying rhyolites and quartzose sedimentary rocks, such as those cropping out in the nearby Al-Jobah area. These rocks were exposed to erosion on the rift shoulder of a Late Paleozoic rift system related to incipient opening of Neo-Tethys. Evidence of pene-contemporaneous bimodal volcanic activity points in turn to deposition of the Al-Khlata and Raab formations in a late syn-rift to early post-rift stage. Arkosic composition of the basal Saiwan sandstones, with negligible recycled quartz, documents widespread exposition of gneissic basement on the dissected rift shoulder. Markedly increased mineralogical stability from the Al-Khlata to the overlying Raab and Saiwan formations points to more intense chemical weathering - possibly coupled with enhanced intrastratal solution of unstable components - related in turn to raised temperatures and humidity at the end of the Gondwanan glaciation.

Furthermore, very significant is the diagenetic sequence of the sandstones, which shows great abundance of celestite from the top of the Al-Khlata to the base of the Saiwan Formation. Celestite not only fills primary intragranular pores but also engulfs and partially replaces selectively less stable framework grains, thus indicating filling of secondary pores at a relatively late diagenetic stage. Occurrence of sulfate cements has been reported from other post-glacial sediments, where diagenetic parageneses developed under the influence of acidic, meteoric-derived pore-waters and the decay of organic matter in humid continental environments.

#80 Oman to Western Australia : Correlation of the Peripheral Gondwanan Permian

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Southeastern Oman, Saudi Arabia, the Salt Range (Pakistan) and Western Australia all possess extensive sequences of Permian strata (in many cases of marine origin) that are developed adjacent to ancient cratonic blocks. These sequences are often representative of a considerable portion of the Permian Period and are less tectonically disturbed than the Permian sequences associated with collision zones and accreted terranes in the Afghanistan, Himalayan - Tibet, and southeast Asian regions of the southern Tethyan Embayment of northeastern Gondwana. Hence these regions act as critical areas for establishing refined biostratigraphies which, in turn, are required for constraining the precise timing of global and regional events including those of a tectonic, climatic or oceanographical nature.

The Arabian Peninsula is characterised by peripheral Gondwanan Permian sequences that show a major climatic change from glacial influences in the earliest Permian to subtropical influences in the Late Permian. The Huqf Area of southeastern Oman, coupled with data from Saudi Arabia, demonstrates that the Al Khlata glacials belong to the *Granulatisporites confluens* palynofloral zone, a zone that is widespread throughout the Early Permian (late Asselian? - Tastubian) of the peripheral Gondwanan regions and Australia (Archbold, 2000). Above the Al Khlata glacials is the marine Saiwan Formation with its distinctive *Sterlitamakian*, cool to warm temperate, *Neospirifer-'Cyrtella'* brachiopod fauna that correlates with the Cimmeriella fauna of southeast Asia and Western Australia. These faunas mark the peak in sea level that followed the Early Permian Gondwanan deglaciation event (Wopfner, 1999). The Saiwan Formation is followed by a substantial break in Oman until the Ufimian - Roadian when the terrestrial Gharif Formation was deposited. However in Western Australia, Peninsular Thailand, Timor and apparently the Papua Province of Indonesia, marine conditions existed for at least part of this missing time interval.

The Kazanian = Wordian of Oman is characterised by a major transgressive event (Angiolini and Bucher, 1999) that is present in Afghanistan and Pakistan (Salt Range and the Karakorum) but not the Himalaya or Lhasa Block. Saudi Arabia preserves evidence of the major Djhulfian - Wuchiapingian transgressive events that occured throughout the southern Tethyan Embayment of Gondwana from the Arabian Peninsula to Northwestern Australia.

#350 Geochemistry and tectonic significance of basalts in the Dar Anar complex: evidence from the Kahnuj ophiolitic complex, southeastern Iran

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The Kahnuj ophiolitic complex, part of the Jaz Murian ophiolitic belt, is located on the western boundary of the Jaz Murian depression and is bounded by two major fault systems. There is a well-preserved, ophiolite pseudostratigraphy of Early Cretaceous to early Palaeocene age and has a bearing on the Mesozoic development of southeastern part of Iran and adjacent region. The Kahnuj ophiolitic complex consist mainly of lava flows and pillow lavas with intermittent pelagic limestones, sheeted dykes, gabbros, and plagiogranites, with subordinate ultramafic rocks. Structurally the complex is extensively faulted and fractured. The volcanic rocks have undergone low grade alteration and metamorphism, exhibiting greenschist facies assemblages. The basalts exhibit variable enrichment in LFS elements (Sr, K, Ba) relative to HFS elements (Ti, Zr, Y, Nb, P). The basalts are characterized by low Zr/Y (~ <4), Th/Ta (~ <2), La/Nb (~ <2) and Nb/Y (0.12-0.2) ratios, relatively low TiO_2 and P_2O_5, and progressively enriched normalized patterns and increased Ce and Th values. Based on chemical discrimination parameters the basalts were originally developed in a back-arc basin and as such are representative of supra-subduction zone Tethyan ophiolites.

#174 Rooted ophiolites on the east Oman margin

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We describe results from a coincident seismic reflection and refraction profile across the east Oman continental margin. The profile runs northwest-southeast orthogonally across the margin north of Masirah Island, crossing the Masirah Basin and the Owen Basin. The seismic reflection data show details of the uplift and subsidence history of the area that may be correlated with ophiolite emplacement on land and the wider tectonic evolution of the region. The Masirah Basin has a V-shaped cross-section, and contains at least 3 seconds TWT (3-4 km) of sediments. An intra-basement reflector lies about 2-3 km beneath the sloping west side of the Masirah Basin. Sediments in the Owen Basin show several minor unconformities and evidence of margin-parallel seabed flow and deposition, perhaps controlled by the Owen Ridge. The basement of the Owen Basin deepens and apparently ages towards the Owen Ridge, which is manifested at this latitude as a rather subdued basement high, well to the west of the present day Owen Fracture Zone. Both the Masirah Ridge and the Owen Ridge, both now draped in sediment, show periods of onlap.

The refraction profile was recorded by 10 ocean bottom seismometers along a line about 140 km long. The continental shelf shows only a thin covering of sediments, pinching out towards Masirah Island, with high velocity material close to the surface. The Masirah Basin is floored by thin crust, and wide-angle reflections are recorded both from the landward dipping Moho beneath the margin, and from a deeper landward dipping reflector in the mantle.

The continental margin of east Oman has been interpreted as a site of margin-parallel shear occurring some time after its original formation by extension. The Masirah ophiolite appears to have been upthrust onto the margin as part of this shearing process. We suggest that the intra-basement reflector observed beneath the continental slope may represent the sole of the Masirah ophiolite itself, or part of a stack of imbricated parallel oceanic slivers. The landward-dipping reflector in the mantle beneath the margin may be interpreted in terms of the delaminated lower part of the oceanic lithosphere, thrust beneath the continental margin.

#122 The Permian-Triassic boundary in Oman, a review

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The Oman Mountains expose a segment of Neo-Tethyan southern margin interpreted as an upper plate flexural margin. Permian and Triassic successions are visible in various sections from shallow to deep -water sedimentary facies. The shallow-water environment occurs in the Jebel Akhdar Mountains (Wadi Sathan section, Saiq and Mahil Formation.). The slope carbonates of the platform margin crop out in the Sumeini area (Wadi Maqam section, Maqam Formation). Drowned carbonate platform (Oman Exotics) and deep-water deposits occurring in the distal and basinal sector of the margin belong to the thin-skinned Hawasina nappes (Wadi Alwa, Wadi Wasit and Wadi Musjah sections).

There is apparently no sedimentary gap between the Permian and the Triassic in the Wadi Sathan carbonate platform succession. There, the Permian-Triassic transition spans a 110-120 m interval between the last Upper Permian corals and *Paradagmarita* foraminifera (near the top of member B, Saiq Formation) and the first lower Triassic (Induan) microforaminifera assemblage (10 m above the base of Mahil Formation). The uppermost transgressive-regressive cycle of the Saiq Formation (member C, about 100 m in thickness) consists of recrystallized dolopackstone to grainstone and is deprived of macro and microfauna. The main negative shift of carbone isotope, usually indicating the P-T boundary, takes place at the top of the member B. Accordingly, the member C of the Saiq Formation is lower Triassic (?Griesbachian) in age.

Furthermore, in the Wadi Maqam section there is apparently no sedimentary gap between the Permian and the Triassic. The Maqam Formation (upper Permian to upper Triassic, 1,700 m thick) is divided into 6 members, A to F. The Permian-

Triassic transition occurs within a 160 m interval, between the last Upper Permian bryozoans and sponge spicules (cherty dolomites at the top of the member B) and the first lower Triassic microforaminifera assemblage (160 m above the base of the member C). A very important negative shift of carbon isotope takes place at the top of the member B and continues into the basal part of the member C (Richoz et al., this volume). This basal part is made of thinly-laminated stromatolitic deposits that are typical of the basal Triassic carbonate transgression in the Tethys. As a result, the Permian-Triassic transition can be constrained within few meters, at the very base of the member C.

In the deep-water Hawasina nappes, the Permian-Triassic transition seems locally exposed as a succession of radiolarian chert and argillite grading into flaggy limestones. However no diagnostic Changxingian/Griesbachian fossils were so far recovered in the probable boundary interval. In the Oman exotics, the transition is missing and the sedimentary succession between the Permian and the Triassic is characterized by an abrupt lithological change and a significant time gap from Guadalupian to Dienerian. Upper Permian and Griesbachian deposits are present only as clasts or boulders within lower Triassic (Smithian) debris flow.

In the basinal Wadi Wasit deposits, a unique decametric boulder from a hudge Dienerian debris flow shows a Griesbachian to basal Dienerian coquinite made of bivalves (*Claraia* at the top) overlying a reefoidal Guadalupian lime boundstone. Here, the time gap is shorter and spans the Capitanian to the basal Griesbachian.

#300 Demise of Permian biogenic chert along the margins of northwest Pangea, Western Tethys and Gondwana: evidence for paleoceanographic disruption and global warming

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Anomalously-high biogenic chert deposition occurred for more than 30 my years along the oceanic margins of northwest Pangea. The onset of the Permian Chert Interval at about the Sakmarian-Artinskian boundary in the deeper-water distal areas and the coeval shift to narrower and less productive, faunally-impoverished carbonate factories in the shallow-water proximal areas indicates that much colder oceanic conditions were suddenly established all along this margin. This process intensified during the Guadalupian and reached its zenith during the Lopingian when silica factories occupied most shelf areas while carbonate factories were all but eradicated.

The occurrence of Lopingian chert deposits within the widespread carbonate platforms of the western Tethyan and Gondwanan margins suggests that similar paleoceanographic conditions may have occurred elsewhere. For instance, the upper part of the Episkopi Formation (Lopingian) on Hydra Island (Greece) consists of spiculitic bioclastic lime wackestone-packstone with abundant black cherts and silicified horizons in its upper part. Similar cherty limestones occur in the Changhsingian reefal lime boundstones of Aegina Island, Greece. Changhsingian basinal siliceous lime wackestones rich in calcitized radiolarians occur in the adjacent Salamis Island. Cherty intervals occur locally in the Upper Permian carbonate platform of Taurus, southern Turkey (Kokarkuyu Formation, Curuck Dagh section, Lopingian). Likewise, a chert interval of probable Lopingian age is recorded in Oman. A 50 m thick deposit of cherty thin-bedded dolomites associated with sponge spicules and radiolarian occurs at the top part of Member B of the Maqam Formation (slope deposits of the Sumeini Group, western Oman Mountains).

Biogenic silica factories collapsed near the end of the Permian period throughout the world, abruptly bringing the Permian Chert Interval to an end. Then followed a long Early Triassic episode during which apparently no biogenic chert of any kind was to be preserved anywhere. In northwest Pangea, this event recorded a major transgression in the marine environment and a shift to much warmer, redbed- and caliche-forming conditions in the terrestrial environment. Similarly, Permian siliceous biota abruptly disappeared in the Tethys and were replaced by stromatolitic lime boundstone, which are overlain by thick successions of platy, chert-free lime mudstone. The demise of the Permian Chert Interval near the end of the Permian coincides with the irreversible disruption of a stable paleoceanographic setting, one that was characterized by the vigourous thermohaline circulation of northerly-derived, cold and nutrient-rich waters along the western and northwestern margin of Pangea, and possibly along its eastern margin as well. The seasonal melting of sea ice, and possibly land ice, was presumably the source of northerly-derived cold waters and thus the engine for thermohaline circulation. Rapid warming during the latest part of the Permian led to the rapid meltdown and disappearance of the northern cold-water source, which resulted in much warmer marine conditions associated with sluggish, if any, thermohaline circulation.

#21 Al Aridh Group: Revised stratigraphy and significance of a Mesozoic Hawasina unit in the Oman Mountains

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The Al Aridh Group, well exposed on the southern flank of the central Oman Mountains, forms part of the Hawasina Nappes overthrusted, in the Late Cretaceous, onto the Arabian Platform. In spite of tectonics, four stratigraphic units are clearly identified, from bottom to top:

(1) A thick series of hyaloclastite and subordinate pillowed-

basalt, capped, locally, by Carnian radiolarian chert and, more generally, by an erosive megabreccia; this latter horizon is overlain by an hemipelagic succession with fine-grained calcarenite, "*Halobia*"-bearing micritic limestone and radiolarian chert, Norian in age at the base and Rhetian at the top.

(2) A thick series of massive grey-white pelletal/oolitic calciturbidite, which rests conformably upon the basal unit; the Jurassic age of this second unit is not well documented yet.

(3) A Toarcian to Valanginian series of radiolarian chert that includes a breccia horizon; this latter unit, Toarcian/Bajocian in age, is characterized, either by clast-supported conglomerates with subrounded blocks of Permian and Triassic shallow-water carbonates or by several debris flow sequences.

(4) An Aptian/Albian to Turonian series of radiolarian chert including, at the top, a breccia horizon with several debris flow sequences.

The Al Aridh Group shows characteristics of slope and/or proximal basin facies, i.e. the association of pelagic/hemipelagic deposits with breccia horizons. A lateral passage between coarse-grained quartzose calcarenite (Hamrat Duru Group) and the Triassic/Liassic facies of the Al Aridh Group, supports a proximal paleogeographic setting interpretation.

Thus, the Al Aridh continental slope succession is interpreted as a southern lateral equivalent of the northwestern Sumeini series. Nevertheless, the slope facies of these two units are not similar and these differences clearly indicate the Arabian shelf edge presented two morphological types: an homoclinal and/or distally steepened-ramp in the north (Sumeini type slope) and a bypass gullied slope in the south (Al Aridh type slope).

#14 Second-order cycle development of the Arabian platform and Hawasina seamounts: Permian and Triassic outcrop data from central Oman

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A distinctive second-order cycle development characterizes Permian and Triassic carbonate platforms. These long-term transgressive-regressive cycles, which span 5-20 my may be composed of stacked higher frequency cycles.

Arabian platform, Huqf uplift: Sediments of the Huqf area represent a marginal setting with reduced thickness. The first sequence commenced with the Lower Permian Saiwan Formation upon glacial deposits (Al Khlata Formation) and is composed of 50 m crossed-bedded, mixed carbonate-siliciclastic sediments yielding marine biota. This cycle is characterized by rapid flooding. After an indistinct unconformity, the next second-order cycle started with lowstand deposits of the Gharif Formation (50 m) followed by 30 m of Middle-Upper Permian carbonates and marls of the Khuff Formation. In the Huqf area, the Khuff is an alteration of mudstones and tempestites, no cyclicity can be observed in this marginal setting. In the subsurface however, at least three transgressive cycles with basal coastal plain claystones were observed by Mercadier and Livera (1993). Triassic-Lower Jurassic terrestrial sediments (Minjur Formation) are composed of 15 m terrestrial marls and sandstones.

Arabian platform, central Oman Mountains: The Akhdar Group forms two long-term transgressive-regressive cycles with short transgressive phases. The basal 0-20 m of the Middle to Upper Permian Saiq Formation are dominated by clastic sediments (equivalent to the uppermost Gharif Formation). Bituminous, dark limestones marking the maximum flooding surface are overlain by coral-rich thick-bedded limestones (Saih Hatat). Most of the Saiq Formation (equivalent of the Khuff) is characterized by monotonous, inner shelf limestones/dolomites lacking exposure horizons. Locally, three shallowing upward cycles were differentiated due to transgressive marine facies with rugose corals or alatoconchid bivalves. Cycle correlation is impossible due to graben structures with rapidly changing subsidence rates and volcanic sequences. The Saiq Formation is terminated by a short-termed regression. The Triassic Mahil Formation is the next sequence and consists of well-bedded, monotonous dolomite with algal laminations (sabkha environment). *Aulotortus sinuosus* indicates a Norian to Rhaetian age at the top.

Isolated carbonate platforms of the Hawasina basin: Slope deposits of the Permian Bai'id and Al Jil formations represent a second-order cycle equivalent to the Saiq Formation starting with calciturbidites (highstand-shedding). Overlying pelagic sediments indicate falling sea-level and karstified reef blocks reflect subaerial exposure of the carbonate platform. Platform blocks suggest indistinct high-frequency cycles. Lower and Middle Triassic sediments represent either deep-water deposits or rift volcanics. Late Triassic (Carnian? - Rhaetian) carbonates build the youngest sequence and exhibit a short transgressive interval followed by patch reef development and a thick sequence of Lofer cycles. The Lofer cycles reflect high frequency sea-level fluctuations comparable to other locations in the Tethys.

The primary controls on the development of the second-order architecture include Middle/Late Permian and Early Triassic rift pulses, variations in subsidence, long-term sea-level changes with a major sea-level fall during the Permo-Triassic, and a shift in climate from icehouse to greenhouse conditions. At present, two Permian second-order cycles and one Triassic second-order cycle can be differentiated. Higher frequency cycles are prominent during the Late Triassic and indistinct during the Permian.

#15 Control mechanisms of biogenic sedimentation on the Arabian shelf: Reef limestones from the Tertiary of Oman?

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The distribution of the coral faunas during the Tertiary in the Middle East depends on the development of the Arabian shelf. During the Eocene/Oligocene and middle Miocene global and regional mechanisms like tectonic movements and eustatic sea-level changes controlled dimension and facies distribution on the platform. This triggering mechanisms influenced the coral growth during the different time-slices.

The Tertiary transgression started during the late Paleocene and an epicontinental sea persisted continuously up to the late Eocene. Later, due to a fairly generized regression of the Eastern Arabian Peninsula, the Oligocene and the Miocene seas were much more limited in extent. At the end of the early Miocene very littoral sedimentation only occurred in several small inlets, bordering the present-day coast.

Study areas are in North Oman (Sumeini), Central Oman (Seeb/Quriyat) and South Oman (Duqm/Dhofar). The following formations characterize the reef types during different time slices:

Sirab Formation: (large isolated dendroid coral colonies) This formation is comprised of calcareous and marly deposits varying in thickness considerably as deposition took place on the slopes and the lower edges of the shelf. The formation is dated as Thanetian to Cusian age and marks the beginning of the Tertiary coral development on the Arabian Peninsula.

Seeb Formation: (coralgal and coral patch reefs) The Seeb formation is dominated by foraminifera (*Nummulites/Assilina*) assemblages. Higher energy shoals and coralgal patch reefs were formed in a shallow open carbonate shelf environment. The diverse benthonic foraminifera fauna in the type area indicates a Middle Eocene age. Coral limestones of the Late Eocene/Early Oligocene (e.g. with *Actinacis, Alveopora*) are also exposed on the top of the Seeb limestone.

Aydim Formation: (coral banks) The calcarenitic deposits are characterized by a rich macrofauna (molluscs, echinids and corals). The corals are abundant in the basal part (e.g. *Astrocoenia, Dendracis, Montastraea, Porites, Stylophora*). The Aydim Formation contains a rich benthic foraminifera microfauna, and the nummulitids indicate a Barthonian to Priabonian age.

Warak Formation: (coral banks, thickets and patch reefs) This formation forms a small cliff composed of alternating beds of pure white chalky to bioclastic limestone with coral biostromes and bioherms up to 5 m thick and debris flow deposits. Some beds of micritic limestones with fenestral fabric or mudcracks at the top reflect episodes of emergence that have affected sedimentation and coral growth. The highly diverse fauna contains corals of different size and growth form, molluscs and echinoids. The foraminiferal assemblages dominated by peneroplids are good evidence for Burdigalian to early Langhian age.

The collision of Afro-Arabia and Eurasia led to the rise of the alpinotype mountain ranges. This caused a transection of the Tethys in the Middle East region and influenced the paleogeography, marine circulation and climate. The formation of the Oman Mountains restricted the shelf development especially in the north. The coral distribution ended with the end of the existance of the Arabian platform in the Middle to Late Miocene.

#31 Tectono-sedimentary Evolution of the Mesozoic Hamrat Duru Group in the Oman Mountains

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The Hawasina Complex is a stack of nappes forming part of the Oman Mountains in the northern Sultanate of Oman. The sediments of this complex were deposited during the Mesozoic on the north-eastern Arabian continental margin and in the adjacent Neo-Tethys Ocean. The subject of this investigation is the Hamrat Duru Group, a subunit of the Hawasina Complex. These Late Permian to Late Cretaceous deep marine sediments were deposited in a single flysch basin. During the Late Cretaceous SSW-directed obduction of the Semail Ophiolite, the Hawasina complex was emplaced onto the autochthonous cover of the Arabian basement.

The sediments contain base-of-slope and abyssal plain facies. Depositional systems comprise turbidity channel belts, terminal lobes, as well as a basin-plain and hemipelagic environment. Proximal lithologies include exotic carbonate blocks of Permian and Triassic age, lithoclastic and resedimented oolithic limestones and terrigeneous (siliciclastic) turbidites. Distal deeper water lithologies comprise ooid-rich and lithoclastic limestones, silicified limestones and radiolarian cherts, interbedded with mud-rich and turbiditic siltstones. Siliciclastic sediments dominate the lower succession (Upper Triassic/ Lower Jurrasic). Sediment transport in the areas with distal facies was mainly towards the east and southeast. Flute marks and current ripples in the proximal facies indicate sediment transport to northerly directions.

New high resolution biostratigraphical dating by radiolarians allows a striking good correlation between the different facies zones throughout the deep marine basin. High and low sea-levels controlled by eustacy and/or tectonism were accompanied by significant changes of carbonate production and input of siliciclastic material into the basin.

The post-sedimentary evolution is recorded by SW-directed thrusts and associated obduction-related folds that are overprinted by relatively open, asymmetric and SSW-verging Tertiary folds (long normal limbs and steep to overturned short limbs and upward facing). Normal faulting is related to the subsequent phase of extension.

#215 The Permian "Gharif paleoflora" and the ostracodes from the Khuff Formation (Huqf area, Sultanate of Oman): a review

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In the Huqf area (Sultanante of Oman), a complete biogeographic sequence is now well documented from " late-early Westphalian/ early Stephanian " to early Late Permian which can be extended until latest Permian, integrating the phytogeographical sequences recorded in the Arabian Peninsula.

In this Huqf area, a continental "Gharif Formation" is bracketed by the marine Saiwan Formation of late Sakmarian age and the marine Khuff Formation of ?Kubergandian-Murgabian age.

This sequence provides new dating constraints for the rich and well preserved macro- and microfloras discovered in the dark pelitic horizons of the Gharif. The Oman succession represents a key section for the intercalibration of marine and continental biostratigraphical scales. The early Murgabian age previously assigned to the microflora of the Gharif must be revised in the light of the newly obtained age from the overlying brachiopod faunas of the Khuff Formation.

The newly named "Gharif Paleoflora" is erected as a standard for the Arabian Peninsula. This warm humid floral assemblage is of outstanding paleogeographic significance. Gondwanan, Cathaysian and Laurasian elements are found to be associated in this flora. During the Early Permian, floristic data indicate that the Huqf area was part of the Gondwana floral province, in contrast with the Moroccan paleoflora which shows mainly Laurasian affinities, at the other end of our transect, but with the occurrence of "exotic" Cathaysian and Gondwanan floral elements.

The provincialism of the ostracode association of the marine Khuff Formation is analysed with reference to the other Permian occurrences wordlwide. A mixed fauna existed on the Arabian Platform. Together with the endemic elements, the other species present clear relationships with other Paleo-Tethyan areas and south China. This new record of Permian ostracodes, combined with recent data obtained in Greece and Southern Tunisia, emphasize the close relationship between the southwestern Paleo-Tethys realm and South China.

In combination with marine paleontological data, the understanding of the kinematics of the Permian vegetal cover will lead to test the proposed peritethyan paleogeographical reconstructions.

The paleogeographic significance of the diachronic appearences of " mixed " paleofloras during the Permian period is discussed.

Most of these works have been supported by the International "Peri-Tethys Programme "

#294 New geological findings in the Gulf of Oman (Northern Sohar Basin) Shell Oman Deepwater Block-18

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Block 18 is located in the Gulf of Oman in the northern part of Sohar Basin. The Block was awarded to SDO (on a 100 % basis) in April 1999 for an initial exploration period of 3 years. The block covers an area of 18,267 sq km and water depths range from 25 m to 2,900 m. During the last 2 $^1/_2$ years SDO has acquired 3,050 km of new 2-D seismic data, reprocessed all historical 2-D data covering Block-18 (2,654 km) and performed a Block-wide evaluation study, making also use of all available, though limited well data. This paper summarises the tectono-sedimentary interpretation of Block 18 carried out by a multi-disciplinary team in Shell comprising Shell Deepwater Oman (SDO) and E & P Technology Applications and Research (SEPTAR) staff.

Regionally the Sohar Basin, in the Gulf of Oman, is a Cretaceous-Tertiary deepwater basin confined between the narrow Omani continental shelf and the Makran Accretionary Prism to the north, with its associated thrust belt. The basin is narrow and shallow to the northwest whereas to the southeast, it becomes wider and deeper. During the Late Cretaceous much of the Sohar Basin appears to have been a deep marine setting. A major unconformity separates the Cretaceous from the Tertiary and during the Early Tertiary, in the shelf area, shallow marine carbonates and fine clastics were deposited. The extent of these sequences to the other parts of the basin is unclear. During the Miocene, uplift and erosion of the Arabian Plate margin resulted in major sediment input into the Sohar Basin. As a result of sedimentary loading, major growth faults with their associated toe thrusts and mud diapirs became active. From the Miocene to the Present continued uplift and erosion of the Oman Mountains has resulted in continued input into the basin. A regional gravity model for the basin has been established and highlights the thick sedimentary pile in the basin.

Based on the seismic interpretation, performed on the newly acquired, processed and historical, reprocessed seismic data (interpreted down to levels between 2 - 4 seconds), five main structural provinces could be recognised in Block 18:

(1) *Growth Fault province:* A regional down-to-the basin listric fault has been identified along the border of the Oman continental shelf. Continuous subsidence on the down thrown side of this fault has led to the deposition of huge amounts of Neogene deposits in the deeper part of the basin. The high sedimentation rates have resulted in the development of a spectacular Neogene growth fault system. Direct measurements on seismic suggest maximum deposition rates in the order of 500 m/my during the Late Miocene. Seismic data shows that it is possible to define different episodes of growth faulting, which are thought to be linked to periods of uplifting in the adjacent continental areas. As most of the sedi-

ment supply came from the adjacent Oman Mountains, it is believed that sediments in the Sohar Basin are compositionally and texturally immature. This interpretation is also supported by data from available wells on the shelf.

(2) *Makran Thrust belt province:* The Northern flank of the Sohar basin is limited by the Makran Accretionary Prism. This is an elongated and structurally complex thrust belt resulting from the subduction of oceanic basement under the Eurasian Plate. The Makran is actively subducting today and advancing southwards at a maximum rate of some 10 cm/yr. Large overthrust anticlines are recognised along the frontal thrust belt and involving Upper Miocene to Recent sediments. Towards the core of the accretionary prism fault density increases creating a highly complex and deformed thrust belt.

(3) *Toe Thrust province:* Locally, in the Northwest corner of Block 18, an Oligocene/Miocene toe-thrust system has been identified. This toe-thrust system is structurally related to the far side of the growth fault system and the reduction of space accommodation in the Northwest part of the basin.

(4) *Mud Diapiritic province:* To the south, where the Neogene sedimentary pile reaches its maximum thickness, a mud diapir zone has been identified. These diapirs are believed to be mobile shales of Maastrichtian age. In addition to the deformation caused by the diapirs, this area lies at the junction of the Growth Fault province and the Makran Accretionary Prism resulting in a very complex structural picture.

(5) *Undeformed province:* The intensity of the faulting and deformation decreases towards the Southeast corner of the Block, where only few and small normal faults are disturbing the sedimentary cover.

#198 Permian-Triassic deep water sediments of the Wadi Wasit revisited

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Located along the southern flank of the Saih Hatat, the Wadi Wasit area provides one of the best exposures of Permian and Triassic deep water sediments in the Hawasina allochthon. This unit, thrusted onto the Saih Hatat Arabian Platform series and capped by the Semail Ophiolite, is exposed in a tectonic window forming an anticline with a roughly N-trending axis.

The most complete Wadi Wasit section includes the Permian and Triassic Al Jil Formation (Béchennec, 1988, 1992). Seven main lithological units can be identified in this section, from the base up: (1) a thick volcano-sedimentary sequence of pillow basalts of WPB-type; (2) medium bedded red limestones with layers of fine-grained resedimented limestone and shale interbeds, Wordian in age on the basis of ammonoids (det. Furnish and Glenister in Blendinger et al., 1992) and the conodont *Mesogondolella siciliensis* (det. H. Kozur); (3) cherty and turbiditic (allodapic) limestones with occasional chert nodules ; (4) a massive dolomitized breccia with blocks of reefal limestones (Weidlich et al., 1993); in a distinct tectonic slice, a lateraly equivalent undolomitized unit contain a large boulder with a Griesbachian bivalve lumachelle and ammonoids resting on Wordian reef boundstone; (5) gray platy limestones and thin shale or marlstone interbeds, Dienerian in age on the basis of conodonts, constraining the breccia deposition at the end of the Griesbachian or the beginning of the Dienerian. The reef biota of the Permian reef boulders deposited in these deep water sediments have been compared with the El Capitan reference section of West Texas (Weidlich et al.,1993; Weidlich, 1996; Weidlich and Senowbari Daryan, 1996); (6) light brownish folded radiolarites; (7) gray platy limestones. Radiolarians have been detected in the three top units but are commonly recrystallized.

The Wadi Wasit succession is well correlated with other exposures of the Permian Hawasina series as those of Al Ajal, Rustaq, or Al Buday'ah, where basaltic flows are also capped by " Murghabian " sedimentary sequences. However, it shows distinctive features such as a gap of Upper Permian strata and the occurrence of reworked blocks of Lower and Middle Permian platform carbonates, similar to successions exposed in the Al Ashkharah area. This gives a clear indication regarding initiation of the Tethyan extension in the region. Nevertheless, the pillow lavas geochemistry suggests that these units have continental crust affinities and that the Wadi Wasit unit was close to the Oman margin.

#310 From carbonate ramp differentation to basin evolution: The late Precambrian Buah Formation (Nafun Group), northcentral Oman

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Terminal Neoproterozoic carbonates of the Buah Formation (Nafun Group) crop out extensively in northern Oman (Jabal Akhdar) and in central Oman (Huqf area). In the Huqf area sedimentation took place on a storm-dominated shallow water carbonate ramp which evolved through time into a hypersaline restricted peritidal complex. Lateral facies variability is negligible. The thickness of the Buah varies on a large scale, with an overall trend of thickening away from basement high where pan-African granites (c. 820 Ma) are exposed to the surface, reflecting increasing subsidence rates from north to south.

The Buah in Jabal Akhdar started as a shallow water storm-dominated carbonate ramp, but underwent a major differentiation through time into platform and slope paleodepositional environments. As a result, a shallow water platform sequence (Wadi Hajir) accumulated at much faster rates that the sediment-starved adjacent slope succession (Wadi Bani Awf). Using high-resolution chemostratigraphy it is possible to estimate a platform relief of more than 100 m over a lateral distance of few kilometers. Much of the relief was attained via a vertical aggradation phase that finds its sedimentological expression in stacked m-scale stromatolite mounds in the platform and a condensed sequence made of black shales and bituminous mudstones in the slope section. Both platform and slope deposition were punctuated by the occurrence of a breccia and megabreccia deposit, possibly the result of a major platform collapse induced by tectonic instability. The Buah is capped in Wadi Bani Awf by the thick volcaniclastic succession of the Fara Formation that encompasses the Precambrian-Cambrian boundary.

With a wider perspective, the different evolution of Buah deposition in the Jabal Akhdar and in the Huqf area reflects the different location of the two areas with respect to the distribution of tectonic subsidence during Late Neoproterozoic time. The Nafun Group is thought to have been deposited at the distal margin of a foreland basin flexed down by loads situated to the west, the Western Deformation Front representing the most forelandward progradation of the orogen. The Jabal Akhdar area experienced rapid subsidence, volcanicity and basin compartmentalisation at terminal Buah times, perhaps related to the onset of strike-slip tectonics along a zone adjacent to the Western Deformation Front. In contrast, the Huqf area was practically unaffected and experienced a much slower subsidence rate favoring the development of laterally extensive shallow water carbonate ramp deposits throughout the area.

#162 The Tectono-Stratigraphic framework of Oman

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Since the publication of the last formal lithostratigraphic lexicon for Oman (Hughes Clarke 1988), a wealth of new seismic, well and biostratigraphic data has become available that has improved our understanding of the Oman stratigraphy. This has lead to several changes and revisions of the tectonostratigraphic framework. Highlights include the recognition of the Precambrian-Cambrian boundary, new views on the nature of the Angudan unconformity and the Huqf-Haima boundary, a better understanding of Ordovician and Silurian stratigraphy, refined calibration of Devonian stratigraphy, and improved biostratigraphic control leading to better understanding of the Permo-Carboniferous Haushi Group, the Jurassic Mafraq, and the Upper Cretaceous Natih and Fiqa formations.

The objective of this poster is to present the latest PDO view of the Oman Tectono-stratigraphy and some of the issues and problems that are still under discussion.

#115 The Upper Jurassic to Lower Cretaceous Succession near Khatt, Oman Mountains, UAE: Aspects on carbonate channel deposits and their geometries

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The Jurassic and Lower Cretaceous carbonate rocks exposed near Khatt account for a compressional tectonic setting. N-trending (plunging) anticlines, synclines, low-angle thrusts and at least three different generations of fault systems are the key structural elements of the outcrops examined.

Sedimentologically, a coarsening-upward sequence in the Lower Cretaceous limestone indicates decreasing depths of deposition - i.e. a slope environment with a well-exposed basin to platform transect - and pronounced shedding of sediments from a nearby reef. The carbonate rock types include mudstone, wackestone, grainstone, coarse rudstone with conglomeratic/breccious intercalations and reefal framestone. The depositional architecture is characterised by the abundance of massive sheet or channel-like limestone deposits within thinly-bedded, rather uniform strata. Quantitative analysis of a large number of carbonate channel deposits and their geometries led to the distinction of two major types: Thin (0.3 to 5 m), often irregularly shaped Type I channel deposits generally show high values for width (up to 200 m), whereas the thickness/width ratio of the more regularly bedded Type II channels is much larger and comes close to 1:10 in most cases. In contrast to Type I channel deposits with a wide size-range of bioclast and non-bioclast carbonate components, Type II channels are uniquely composed of calciturbidite sediments (very fine-grained grainstone).

#189 Linear thermal anomaly offshore from Wadi Dayqah: A probable ground-water seep along fracture zones

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The Wadi Dayqah area of the eastern Hajar Mountains is prone to flash floods following seasonal heavy rainfall. The wadi is a deep incision in the rocks that descends from the ophiolitic exposures above to the limestone beds near the coastal plain. The force of these floods is manifested by the size of the boulders carried along and deposited on the sides of the wadi. In spite of the flash floods, a great amount of water, possibly millions of cubic meters, is lost into the karst of the coastal Tertiary limestone block. The point at which the water disappears is located at the head of a narrow gorge through the limestone beds above Hayl Al Ghaf.

In an attempt to find out if some of the ground water seeps into the coastal zone, we analyzed thermal Landsat image data of the region obtained on three different dates. A warm thermal anomaly was identified offshore that can only be related to faulting because of its linearity. The primary thermal anomaly trends NNW and stretches approximately 60 km in length and 5 km in width at a point where it shows a warmer area in the center. Intersecting this thermal anomaly is a smaller one that begins at Dibab along the coast and trends in a NE direction. From this point on the coast and for approximately 26 km to the south are what appear to be signs of warm water occurrences near the coastline that might be the result of springs. Fresh water springs have previously been identified by pearl divers offshore in the Gulf of Oman and the Arabian Gulf.

We believe that fault zones are responsible for the transmission and loss of flood water into the Gulf of Oman. It is significant to note that the warm water anomaly is only evident in image data that were collected about a month after a series of heavy rains. This suggests that enough time would have passed to allow the water to travel through the karst into fracture zones and then seep along extensions of the faults beneath the coastal water.

#114 Sequence stratigraphy and palaeoenvironments of the Shargi Formation, North Oman Foreland Basin

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2-D seismic data, biostratigraphy and field observations have been integrated to develop a model of evolving palaeoenvironments and depositional systems in the Santonian and Campanian foreland basin of the Oman Mountains. The depositional sequences studied form part of the Aruma Group, unconformably overlying the carbonate dominated Natih Formation (of the Wasia Group). The Aruma Group has previously been subdivided into the Fiqa, Arada and Simsima formations. The focus of the analysis carried out has been on the older units of this group equivalent to the Fiqa, here informally referred to as the Lower and Upper Shargi members based on micropalaeontological evidence and largely subsurface data.

The Lower Shargi is represented by deep-water shales overlying a sequence boundary which separates terrigenous clastic deposition from the Natih carbonates, following rapid submergence during the Coniacian to Santonian. The top of the Lower Shargi is defined by an extensive erosional cut, interpreted as a coalescence of major slump scars over a strike length of up to 100 km. Within the Lower Shargi, deep canyons and channels a few hundred metres to kilometres wide, trending N-S, erode up to 100 m into bathyal deposits. These probably carried sediment derived from the emergent Huqf High to the south towards the deepening trough ahead of the developing Oman Mountain front.

Above the slump scars, convergent, onlapping reflection geometries have been mapped on 2D seismic data and can be related to deposition of turbiditic sheet sands in a deep-water environment during the early Campanian. Up to 400 m of accommodation space was originally available, and is now occupied by a fining-upwards sequence of sands and silts possibly equivalent to the Fayah described on the Batain Coast 150 km to the east. The strike of the shelf-slope break, defined by biostratigraphic data from several wells, was oriented E-W. Its continuation towards the west was oriented NW-SE a few kilometres from the Maradi Fault Zone. The Campanian shelf to the south was dominated by shales apparently by-passed by coarser clastic sediment input. The slope acted as a backstop for deposition of the turbidites from the east and north with an increasing ophiolite-derived component through time. Infill of the basin was rapid and coincided with a transgression (of probable mid-Campanian age) resulting in submergence of the clastic source area to the southeast.

#50 Post-obduction extension in northern Oman

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A syn-sedimentary extensional activity took place in the Northern Oman Mountains, just after the obduction of the Semail Ophiolite onto the Arabian continental margin. This brittle tectonic regime of extension started as soon as the deposition of the Late Campanian-Maestrichtian Qahlah Formation, following a period of more ductile deformation with top-to-the-north extensional shear zones observed in the Saih Hatat window (Jolivet et al., 1998). Extension is still recorded, with several stages, in the subsequent early Tertiary Jafnayn and Rusayl formations. This post-obduction deformational history has been documented through a detailed fault-slip analysis and associated paleostress reconstruction, mainly in the Batinah Coast Plain, in the area of Muscat and in the northeastern zone from Tiwi to Sur. The direction of extension is mainly NNE-SSW to NE-SW but turns locally to E-W. Superimposed to the extensional event a period of compression occured in the same area during the Neogene, resulting in the partial inversion of the earlier structures; the direction of compression is NE-SW to E-W.

#263 Modern rifted-margin to orogenic sands of Oman: tectonic control on sediment composition

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Composition of modern beach, wadi and eolian sediments of Oman changes markedly from the Gulf of Aden rifted-margin to the Gulf foreland basin, in close response to nature and tectonic setting of source rocks.

The Masirah and Samail oceanic allochtons shed ophioliticlastic detritus with contrasting mineralogical and petrographic features ("obducted ophiolite" provenance). The former mostly supplies plagioclase, basalt, diabase, gabbro and metabasite grains from igneous rocks of the oceanic crust, with heavy mineral suites characterized by epidote, amphiboles and clinopyroxenes ("undissected" stage). The latter sheds instead a wealth of serpentinite to serpentinized peridotite grains and enstatite-dominated dense mineral assemblages, reflecting widespread exposure of tectonized mantle harzburgites ("dissected" stage).

All around the northern Oman Mountains, detritus from the Samail Ophiolite is mixed in various proportions - depending on depth of erosion level within the nappe pile of the fold-thrust belt - with grains from the underlying sedimentary units ("mixed thrust-belt" to "accretionary prism" provenance). The Hawasina pelagic successions ("distal continental margin" sources) provide limestone, chert and some terrigenous lithics, whereas shallow-water carbonates of the Arabian Platform ("proximal continental margin" sources) supply virtually exclusive limestone (Musandam Peninsula) or both limestone and dolostone with little recycled quartz (Jabal Akhdar dome). Equivalent successions of the Saih Hatat dome, which have undergone high-pressure metamorphism up to eclogite facies ("metasedimentary" to "metavolcanic" sources), provide additional metapelite, metafelsite and metabasite lithics; dense minerals include epidote, blue sodic amphiboles, lawsonite, and garnet. Locally significant (Diba Zone) are fine-grained quartzite to quartz-mica lithics and polycrystalline quartz from metasediments incorporated in the metamorphic sole of the Samail Ophiolite.

Pure carbonaticlastic sands also occur along the multistage rifted-margin of the Arabian Sea, fed from tablelands of Tertiary carbonates (e.g., Shuwaymiyah to Sawqirah bays; "undissected rift-shoulder" stage). Plagioclase arkoses are found instead where Pan-African crystalline basement is widely exposed (Marbat/Juzor Al-Halaaniyaat area; "dissected rift-shoulder" stage). Relatively quartzose sands characterize the Wahibah coastal desert. Their composition radically differs from sediments carried by major widyan bordering the erg, and compares instead closely with other dune fields of central Oman, suggesting eolian sand transport from interior Arabia ("continental interior" provenance).

#41 Tectonogenesis of the Khoy Ophiolite, northwest Iran: Results from biostratigraphic/ chronostratigraphic and ^{40}Ar/^{39}Ar studies

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The Khoy Ophiolite is located in northwestern Iran along the Turkish border. This ophiolite complex represents a remnant of oceanic lithosphere formed in the Mesozoic Neo-Tethys. This is a NW-trending ophiolite complex which consists from bottom to top (northeast to southwest) of a well-defined basal zone of metamorphic rocks, peridotites (mainly harzburgites and dunites) and serpentinized peridotites, gabbros, sheeted dikes (?), very extensive pillow and massive lava flows. The associated sedimentary rocks include a variety of Upper to Lower Cretaceous deep- and shallow-marine rocks. These include pelagic fossiliferous carbonates, which are mixed with the pillow basalts and the basaltic andesite as interlayers or exotic blocks, ranging in size from 10 to 100 m. Also present are extensive units of radiolarian chert which are interbedded within the basalts and basaltic andesites. The rocks of the metamorphic zone have an inverse thermal gradient from amphibolite facies to greenschist facies. The metamorphic rocks are in the northeastern sections of the area, immediately adjacent to the peridotite and the gabbros and the low-grade rocks are in contact with the Precambrian Kahar Formation. Two ^{40}Ar-^{39}Ar plateau ages of 158.6 ± 1.4 Ma and 154.9 ± 1.0 Ma for the hornblende gabbros suggest that rocks from this ophiolite were formed during the Late Jurassic. However, four ^{40}Ar-^{39}Ar plateau ages for hornblendes from amphibolites from the basal metamorphic zone give values of 104.6 ± 0.3 Ma, 105.7 ± 0.2 Ma, 106.7 ± 0.2 Ma,109.8 ± 0.7 Ma, suggesting an emplacement age of about mid-Albian. Several pelagic limestone samples from the volcanic member produced several identifiable radiolaria (e.g., *Novixitus* spp., *Pseudodictyomitra pseudomacrocephala*, *Archaeodictyomitra sliteri*, *Thanarla praeveneta*) and planktonic foraminifera (e.g., *Hedbergella planispira*, *Hedbergellea delrioensis*, *Thalmaninella evoluta*) which gives bio-chronostratigraphic age determination in Zone 10, Sub-zone 10A (Pessagno 1977); Early Cretaceous: late Albian to late Cretaceous: Early Cenomanian. The 1999 Geological Society of America time scale places the Cenomanian-Albian boundary at 99 ± Ma and the Cenomanian-Turonian boundary at 93.5 ± 4 Ma. Therefore, the early Cenomanian chronostratigraphic assignment of pelagic limestone samples are relatively compatible with the ^{40}Ar-^{39}Ar ages of emplacement. Such large differences between crystallization and emplacement age implies that the ophiolite cooled relatively slowly than normal oceanic lithosphere, retaining heat by some mechanism such as intra oceanic magmatism.

#195 Neo-Tethys 1 and Neo-Tethys 2: Successive Permian to Cenozoic oceans that flanked northeast Arabia

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The mid-Permian to Cenozoic geological history of the northeastern margin of Arabia was controlled by the successive crustal separation of flanking microcontinents, and the spreading and eventual closure of the intervening oceans Neo-Tethys 1 and Neo Tethys 2. Prior to the development of Neo-Tethys 1, crustal separation was heralded by Early Permian uplift and mountain glaciation centred, probably, offshore Ras al Hadd; glacial striae underlie the Al Khlata Formation in The Huqf. A linear microcontinent separated from Arabia's northeastern margin; it probably included Anatolia, Sanandaj-Sirjan and the Central Iran-Lut area of Iran and the Kawr Ridge in Oman. The basin fill of Neo-Tethys 1 comprised most of the Hawasina Series of Oman and the Coloured Melange of the Crush Zone area of Iran; by the mid-Triassic it had a calculated width of some 400 km.

Spreading in Neo-Tethys 1 ceased in the mid-Triassic. A new axis of spreading, Neo-Tethys 2, began to develop between Sanandaj-Sirjan and Central Iran-Lut. Neo-Tethys 2 continued to widen, with South America-Afro-Arabia moving westward relative to the spreading axis until early in the Cretaceous, when compressive stresses generated by the opening of the South Atlantic Ocean forced Afro-Arabia to move back to the east; Tethyan oceanic crust was lost in new, east-dipping, subduction trenches. In the Iranian sector, subduction is thought to have taken place initially in Neo-Tethys 1, obduction of ocean-floor sediments and underlying crust occurring mostly in the Campanian. Subduction ceased when the thick and relatively buoyant crust of Arabia's eastern continental margin could not be consumed within the subduction trench. Compressive stresses continued to build up to a level where a new subduction trench had to form within

Neo-Tethys 2. Associated submarine volcanism in the Inner Makran suggests that this began during the Maastrichtian.

The Dibba Line in northern Oman marks a probable former transform fault. To its south, Cretaceous subduction began in Neo-Tethys 2, with back-arc spreading leading to the development of what became the Semail Ophiolite nappe. Because the microcontinent separating Neo-Tethys 1 and Neo-Tethys 2 in the Oman sector was the very narrow Jebel Qamar-Kawr Ridge, there was little effective resistance to the subduction process until the Maastrichtian, when inability to consume the Oman sector of the Arabian continental margin brought the process to a halt. With compressive stresses absorbed in Palaeo-Tethys, Late Cretaceous obduction in Neo-Tethys 1 and 2 did not lead to creation of the Oman and Zagros Mountains. This was delayed until the Neogene opening of the Red Sea (possibly coupled with India's collision with southern Asia) with continent-continent collision in Iran leading to folding of the Zagros Mountains. In Oman, a less severe continent-ocean collision resulted in the Semail Nappe being the largest and best preserved ophiolite in the world. North-directed subduction in Neo-Tethys 2 continues today south of the Makran coast.

#64 Semail ophiolite rotational thrusting. What happened during, and after the obduction

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Plate reorganization during the Cretaceous magnetic quiet period included separation of India/Seychelles from Madagascar at about 100 Ma and initiation of a west-dipping subduction zone close to the Arabian continental edge. Paleomagnetic data on lavas and sedimentary rocks from the Samail Ophiolite have shown that the ophiolite nappe rotated 145° clockwise during its thrusting onto the Arabian continental edge from about 95 – 80 Ma, and that the pole of rotation was located near the present day northern end of the ophiolite nappe. During the rotation the subduction facing changed continuously from continentward to oceanward. Consequently proximal sedimentary material was first subducted and accreted (e.g., Al Aridh, Halfa, Al Ain formations), followed by distal pelagic sediments (Wahrarah Formation), and finally again proximal sedimentary sequences (e.g., Hamrat ad Duru and Sumeini groups) accreted beneath the ophiolite nappe as Hawasina Complex.

Sedimentary material at the contact to the ophiolite became metamorphosed at the same time as the chemical character of the ophiolite extrusives and sheeted dikes changed from mid-ocean ridge to island arc type. The subduction caused the formation of an asymmetrically spreading back arc basin similar to present day equivalent as, for example, in the Indonesia-Australia region. Although palinspastic restoration based on paleocurrent directions suggest little rotation for the Hamrat ad Duru units accreted at the end of the obduction, paleocurrent directions for the distal Wahrah Formation show opposite direction suggesting rotation of this sedimentary unit with the ophiolite.

Several Upper Cretaceous to Eocene units are found above the Semail Ophiolite. These units are separated from each other by unconformities which indicate continuing tectonic activities. The Turonian–Santonian Suhaylah Formation unconformably covers the ophiolite extrusives and shows itself an unconfomable contact to the overlying undated conglomerates of the Zabyat Formation which consists of of ophiolitic material. The Zabyat is again covered with the Batinah olistostrom containing reworked Hawasina sediments, serpentinite, and phyllites. The Suhaylah to Batinah olistostrom sedimentary sequence is interpreted as a result of subduction of the Arabian shelf beneath the arriving ophiolite nappe leading to shelf collapse and olisthostromal depositions on top of the Samail extrusives. The Batinah Complex which overlies the Batinah olistostromal unit is interpreted as a sedimentary nappe thrusted over all these units and the Samail Ophiolite as a result of the northward movement of India/Seychelles. The compressional regime led first to the obduction of the two Masirah Ophiolite nappes and the Batain Complex, followed by thrusting of the Batinah Complex and finally thrusting of the Bela and Muslim Bagh Ophiolite Complexes in Pakistan. Such an interpretation is supported by seismic and gravimetric studies on the Makran subduction and the Gulf of Oman which both suggest a doubling of the oceanic floor by overthrusting with cold material. Moreover, Maastrichtian clastic rocks unconformably overly the Batinah complex, and are unconformably covered with Middle Eocene carbonates. This is indirect evidence that tectonic activity occurred at the Cretaceous-Tertiary boundary which caused internal deformation in the Arabian continental plate associated with alkaline volcanism in the Qalhat are in northeast Oman.

#334 Palynology of the Early-Middle Eocene Rusayl Formation, Northern Oman

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The Rusayl Formation comprises a Early to early Middle Eocene sequence of limestones, sandstones, shales and occassional coals deposited in a variety of dominantly marginal marine to inner shelf palaeoenvironments.

The presence of common (>50%) mangrove pollen such as *Spinozonocolpites* spp. (Nypa), *Pellicieroipollis langenheimii*, *Proxapertites operculatus* is interpreted as representing a typical front mangrove assemblage and indicates a brackish, coastal tropical and humid environment. The abundance of *Spinozonocolpites* is associated with the Rusayl Formation transgressive systems tracts (TSTs). Dinocysts and leiospheres are also present suggesting that the woody material which generated the coals was most likely derived from a parent plant flora that grew in this littoral setting. High abundances of *Spirosyncolporites brunii* and *Longapertites retipilatus* are commonly associated with the *Spinozonocolpites*-dominated assemblages. The predominance of probable Pandanus pollen near the top of the section suggests a palaeoenvironmental shift, which may be associated with climate, depositional setting or salinity changes associated with increasing transgression. This shift effectively terminated the Nypa flora. The pollen flora therefore suggests a partially submerged mangrove (Nypa) flora, with influences from *Spirosyncolpites*, *Longapertites*, sporadically *Triatriopollenites* spp. and possible back mangrove peat dwelling plants (*Warkallipollenites* spp.). No convincing evidence for a strong back-mangrove forest or savana influence has been observed.

The dominant dinocysts recorded include *Polysphaeridium subtile*, *Operculodinium* spp., *Cleistosphaeridium* spp., *Thalassiphora patulum* and *Cribroperidinium tenuitabulata*, with rare/sporadic occurrences of *Areosphaeridium* spp., *Areoligera/Glaphyrocysta* spp., *Heteraulacacysta leptidae*, *Spiniferites ramosus*, *Dinopterigium cladoides*, and *Homotryblium tenuispinosum*. These assemblages record a variable marine influence throughout the formation with high abundances of *Operculodinium* spp., *P. subtile, T. patulum* and *C. tenuitabulata* occurring at certain levels. The rare presence of *Apectodinium homomorphum* and *A. quinquelatum* suggests a lower salinity brackish depositional environment. Overall the dinocysts present are typical of the Early-Middle Eocene with *A. quinquelatum* indicating a NP11-NP13 (most likely NP12) age.

Spores are rare and are mainly restricted to the upper part of the sequence being dominated by *Cyathidites minor*, *Polypodiaceoisporites* spp., *Polypodiisporites usmensis* and *Lycopodiumsporites* spp.

Reworking comprises rare specimens of bisaccate pollen (*Podocarpus* spp.), *Callialasporites* spp. and *Cerebropollenites* spp. suggesting derivation from a Jurassic to Lower Cretaceous source. Of particular note is the presence of chitinozoa towards the base of the formation which do not appear to be reworked.

Eocene assemblages from Pakistan are comparable to the assemblages noted here but show greater diversity. The predominance of Nypa pollen (*Proxapertites* and *Spinozonocolpites*), *Longapertites* and *Triatriopollenites* is common to all the assemblages, and also appears to be typical of assemblages from Nigeria, Borneo, India, Venezuela, Saudi Arabia and the Caribbean. Certain key elements of the Pakistan pollen assemblage appear to be absent in the Rusayl Formation including *Grevilloideaepites* spp., *Retistephanocolpites* spp. (Ctenolophon), *Polycolporopollenites* spp., *Crassivestibulites* spp., and *Yeguapollis* spp.

#336 Sequence stratigraphy and petroleum potential of the Early-Middle Eocene Rusayl Formation of Northern Oman

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The Rusayl Formation represents a mixed carbonate and clastic depositional system (predominantly carbonates) deposited as a coastal complex on a carbonate ramp. Climatic conditions are considered to have been humid-tropical based on the contained palynoflora and microfauna. The Early-Middle Eocene Rusayl Formation comprises a predominantly transgressive systems tract (TST) (Have to include fluvials which are late LSW) deposited as a series of mixed carbonates, clastics and coaly beds on the top of the underlying Upper Jafnyn Limestone. The base of the TST is located at the contact between the identified fluvial systems (late lowstand), or as is more often seen, the contact between the Upper Jafnayn and the base Rusayl Formation. The top of the TST is marked by a flooding surface at the base of the overlying Middle Eocene Seeb Limestone Formation which represents the subsequent highstand systems tract (HST).

The shales and coaly shales from Al Khawd have total organic carbon values of 0.5-18% with bed thicknesses of 0.2-4.20 m. These shales locally contain abundant oil-prone lipid rich cuticle, chitinous arthropod derived material and locally abundant gas-prone woody kerogen. The samples are dominated by cuticle/membrane material derived from a Nypa-dominated flora i.e. mangrove. The palynofacies associations indicate a very marginal marine/littoral depositional setting near to a terrestrial source with little or no transport, indicated by the large fragments of delicate cuticle and membrane materials observed in the palynology preparations. Pyrolysis data indicates S2 yields of 0.6-5.56 mg/g. Although spore colouration and AOM reflectance indicate that the shales are immature (just above oil window) these sediments may have been sufficiently buried to have generated significant volumes of hydrocarbons in the near offshore where the formation is overlain by approximately 1 km of Middle Eocene, highstand, shallow marine ramp limestones (Seeb Limestone Formation) which in turn are overlain by up to 5,000 m of Upper Cenozoic molasse.

In terms of other potential play types based on the sequence stratigraphic interpretation one should look for the lowstand wedge and its associated slope-front fan and, basin floor fans as potential reservoirs. During the highstand, shedding of carbonate blocks and other potential talus fans may provide additional reservoir targets, at the shelf-slope break. Coeval with the transgressive Rusayl Formation anoxic condensed shales may have developed and thus development of potential source rocks (additional to the coals and organic rich shales already identified in the more proximal onshore sequences).

#51 Structural arguments from the Saih Hatat and Hawasina windows for nonpassive margin behaviour during ophiolite obduction

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The popular view of Samail Ophiolite emplacement involves Late Cretaceous closure of the former Tethys Ocean by "piggy-back" thrusting with northeast to southwest emplacement of successively lower "thrust slices" from an external oceanic domain over and towards a "passive" Arabian continental margin. The Samail Ophiolite nappe, the structurally highest and farthest travelled "thrust-sheet", now overlies "thrust-sheets" of Permian-Mesozoic ocean floor and continental rise sediments (Haybi and Hawasina units), and time equivalent Permian-Mesozoic slope and shelf facies carbonates (Sumeini and Hajar carbonate units) that form para-autochthonous "thrust slices" at the base of the pile. The recognition of major NE-facing isoclinal fold closures in these carbonates of both the Saih Hatat and Hawasina windows however, provides a major contradiction for the Oman Mountains. Isoclinal folds that verge away from the Arabian craton have been previously recognised, but have been simply related to back-thrusting. These folds are extensively developed however, have regional scale and extent, and are the major structures of the Saih Hatat dome. Their presence indicates that: (1) for at least part of the history the platform to slope carbonates sequences were "thrust" to the northeast; and (2) requires non-passive margin behaviour for part of the ophiolite obduction. In Saih Hatat the upper limb of a major, antiformal fold-nappe is pinned to the relatively undeformed Permian to Cretaceous shelf carbonates of the autochthon, whereas the lower limb is isoclinally folded and intensely deformed. The Hatat Schist is folded into the core of this fold-nappe and the schistosity, stretching lineation, and degree of strain match those of the intensely deformed rocks of the nappe lower limb. The intensity of deformation in the Hatat Schist is relatively uniform across the window, particularly in the northern half of the dome. This necessitates a fault break between Hatat Schist and the relatively undeformed on the northwest side of the dome (i.e. upper limb of the fold-nappe). This break must either root into an undeformed basement cover contact to the southwest (i.e. towards the craton), or is part of a through-going crustal-scale shear that appears to deepen and intersect the Moho to the southwest. The kinematics for the development of the major antiformal fold-nappe requires underthrusting beneath the pinned upper limb, that is the paraautochthonous carbonate of the margin (i.e. underthrusting towards the margin). Ar-Ar geochronology from the Saih Hatat window requires Late Cretaceous (~76 to 70 Ma) movement of the para-autochthonous Arabian margin rocks to the northeast due to underthrusting of the margin. This is an important part of the tectonic evolution (and ophiolite obduction) that has not been previously recognised. Therefore, models involving craton-directed thrusting with domal culminations related to deep-seated, footwall and lateral ramps are too simplistic for the overall tectonic evolution of this part of the Arabian Peninsula. Such models may however, be more applicable to the Tertiary structure and Tertiary evolution of the Mountains.

#52 Structure and strain variations within the Saih Hatat domal culmination: evolution of a fold-nappe

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Structurally the Saih Hatat domal culmination is dominated by a Late Cretaceous antiformal fold-nappe. This fold-nappe is NE-facing and closing within Hatat Schist basement and carbonates of the Hajar Supergroup. The upper limb of the fold (southwest side of the dome) consists of relatively undeformed Permian to Cretaceous carbonates of the autochthon, whereas the lower limb (northeast side of the dome) has inverted stratigraphy, is isoclinally folded and intensely deformed. This structure is responsible for a deepening structural level towards the northeast, and has produced an apparent NE-increase in deformation across the structural dome (c.f. Le Métour et al. 1990). This deformation gradient is reflected by strong fabric (L-S tectonite) development and increasing pressure of metamorphism, culminating in a pervasive schistosity and regional fold-nappes that have isoclinal, sheath-like fold geometry and markedly attenuated stratigraphy along fold limbs. Deformation associated with these early recumbent closures has produced a consistent N- to NE-trending stretching lineation in the upper plate. This is defined by pressure shadows on framboidal pyrites, the long axes of deformed clasts in conglomerate units, mineral lineations defined by white mica, and more rarely by the long axes of pencils that form in units adjacent to the Saiq 2v volcanics. In the upper plate there is a significant increase in strain towards a major structural break where X/Z strain ratios change from ~16:1 to over 100:1; X, Y and Z are the maximum, intermediate and minimum principal stretches respectively. Pressure shadows on pyrite are very common in limestones, dolomites, and some quartzites and mafic schists of the upper and lower plates. In the foliation (XY plane) pressure shadows are long, straight to slightly arcuate, with tapered form. When fibres are curved they show a 20° to 40° rotation (commonly clockwise sense) of X during pressure shadow development. In XZ sections pressure shadow fibre tails are also generally long and straight, although those with slight curvature indicate top to the north shear sense. Strain magnitudes clearly vary with lithology; limestone> dolomite>>mafic schist>quartzite. The lower plate has a pervasive schistosity and stretching lineation associated with the formation of regional isoclinal folds with sheath-like form and hinges that are subparallel to the regional stretching lineation. These regional isoclines fold the earlier higher-grade assemblages. Deformed conglomerates and calc-schists within the lower plate reflect a strong component of flattening accompanied by marked stretch in X, producing flattened "cigar-like" forms (constrictional strain) and extensive shear bands that indicate top to the NE shear sense. Strains in the lower plate are more uniform than in the upper plate, and range from 20:1 to 30:1. Strain magnitude and kinematic considerations based on pressure shadows requires Saih Hatat fold-nappe development to involve: (1) underthrusting with fold-nappe development in the hanging wall; (2) a pinned, essentially undeformed upper limb; and (3) a'rolling hinge' where the upper limb cycles through the hinge into a zone of intense shear strain on the fold lower limb (e.g. Morcles nappe development in the Helvetic Alps).

#57 Structural and geometric constraints on emplacement of the Samail Ophiolite: New inferences from the Muscat-Ibra Transect

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The Muscat-Ibra transect provides a cross section through the Oman Mountains. The northeastern side of the Saih Hatat window samples the deepest levels of the mountain belt accessible to surface observation. The Saih Hatat window is a part of a Tertiary dome that refolds regional Cretaceous nappe structures developed in the Arabian Platform succession. The margin was not a passive recipient of the Samail Ophiolite Complex with deformation possibly predating the ophiolite's formation. Exposed between the village of As Sifah to the east, and Wadi Meeh on the west, are two windows into continental shelf rocks that were subducted to subcrustal depths coeval with the formation of the Samail Ophiolite in an oceanic setting. Above this lower plate, the Saih Hatat dome consists of an upper plate dominated by a large anticlinal nappe that closes to the north and whose upper limb is pinned to the autochthonous Arabian margin to the south. The Hatat Schist, a major shear zone, is folded into the core of this regional upper plate nappe. Below the upper anticlinal structure is a major recumbent syncline (e.g. Wadi Meeh gorge) that truncates against the shear zone that juxtaposes lower grade carpholite-bearing rocks of the upper plate against retrograded blueschist to eclogite facies rocks of the lower plate. The south limb of the Saih Hatat dome is the uplifted upper limb of the uppermost anticlinal nappe and is overlain by allochthonous Hawasina Group sedimentary rocks. The Samail "thrust" is exposed in Wadi Tayin at about 600 m elevation, a level common for the Samail "thrust" exposed south of the major domes. This indicates very little relief on the surface of the boundary except along the major axis of the mountain range. In contrast, the ophiolite itself is folded into dome and basin structures having shorter wavelengths with the Moho and other internal ophiolitic boundaries mapping out these structures that are truncated against the Samail "thrust." In the core of the Ibra syncline, a window into deformed Hawasina with steeply-plunging fold axes and rodding lineation requires upper parts of the ophiolite to be in low angle fault contact with the underlying units. This highlights the truncation of ophiolitic pseudostratigraphy by the late stage of the Samail "thrust" fault. While the Wadi Tayin-Jabal Dima-Al Yahamdi section of the ophiolite appears to be intact lithosphere, i.e. the north limb of the Ibra syncline, sections of the ophiolite to the east and south also show evidence of tectonic thinning. Around the Ibra dome, the contact between layered gabbro and peridotite is tectonic with gabbroic layering rotated and truncated by the contact with the peridotite along late brittle faults. The relationships along this transect supports the two-stage emplacement scenario for the emplacement of the ophiolite. An early intraoceanic phase of thrusting is followed by a later extensional collapse onto the margin from a topographic high created by the exhumation of the high pressure rocks and the Cretaceous development of the regional Saih Hatat fold nappe.

#204 Sedimentology and sequence stratigraphy of the carbonate turbiditic system of the Guweysah Formation (Middle Jurassic, Hawasina Basin)

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The Guweysah Formation (Middle to Upper Jurassic) is the most proximal turbiditic system of the deep-sea Hawasina Basin, low part of the Tethysian passive margin of Oman.

This turbiditic succession has been studied in the most proximal outcrops along the Jebel Akhdar window (Wadi Muaydin to Wadi Muti). The goal of this study is to; (1) establish the geometry of the turbiditic system along exceptional outcrops; (2) to discuss sequence hierarchy; and (3) to develop correlation techniques (stacking pattern) for turbiditic sediments.

The turbiditic deposits go from low density turbiditic currents deposits (stow sequence) to a large amount of high density turbidity currents deposits mainly made up of ooids, and some conglomeratic debris flows.

Four orders of sequences have been traced along 30 km long sections: one 2nd order (30 my), four 3rd order (1-15 my), several parasequences/genetic units sets (4th order) and parasequences (genetic units) (5th order).

This third order sequences have been studied carefully. They have been traced along two other tectonic units (Wadi Andam and Jebel Safra). They result from the superposition of two types of turbiditic systems: (1) a sand-rich system, mainly homolithic, with few facies and few lateral facies variations, mainly composed of high density turbiditic current deposits (ooids), with slow lateral thinning; (2) a mud-rich system, mainly heterolithic, with strong lateral facies variations (muddy carbonates due to the low density turbiditic currents, to conglomeratic debris-flows).

Fourth and fifth orders sequences show autosimilar sequential organization. The significance of these sequences in term of accommodation versus sediment supply ratio variation will be discussed.

Tectonic Development of the Gabba Salt Basin, Block 3 Oman

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Seismic data over Block 3, Oman, demonstrates that the tectonic history of the Gabba salt basin is dominated by compressional events ranging in age from Late Precambrian to Tertiary. Thrusting began during deposition of the Abu Maharah Group. Opposite verging thrust belts can be seen under the western margin of the salt basin and under the Huqf Arch. The initial phase of compression ceased in the early Cambrian (intra-Nimr times ie contemporaneous with cessation of movement on the Najd Fault System in Saudi

Arabia). The Gabba Salt Basin is best described as a push-down basin and is compressional in origin. Several phases of reactivation occurred in the Cambro-Ordovician during the deposition of Andam and Ghudun sediments and many thrust structures were modified by salt movement.

Little evidence for thrust reactivation is then apparent on seismic data until the Late Cretaceous to Tertiary phase of deformation. Well data indicates large scale erosion at the Hercynian unconformity but the angular unconformity is barely apparent on seismic data. This is possibly a consequence of the position of Oman at this time, remote from the main focus of the Hercynian event in Egypt.

Major reactivation occurred in the Late Cretaceous and Tertiary. First, loading of the Oman Mountains led to the development of a Late Cretaceous foreland basin. Loading from the north resulted in a regional dip in that direction on which the Mesozoic carbonate section began to slide, resulting in a series of extensional faults of WNW orientation. This event allowed reactivation f the salt and many diapirs developed. It was followed by renewed uplift of the Huqf Arch, probably due to the obduction of the Masirah ophiolite in intra-Fiqa times. The thrusts beneath the western margin of the salt basin were reactivated and a major inversion, the Afar high oriented NNW in the north of the block developed at this time. The uplift was buffered to the west by the Maradi fault Zone. The present-day structural configuration of the block is thus related more to transpressional events along the east coast than to the more obvious mountain building to the north.

#131 Post-orogenic extension in northern Oman: the Fanjah rangefront fault

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The Fanjah Fault in northern Oman was studied to test the hypothesis that it accommodated both shortening and extension during closure of the Neo-Tethys Sea. The N-dipping fault is located along the northeastern flank of the Oman Mountains, and kinematic analysis of minor faults indicates three slip directions for hanging wall rocks — NNE, NW, and WNW. Overall, the fault is primarily a NNE-directed normal fault with at least 600 m of slip. The age of the fault is interpreted to be Paleogene based on growth-fault relationships and nearby outcrops of 38 Ma mantle-derived basalt.

The Fanjah Fault appears to reactivate an older (80-70 Ma?) brittle-ductile shear zone characterized by asymmetric footwall folds and cataclasis of hanging wall rocks. Reconnaissance field study of kinematic indicators indicates dip-slip normal displacement across the shear zone. Restoration of pinpoints near Fanjah village indicates at least 4,000 m and more likely 7,000 m of NNE-directed normal slip along the shear zone and Fanjah fault.

The Fanjah Fault System is interpreted to be a normal fault that accommodated deep-seated “post-orogenic” extension and exhumation of the Oman Mountains. In contrast to previous theories, the Fanjah Fault is not an amalgamation of reactivated thrust faults — it transects such thrusts.

#166 Structure and Composition of carbonate-rich diatremes and associated vein dike systems in Oman

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The structure and composition of carbonate-rich vein dikes found intruding Precambrian basement and major faults throughout Oman is emblematic of carbonatite diatremes. In the Marbat region we found vein dikes radiating outward from a diatreme and breccia zone up to 200 m wide that intrudes the western edge of the Sadh Metamorphic Complex. The carbonate rich intrusions associated with the diatreme create a relatively resistant ridge that forms Jabal Ali and extends north for about 3 km before being buried by sedimentary cover sequences. This ridge is composed of a central elliptical-shaped diatreme and breccia zone near Jabal Ali that bifurcates into a series of vein dikes up to 20 m in width that mostly extend north and south of the diatreme. To the north the vein dikes are mostly contained within NE-SW and NW-SE fracture systems of the Marbat granodiorite body. To the south the carbonate-rich vein dikes radiate in various directions to form Jabal Ali, but do not extend as far as the town of Marbat. The western edge of the diatreme is obscured by the Marbat Formation. To the east, small vein dikes are found within a few hundred of meters of the diatreme. The localized nature of the diatreme is further supported by the lack of any other vein dike systems throughout the remainder of the Zalawt Plain. The sequence of multiple intrusions associated with the diatreme consists of pyroxenite and gabbro intruded by felsic dikes that are in turn cut by three generations of carbonate vein dikes. Clasts embedded within the carbonate vein dikes are up to several meters in diameter and contain rounded blocks of both country rock and breccia. The host rock for the diatreme and vein dikes is highly impregnated with carbonate and effervesces in HCL. The diatreme is younger than the Marbat granodiorite (706 ± 40 Ma, Briner et al., 1997) that it intrudes and is most likely older than the late Proterozoic to Paleozoic Marbat Formation that may be deposited over it.

Another diatreme and associated vein dike system, similar in structure and composition to the Jabal Ali diatreme, was discovered in the Jabal Ja’alan region. The diatreme is at least 5 m wide and is associated with a vein dike 3 m wide that dips steeply to the northeast. Both intrusions contain the same sequence of multiple intrusions and types of rounded clasts embedded in carbonate as found in the Jabal Ali diatreme. Both diatremes are also embedded in pyroxenite intrusions. Carbonate-rich vein dike systems are also found intruding the Upper Cambrian El Hota - Ain Sarit Formation near Rakhyut. These intrusions generally trend NE-SW and cut across the structural grain of the fold-thrust system developed in these rocks. Compositional similarities also exist between the carbonate vein dike systems we discovered and listwaenite deposits documented in northern Oman.

#292 A Reference CD-Rom for Geoscientific Information of Oman

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With the advancement of information technology (IT), geoscientific data can be effectively handled with a small personal computer. Geographical Information Systems (GIS) have become a popular tool for examining geospacial data sets to make regional plans or development decisions in government and businesses. However, the availability of geospatial data sets is crucial for GIS. Thus the preparation of basic digital geoscientific data sets (geological maps, mineral resources data, aeromagnetic survey data, etc.) is an important task for the government organizations. Furthermore, the availability of published geoscientific data with classical printed form is still not easily examined without appropriate map catalogs or report lists. The evaluation of the available data is necessary before starting GIS oriented data set. In this study, available maps and reports kept in the Directorate General of Minerals (DGM), Ministry of Commerce and Industry (MCI), Sultanate of Oman, have been evaluated and listed for further effective use of the data as basic reference materials. On the basis of the work, a CD-ROM "Geoscientific Information of Oman" is prepared to provide the reference data of geology and mineral resources of the Sultanate of Oman. A CD-ROM is also planned to provide useful geoscientific information for education. This study provides a detail designing procedure of the CD-ROM, and the list of information available in it.

The data on the CD-ROM can be classified into two major parts, i.e., image data index and data reference index. The image data index contains raster images stored as JPEG format. Raster image data of the available maps have been captured with a large A0 scanner. 150 dpi images and 75 dpi quick-look images have been prepared for evaluation of the maps. Images of geological maps, mineral resources maps, and gravity maps are included. As the data index was constructed with HTML language, any map can be easily searched with standard Internet browse software. Various topographic images based, on DEM, are also presented to understand geographical features of the country. Preparation of a 3-D simulation movie with MPEG format is in progress. DEM and a raster image of 1:1,000,000 geological map are used as data for the simulation. The movie will provide simulation image of flight over the Oman Mountains. The data reference index contains detailed list of various reports kept in the DGM. New index maps were constructed to show the areas that were surveyed or studied. Similar to the image data index, the necessary information can be easily searched.

#8 Tectonogenesis of ophiolites from the Makran Accrretionary Prism, southeast Iran

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The Makran Accretionary Prism in southeastern Iran contains extensive Mesozoic zones of melange and large intact ophiolites, representing remnants of the Tethys oceanic crust that was subducted beneath Eurasia. To the north of the Makran accretionary prism lies the Jaz Murian depression which is a subduction-related back-arc basin. The Band-e-Zeyarat/Dar Anar Ophiolite is one of the intact ophiolites; it is located on the west side of the Makran Accretionary Prism and Jaz Murian depression, and is bounded by two major fault systems. The principal rock units of this complex are a gabbro sequence which includes low- and high-level gabbros, an extensive sheeted diabase dike sequence, late intrusive rocks which consist largely of trondhjemites and diorites, and volcanic rocks which are largely pillow basalts interbedded with pelagic sedimentary rocks, including radiolarian chert. Chondrite- and primitive -mantle -normalized incompatible trace element data and age-corrected Nd, Pb and Sr isotopic data indicate that the Band-e-Zeyarat/Dar Anar Ophiolite were derived from a mid ocean ridge basalt-like mantle source. The isotopic data also reveal that the source for basalts was Indian-Ocean-type mantle. Based on the rare earth element (REE) data and small isotopic range, all the rocks from the Band-e-Zeyarat/Dar Anar Ophiolite are cogenetic and were derived by fractionation from melts with a composition similar to average E-MORB; fractionation was controlled by the removal of clinopyroxene, hornblende and plagioclase. Three ^{40}Ar-^{39}Ar plateau ages of 140.7 ± 2.2 Ma, 142.9 ± 3.5 Ma and 141.7 ± 1.0 Ma, and five previously published K-Ar ages ranging from 121 ± 4 Ma to 146 ± 5 Ma for the hornblende gabbros suggest that rocks from this ophiolite were formed during the late Jurassic-Early Cretaceous. The rocks appear to be approximately contemporaneous with the Masirah Ophiolite (~ 150 Ma). Like Masirah, the rocks from the Band-e-Zeyarat/Dar Anar Ophiolite Complex represent southern Tethyan ocean crust that was formed distinctly earlier than crust preserved in the 90-100 Ma Zagros Ophiolites (including the Samail Ophiolite). Plate reconstructions suggest that the rocks of this complex were formed during rifting of a narrow but deep seaway that separated the Central Iranian micro-continent from the Arabian Plate.

#208 Regional Significance, genetic types and tectonic environments of late Precambrian granitoids in Wadi Ager-Seih area, Sinai, Egypt

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Granitoid rocks of late Precambrian age around Wadis Ager-Seih area are classified into three discrete age groups of relatively fractionated, post-tectonic late-Precambrian granitoid rocks. Two groups occur within the two feldspar granites, while the third type is close to the syenogranite and alkali-feldspar granite. Non off three episodes of granitoid magmatism can be directly linked to orogenic activity in its immediate surroundings. One of the three units can be correlated confidently with anorogenic or postorogenic magmatism. The other two groups represent significantly older close to late- to post-orogenic magmatism.

These granites may have been intruded post-kinematically into a stable upper Precambrian foreland representing a delayed effect of a proceeding tectonic event.

Chemical and mineralogical composition of the granitoid indicate a subduction-related origin, the bulk geochemistry of the granodiorites, especially their REE concentrations, has not suffered significant changes except in the LILE and possibly Nb. The mafic enclaves show a similar compositional range to discrete dioritic bodies in the other plutons. The volcanic rocks are rich in Ti and Y and may rift-related volcanics.

#7 The stratigraphic and sedimentary evolution of the Batain embayment at the northeast Oman continental margin

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The Batain Nappes display a continuous stratigraphic record of marine sediments and volcanic rocks of Permian to Late Cretaceous age. They represent the geological evolution of a marine embayment at the southern Neo-Tethyan margin. Ammonoid-bearing shelf deposits and fusulinid-rich limestones indicate the existence of a Permian carbonate platform. After a stratigraphic gap at the Permian/Triassic boundary, calcareous sedimentation took place in the Early Triassic. A deepening of the basin, a change from a homoclinal to a distally-steepened ramp and finally to a toe-of-slope-morphology together with the increase of carbonate production during Ladinian to Norian indicates the development of shallow-marine environments. The occurrence of large slope deposits with within-plate basalts indicate onset of rifting and the collapse of the Late Triassic carbonate platforms during the latest Triassic. The sedimentation of oolitic limestone turbidite, interrupted by conglomerate sheddings and magmatic activity indicate again tectonic instability at the Jurassic/Cretaceous boundary, followed by oceanisation and a drastic deepening of the Batain Basin. After the deposition of partly mangan-bearing radiolarian cherts, the sedimentation in the Batain Basin ends with the terrigenous deposits of the Fayah Formation. These were deposited during the contractional deformation due to the transpressional motion between the Arabian and Indian plates around the Cretaceous/Paleogene boundary, which lead to the destruction of the Batain Basin, cessation of sedimentation and to the obduction of the Batain and Ophiolite Nappes onto the Arabian continent.

#333 Oman Palaeocene Nummulitids - A revised generic classification

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Fifteen nummulitid species are described from the Upper Palaeocene to lower Eocene of northern Oman. These comprise *Operculina* (five), *Assilina* (one), *Planocamerinoides* (two), *Ranikothalia* (one), *Nummulitoides* (three), *Palaeonummulites* (one) and *Chordoperculinoides* (two). The taxa *Nummulitoides margaretae*, *Chordoperculinoides bermudezi*, *Palaeonummulites thalicus var gwynae*, *Assilina ranikoti* and *Operculina libyca* are recorded from the Middle East for the first time. A revised classification scheme for the subfamily Nummulitinae is proposed and one new genus, *Caudrina* with its type species *C. soldadensis* from the Caribbean is also described. Trabeculae and trabecular canals are redefined and problems in their misidentification in terms of their presence/absence in the classification of the Nummulitidae is discussed as well as the biostratigraphic and palaeobiogeographic significance of this early nummulitid fauna. The presence of *Chordoperculinoides bermudezi* in Oman is considered to be of particular palaeobiogeographic significance as it has been considered to be restricted to the Carribean faunal province. The presence of *Ranikothalia nuttalli kohaticus* in Oman significantly extends the known geographic distribution of this taxon which was previously only known from NW India.

#173 A microbially constructed high-energy platform margin at the eastern Arabin craton, Oman. Implications for the early Aptian environmental change

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Lower Cretaceous strata crop out in a series of closely spaced wadis in the Nakhl area of the northern Oman Mountains and document the evolution of a carbonate platform margin. The late Barremian to early Aptian platform rim shows a rapid transition from bioclastic-oolitic high-energy ramp deposits to a bioconstructed high-energy margin. The rigid construction is due to intense microbial activity rapidly binding and cementing bioclastic debris and isolated autochthonous organisms including rudists, corals and sponges. The outcrops allow investigating the geometries of these "reefs" and their lateral and vertical facies evolution.

The basal interval of the constructed margin situated between two exposure surfaces is studied in detail and shows five phases of buildup growth. In proximal and distal positions they show a low, irregular morphology, whereas in a laterally restricted intermediate position, buildups have a mound-like shape, are regularly spaced, and attain heights of up to ten meters. This pattern suggests that the shape of the constructions was controlled by water depth and different energy levels along a coastal transect. The scale and shape of the constructions resembles that of modern spur and groove structures in wave dominated reef environments.

Commonly, constructed intervals are delimited by bio-perforated hardgrounds and deeply cutting erosional surfaces. Eroded blocks and deposition of large bioclastic rubble in troughs and crevasses between the buildups, together with deposition of rubble beaches, evidence an episodic break in reef growth associated with partial destruction of the reef. Incipient karst occurs only in proximal areas, but indicates that the repetitive facies evolution is due to small-scale changes in relative sea level. Neptunian dykes that can cut through several intervals are interpreted as signatures of large-scale instabilities of the constructed margin, possibly due to over-steepening and/or tectonic activity.

Microfacies analysis reveals that an important part of the binding and encrusting can be attributed *Lithocodium aggregatum* and *Bacinella irregularis* associations and to chasmolithic, cryptic microbialites. Stromatolitic and thrombolitic textures are common and patches and intervals entirely formed by cryptic microbialites do occur.

The dominance of microbial activity is absent in earlier platform margin deposits. Environmental factors that may trigger such a sudden "bloom" in microbial activity include elevated input of nutrients onto the platform trough increased rainfall, increased carbonate alkalinity, and higher water temperatures. Such conditions stress oligotrophic carbonate producers and diminish their carbonate production potential and, thus, favor the microbial community.

Regional correlation and biostratigraphic data show that the studied interval correlates with the early Aptian Selli event and the OAE 1a that mark a major change in the global carbon cycle. The particular "reef" facies observed here, thus correlates with the early Aptian onset of intense greenhouse conditions so commonly recorded in basinal sediments and documents its significant influence on platform evolution and geometry at the Eastern Arabian platform margin.

#4 Middle Cretaceous sea-level record in northern Oman

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The Aptian to Albian interval of the vast Arabian platform was studied in northern Oman for its paleoceanographic and sea-level record. Changes in mean paleo-bathymetry with time have been reconstructed along a transect reaching from the Oman continental margin in the north (Jabal Akhdar), to the Bab intra-cratonic basin further south (Foothills). The shallowest domain (platform top) is represented by the Al Hassanat Formation as investigated in Wadi El Assyi near the village of Nakhl. Intermediate mean paleo-waterdepths (± 30 m) were found in the Nahr Umr Formation in Wadi Bani Kharus near the village of Al Awabi. The deepest setting was reconstructed at Jabal Madar (Nahr Umr Formation) in the Foothills. There, mean Albian paleo-waterdepths were probably in the order of about 50 m.

For the temporal correlation of sea-level cycles throughout the transect our graphic-correlation model for the mid-Cretaceous was used. The spatial correlation was undertaken by marker surfaces and marker bed successions.

Various factors other than sea level might also influence the deposition (or non-deposition) and facies of a given carbonate succession. We thus used subaerial exposure surfaces as pinning points for the reconstruction of the middle Cretaceous sea-level record. The outcome of this study reveals three Albian sea-level cycles that had a sufficiently large amplitude to expose the basinal carbonate seafloor at Jabal Madar. In Wadi Bani Kharus, where an intermediate mean paleobathymetry prevailed, some 10 sea-level events were recorded. In Wadi El Assyi, the platform setting, 29 transgressive-regressive cycles are present. This relation allows for a quantitative estimate of the amplitude of Aptian-Albian sea-level events as recorded in the various sections.

#343 Ammonite records from the Samhan Formation (Aruma Group) in the Saiwan area, Huqf Desert, Sultanate of Oman

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At two outcrops in the Huqf Desert, south of Saiwan, Late Cretaceous ammonoid faunules were collected during fieldwork in March 1998, from strata assigned to the Samhan Formation. Locality 1, exposing Schumann's (1995) Unit 1, yielded all specimens studied by Kennedy et al. (2000), except one, from yellowish white marls and marly limestones. This unit corresponds to Platel et al.'s (1994) 'Marnes silteuses jaunes à Cyclolites' (= lower portion of their 'Membre moyen' of the Samhan Formation). At locality 2, a single specimen was collected from Schumann's Unit 10, which comprises yellowish white, indurated, near-nodular micrites, with silicified scleractinian corals and stromatoporoids and brown chert. This part of the sequence would correspond to the upper portion of Platel et al.'s 'Membre supérieur' of the Samhan Formation.

Previously, an early Campanian date was assigned to the Samhan Formation, as based primarily on planktonic foraminiferal and calcareous nannoplankton dating of the overlying Fiqa Formation (Platel et al., 1994). The faunules described by Kennedy et al (2000) comprise three species, viz. the desmoceratid *Kitchinites angolaensis* Howarth, 1965, the pachydiscid *Pachydiscus (P.) arabicus* Kennedy and Jagt in Kennedy et al., 2000, and the sphenodiscid *Manambolites dandensis* Howarth, 1965. Since this material was collected both from strata underlying and overlying the well-known rudistid reefs in the Saiwan area, it allows a late Campanian age to be assigned to these deposits. *Kitchinites angolaensis* was previously known only from the lower upper Campanian of Egito (Angola), while the type material of *M. dandensis* from Barra do Dande (Angola) is of late late Campanian age. The new pachydiscid is also known from the upper Campanian of the Negev Desert. In spite of the limited number of ammonoids collected, the material yields interesting results both from a biostratigraphical and a palaeobiogeographical point of view. Patterns of faunal distribution and ranges of the ammonoid taxa now recognised need to be worked out in more detail in future studies.

#298 Oman to Kohistan: Cretaceous supra-subduction ophiolites and their emplacement history at the northern India-Arabia continental margin

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The Kohistan terrane of north Pakistan straddles across the collision zone between India and Asia. Originated as an intraoceanic island arc in the Neo-Tethys at the equatorial latitudes during the mid-Cretaceous (~120 Ma), Kohistan occupied a position at the leading edge of the oceanic Indian Plate similar to that of the Semail Ophiolite of Oman at the leading edge of the oceanic Arabian Plate. The evolutionary history of Kohistan and Semail has several features common to both. Both Semail and Kohistan have a subduction-related origin. The juvenile island arc crust in Kohistan yields U-Pb zircon ages of ~100 Ma, which compare well with the earliest ages recorded from the Semail Ophiolite. The subsequent obduction phase is common to both Kohistan and Semail though it is much clearer in Semail than in Kohistan, due to involvement of the latter in collision with the southern margin of Eurasia at about 80-90 Ma. The Semail Ophiolite passed through an obduction history spanning ~ 25 my (97-74 Ma) that involved both intra-oceanic as well as final obduction onto the northern Arabian continental margin. In the case of Kohistan several dozens of mineral ages span 70-90 Ma and all of them come from the southern parts of Kohistan suggesting they may not be directly related with Kohistan-Eurasia collision. Rather these ages reflect a prolonged history of south-vergent intra-arc, arc over oceanic crust, and arc over continental margin thrusting. The geological evidence regarding final obduction of Kohistan at the northern continental margin of the Indian Plate is missing from Kohistan. Ophiolite complexes immediately west and southwest Kohistan (e.g., Waziristan, Muslim Bagh and Bela) were obducted onto the northwestern-western continental margin of the Indian Plate prior to 70 Ma, that may be the case with Kohistan.

The Semail Ophiolite and associated allocthonous units in Oman are unconformably overlain by shallow-marine carbonates, suggesting continuum of Neo-Tethys at the northern margin of Oman. Likewise, Kohistan and Western Ophiolites in Pakistan record continuum of Neo-Tethys sedimentation following 70 Ma ophiolite obduction. The first complete obliteration of Neo-Tethys in Pakistan is recorded at 60 Ma at the site of the Indus Suture that marks Kohistan-India collision. There is evidence preserved in strata deposited in marine conditions that suggests that final closure of the Neo-Tethys at the western margin of the Indian Plate took place much later than the Indus suture. The marine to continental transition preserved in the sedimentary record youngs successively from Waziristan in the northwest to Karachi in the southwest. This may imply that Gulf of Oman marks a continuum of Neo-Tethys.

#229 An Overview of Terminal Proterozoic Earth History

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For more than 150 years, the Cambrian Period has been interpreted as a time of dramatic transition in biology. More recently, the immediately preceding interval of terminal Proterozoic time has been recognized as an equally unusual period of biological, biogeochemical, tectonic, and climatic change that set the stage for Cambrian events.

Carbon isotopes mark the later Neoproterozoic Era as distinct. An interval of unusually strong ^{13}C enrichment in both carbonate and organic carbon began 800-750 Ma, more or less coincident with the development of widespread rift systems in the Rodinian supercontinent.

Elevated C-isotopic values persisted to near the end of the era, terminating at about the time that Gondwana completed its aggregation and North American began to drift independently. The long interval of ^{13}C enrichment was punctuated by several sharp negative excursions in C-isotopic values; at their most extreme, these values approximate or fall below the C-isotopic composition of mantle carbon. At least some negative excursions are associated stratigraphically with ice ages, although a last, pronounced drop near the Proterozoic-Cambrian boundary is not demonstrably associated with continental glaciation.

There is geochronological evidence for at least four glacial episodes, although the exact number of ice ages and their interbasinal correlation remain a subject of debate.

Throughout the Neoproterozoic Era, biology underwent change, at least in part under the influence of changing climate and environment. Eukaryotic algae first became major primary producers in the oceans 1,200-1,300 million years ago, and their fossil record increases in diversity and abundance through most of Neoproterozoic time. Major extinctions of acritarch morphotaxa accompanied Marinoan and, perhaps, Sturtian glaciation, but the strongest decline of acritarch diversity postdates the Marinoan ice age. Ediacaran animals diversified during the last 30 my of the Neoproterozoic Era, as did lightly calcified metazoans and multicellular algae. Both C- and S-isotopic data are consistent with a late Neoproterozoic increase in global oxygen levels that oxidized the deep oceans (perhaps for the first time) and may have facilitated the evolution of large animals with high rates of aerobic metabolism.

Neoproterozoic rocks pose interpretational challenges because they: (1) predate the imposition of skeletal control on carbonate and silica deposition; and (2) reflect tectonic and biogeochemical influences that are both dynamic and incompletely understood. Nonetheless, the emerging history of the Neoproterozoic Earth provides new and potentially powerful tools for stratigraphic correlation, as well as a global framework within which events recorded in individual basins can be evaluated.

#323 A Unique Permian-Triassic Boundary section from Oman

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In the Wadi Wasit area of the Central Oman Mountains breccias of varying thickness sandwiched between Permian allodapic and Lower Triassic platy limestones (Al Jil formation sensu Béchennec 1988; 1992) are widespread. These breccias form channelized debris flows cutting deeply into the underlying calcareous or volcanic rocks of Middle Permian age (Blendinger 1988, 1995, Pillevuit, 1993, Pillevuit et al., 1997). The breccias consist mostly of Guadalupian reefal blocks and are often dolomitised. Calcareous parts of the breccia are otherwise in part silicified, making paleontological studies difficult due to the inextrability of fossils. A rare pure calcareous breccia found 1 km south of the middle part of Wadi Wasit contains several small-sized blocks of lowermost Triassic bivalve-bearing limestones. The largest one, with a size of about 150 m^3, has been studied in detail.

The so-called Wadi Wasit block consists of three main litho-units. The basal, 6 m thick, unstratified grey reefal limestone is developed as rudstone-rich in various reef building organisms (rugose corals, calcareous sponges, stromatoporoids). The finer grained top of the reefal limestone has been dated by rare conodonts (*G.* cf. *slovenica*) as Middle Permian (Wordian). It is disconformably, with sharp microcarstic relief, overlain by a thin lateraly discontinous peloidal packstone layer dated as Early Triassic by conodonts (*H. parvus*). The documented hiatus represents a time break of more than 10 million years. The overlying section consists of 4 m of well- and thin-stratified, light grey to yellowish coloured limestones, rich in molluscs. Two main lithologies (Coquina Limestone resp. Bioclastic Limestone unit) characterise the shelly limestones. Their contact seems gradual and records changes in microfacial and faunistic composition. The lower 2.5 m are developed as Coquina Limestone of mostly 10 to 20 cm thick planar or rarely lenticular bedded bivalve layers. Sediment-free, spar-cemented densely packed, well sorted shells with predominantely oblique orientantion dominate between 0.2 and 1.5 m above the boundary. Below and above are beds with poor shell sorting, more parallel shell orientation (mixed convex-up and -down) and mud-filled shelter porosity. The bivalve fauna is of low diversity and dominated by the genus *Promyalina* with less frequent *Claraia* and rare *Eumorphotis*. In terms of biofacies the Coquina Limestone is thus called as *Promyalina* beds. Other fossil groups are rare; small ammonoids occurences filled cavities. Towards the top part shell accumulations become less dense and *Eumorphotis* more frequent. By further decrease in bivalve shells the lithofacies is changed to the Bioclastic Limestone unit. Shell concentrations are now restricted to thin layers in irregularly stratified beds within the lower meter of the unit. The bivalve composition changes remarkably due to the disappearance of *Promyalina* and its replacement by *Eumorphotis* and *Claraia*. The upper part of the Bioclastic Limestone consists of a single, 1 m thick bed, with a rich (and for the respective time interval) astonishingly diverse invertebrate fauna. It consists predominantly of grain- and packstone with microgastropods, echinoderms (crinoid ossicles, "*Cidaris*" spines), bivalve debris, ostracods and less common juvenile ammonoids, and rather rare bioclastic wackestone. Megafossils are very common and represented by a diverse ammonoid fauna (ophiceratids, *Bukkenites?*, *Pseudosageras* and two new genera related to *Pseudogyronites* and *Kymatites*. resp.), spiriferid and rhynchonellid brachiopods, naticid and pleurotomariid gastropods as well as *Claraia* and *Eumorphotis*. A diverse conodont association constitutes an important part of the microfauna with several hundred specimens per kilogram. This *Neogondolella* dominated fauna with extremely rare *Hindeodus* in the upper Bioclastic L. contrasts well with the pure *Hindeodus* assemblage below. The Bioclastic Limestone is disconformably overlain by a locally-preserved, 1 cm thin, layer of megafossil-free, grey, marly, fine-grained limestone dated by conodonts as Dienerian (e.g. *Neospathodus kummeli*). Both the mud-supported fabric and the high terrigeneous insoluble residue of this peculiar bed indicate a pronounced change of the sedimentary environment from relatively shallow carbonate-rich to deeper and siliciclastic-influenced depositional regime at the final stage of the block history.

Whereas the upper meter of the Bioclastic Limestone is well constrained by the ammonoid and conodont fauna (*N. discreta*, *H. sosioensis*) as topmost Griesbachian, problems arise in dating exactly the sequence below *Hindeodus parvus* is an ubiquistic form with a long range spanning a major part of the Griesbachian. Based on the assumption of a relatively continuous accumulation rate an infered late Griesbachian age may be more likely than an early one for most if not all of the basal Triassic sequence. But this assumption will be discussed later.

$\delta^{13}C$total two isotopic analyses on bulk rock have been operated on this block. Wordian values are in usual range (+2.4‰ - +4.4‰) for this time period, followed by a negative shift to +1.2‰ in the basal Triassic Coquina Limestone. Samples from this unit (*H. parvus* Zone) have values between +1.2‰ and 2.2‰. Then values regulary increase in the upper part of the Bioclastic Limestones (*H. sosiensis* zone) to 3.1‰ (uppermost Griebachian).

In summary, the presently singular block records uniquely: (1) an Upper Permian uplift of parts of the distal carbonate shelf of the Hawasina basin, and cessation of reef building in the area long before the end of the Permian; (2) a pronounced sedimentary break at the P/T boundary; (3) a rapid basal Triassic transgression; and (4) an extraordinary rapid faunal recovery after the P-T crisis with at the same time an increase of $\delta^{13}C$total isotope values from +1.2‰ in the basal Triassic transgression to 3.1‰ at the end of the Griesbachian (increase of productivity ?), a distinct Early Triassic (Dienerian) tectonic extension(?) phase leading to the breakdown of the former margin and to its recycling by debris flows into the attached basin.

#248 Mapping fluid movement in the Second Eocene Dolomite, Wafra field, Partitioned Neutral Zone, Kuwait-Saudi Arabia

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Petrophysical reservoir description has been combined with production data to create an assortment of maps useful for reservoir management and for solving production anomalies in the Wafra field Second Eocene reservoir. The Paleocene Second Eocene reservoir is one of the five major reservoirs in the giant Wafra oil field of the Partitioned Neutral Zone between Kuwait and Saudi Arabia. It has several billion barrels of oil in place and has produced over 320 million barrels of oil from 200 wells since 1958. The Second Eocene reservoir is composed of a set of complex carbonate ramp deposits, formed during eustatic sea-level changes and diagenetically altered to dolomite.

Special core analysis, sequence stratigraphic correlation, construction of deterministic and stochastic geologic models and attempts at history matching are frustrated by the high degree of reservoir heterogeneity. Reservoir heterogeneity has resulted from multiple periods of diagenesis. Primary rock fabric has little affect on porosity and permeability, resulting from the pervasive diagenetic overprint. Attempts to subdivide charted poroperm data into rock facies is unworkable, as porosity versus permeability crossplots yield a “shot-gun” pattern. Lithofacies fields overlap, resulting from the predominant diagenetic overprint, frustrating attempts to map permeability distribution.

Monitoring and predicting fluid movement through such a complex reservoir is critical for calculating production decline, recoverable reserves, planning new well locations, workovers and recompletions. Proposed, future enhanced oil recovery projects in the Wafra Second Eocene reservoir are contingent on detailed reservoir description and accurate estimations of the geometry of “water fingers” and barriers to fluid movement.

The Wafra Second Eocene Team has created a number of reservoir property maps. However, pitfalls are apparent when these maps are used to predict production performance. The team also created contoured production maps, such as cumulative oil and fluid production, cumulative water production, initial production rates, daily oil rate, water cut, bottom hole pressure, salinity and oil gravity. These “iso-productivity” maps have been valuable in qualitatively delineating reservoir quality in the reservoir. Integrating production maps with reservoir property maps has defined vertical pressure barriers, water coning, water fingering and the optimum areas to drill infill and step-out development wells.

Geological and engineering tasks have been combined into multifunctional teams at the Wafra Field office, allowing for maximum exploitation of all available data to delineate complex reservoir problems. Combining petrophysical reservoir description with production data has enhanced the ability to recognize reservoir productivity trends in the Wafra Second Eocene reservoir.

#271 High resolution sequence stratigraphic analysis of the Lower Cretaceous carbonate system in outcrops of Northern Oman

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The Rayda Basin, located in northern Oman at the southern passive margin of the Arabian Plate, has been filled in by a prograding carbonate system during the Early Cretaceous. The system prograded over a distance of 300 km, maintaining a depositional profile of several hundreds of meters waterdepth. In this paper: (1) the different types of elementary cycles (parasequences) found from platform top to deep water setting are documented; (2) their stacking in larger scale sequences is shown; and (3) in a correlation panel the diachronous character of the different lithostratigraphic units is demonstrated.

The study is based on the high-resolution sequence stratigraphic methodology, including the detailed analysis of the depositional environments, recognition of special surfaces, and the hierarchisation of the depositional sequences. The outcrop dataset consists of three outcrop sections, logged in Wadi Mu'aidin (670 m), Wadi Bani Kharoos (485 m), and Jebel Madar (344 m). 125 thin sections have been analysed for microfacies.

Four main depositional environments are distinguished: platform top, platform margin, slope and basin. Typical facies in these environments are: (1) in the platform top plurimetric to decametric shallowing up cycles show an evolution from open lagoon, mixed fauna, wackestones to rudist floatstones/ boundstones/rudstones, followed by more restricted algal and miliolid-rich wackestone to packstones, topped by stromatolitic mudstone to wackestone; (2) the platform margin facies evolves through time from a mixture of ooliths and oncoids in a muddy matrix in Jebel Madar, to pure oolitic grainstones in wadi Muyadin, and rudist/oolitic rudstone to grainstone at the end of the progradation in Wadi Bani Kharus; (3) at the slope small scale cycles are expressed in variations of the amount of bioclastic material shed from the platform; (4) in the deep basin plurimetric cycles are present, which are dominated in the lower part by radiolaria and in the upper part by pelagic foraminifera and microbioclasts.

A preliminary correlation scheme is proposed on the basis of accomodation cycles that control the cycle stacking patterns. The coast-perpendicular transect clearly shows the progradation of the carbonate platform and the strongly diachronous character of the lithostratigraphic units. Future work will include biostratigraphic and chemostratigraphic analyses to further constrain the time framework.

#77 Geology and Mineral wealth of the Sultanate of Oman

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The geology of Oman is famous world-wide as all components of the Earth's geodynamic history are present: a stable craton, a foreland basin, and a mountain belt that includes one of the best exposed segments of oceanic lithosphere in the world, if not the best. In addition, many of these rocks contain mineral substances that materially contribute to the wealth of the Sultanate and its inhabitants.

A geological map at the scale of 1:1,000,000, the scale used by all economically and scientifically developed countries for compilation maps of their natural wealth, has been produced by geologists from BRGM under the authority of the Directorate General of Minerals, of the Sultanate of Oman. An accompanying Explanatory Notes, and an informative book present the results of the compilation of detailed mapping and mineral exploration of the Sultanate for well over a decade.

The factual data and their scientific interpretation has been set within the framework of the General Geology of Oman.

#237 Sedimentology of the glaciomarine sediments of the Neoproterozoic Ghadir Manqil Formation, Jebel Akhdar, Oman

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The Neoproterozoic Ghadir Manqil Formation represents the oldest exposed sediments in Oman. It outcrops in the Jebel Akhdar region of Oman (where this study is based), with equivalents exposed in Salalah, the Huqf region, and Sur.

In the Jebel Akhdar region, the Ghadir Manqil is >1 km thick and is made up of a series of glaciomarine diamictites, turbidites, sediment gravity flow deposits and siltstones often showing soft sediment deformation and rippling. Evidence for glaciation comes from diamictites containing striated and 'flat-iron' shaped pebbles, and from dropstones within laminated mudstones that are too large to have been deposited by traction currents. A number of distinct glacially influenced horizons occur, separated by non-glacial facies, which can be correlated across the Jebel Akhdar with a high degree of confidence. The top of the Ghadir Manqil is overlain by the <10 m thick Hadash Cap Dolomite, which in turn is overlain by about 150 m of deep-water siltstones and argillaceous sandstones that form the Masirah Bay Formation. Above the Hadash Cap Dolomite there is no further evidence for glaciation.

The logged facies and palaeocurrent directions suggest that sediment was derived from both the east and the west. The Ghadir Manqil therefore probably represents the fill of a <50 km wide graben, similar to the basins imaged by seismic in the subsurface from the Oman salt basins.

Volcanics and volcaniclastics occur in the lower parts of the sections to the east. A zircon from an ash-bed within the lower diamictite (Ghubrah Member) in Wadi Mistal has yielded a U-Pb age of 722+16/-10 Ma (Brasier et al. 2000) and suggests that at least the lower part of the section is a Sturtian equivalent (760-700 Ma). However, consideration of the stratigraphy of the overlying Nafun Group (with a U-Pb zircon age of 544.5 ± 3.3 Ma from ignimbrites of the Fara Formation (Brasier et al. 2000)), and many similarities between the Hadash Cap Dolomite overlying the Ghadir Manqil Formation and deposits overlying Marinoan-age glaciations elsewhere suggest that the top of the Ghadir Manqil is most likely to be 600-590 Ma. If this is the case, two major glacial periods are contained within the Ghadir Manqil, and it represents a time period of more than 100 my.

#59 Preliminary results of the Encens-Sheba cruise

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The Encens-Sheba cruise was carried out in July 2000 aboard R/V Marion Dufresne. It produced the best bathymetry, gravity, magnetic and seismic SCS data yet obtained in the eastern part of the Gulf of Aden between southern Oman (Dhofar) and Socotra Island. The segmentation of the Sheba Ridge and of the conjugate margins seem to result from the same process. The two conjugate margins are steep, narrow and asymmetric. The northern margin is composed by tilted blocks, horsts and grabens bounded by faults dipping towards the ocean or to the continent, whereas the southern margin is characterized by a deep basin near the continental slope and in the vinicity of the continent-ocean transition. The two margins are divided by transfer faults in three major segments, as the Sheba Ridge is divided by transform discontinuities from 20 to 200 km. The central part of the western segment of the ridge is characterized by an axial uplift and a large magmatic activity shown by numerous volcanoes on either side of the Sheba spreading center.

The two other segments are more classic for a slow spreading ridge.

The magnetic anomalies are asymmetric and show a complex history of oceanic accretion. Nevertheless, An 5C to 5E could be identified in the northern part of the oceanic basin. The Gulf of Aden in this area thus opened at 16-20 Ma, which is significantly older than the 12-13 Ma suggested by previous studies.

#316 Comparing crustal accretion models from Iceland and Oman

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Oman and Iceland are excellent places to study oceanic crustal accretion mechanisms. Whilst the Oman Ophiolite provides a direct sample of a section through oceanic crust and upper mantle, the petrological characteristics of the Icelandic crust can only be indirectly determined using the compositions of erupted basalts and rare gabbroic nodules found within the lava flows. However, Iceland is a site of active plate spreading and detailed observation can be made of both temporal and spatial variation in the crustal accretion process. Successful models of oceanic crustal accretion should be consistent with both geochemical and geophysical observations from active mid-ocean ridges as well as those from ophiolite sections. The major element concentrations of a set of basalt and picrite samples from the Krafla and Theistareykir volcanic systems of the Northern Volcanic Zone of Iceland show two distinct trends. The compositional variation in samples with MgO>9.5 wt% can be explained by addition/removal of a wehrlitic cumulate, while the major element variability in samples with 5.0-9.5 wt% MgO is dominated by gabbro removal. The composition of this gabbro is almost identical to that of the average Oman cumulate gabbro. The results of thermobaromtery based on the composition of the Iceland samples and the crystals found within them show that crystallisation took place at a range of temperatures (1,160°-1,350° C) and pressures (<0.3-0.9 GPa) in the crust and uppermost mantle under Krafla and Theistareykir. The geochemical results are consistent with crustal accretion models based on observations from the Oman Ophiolite where crystallisation takes place over a range of depths in the crust and uppermost mantle. The geochemical observations allow estimates of the composition, mineralogy, pressure and temperature of material in the crust and shallow mantle under northern Iceland to be made and these estimates can be used to predict the seismic velocity of the material at the ridge axis. These P-wave velocity estimates are in agreement with the results of a seismic survey of the ridge axis at Krafla and suggest that the fraction of cumulate gabbro compared to trapped melt gabbro increases with depth; this feature has also been observed in Oman. The presence of temperatures of over 1,000° C and magma chambers at depths greater than 10 km in the Icelandic crust cannot be ruled out using the available geophysical data from the Icelandic rift zones. Therefore both the geochemical and geophysical observations are consistent with models where crustal accretion takes place at a range of depths under northern Iceland. Although the oceanic crust of Iceland and the Oman Ophiolite were generated in different tectonic settings, several key parts of the crustal accretion processes in these environments are similar.

#159 Palinspastic maps of Oman Neo-Tethyan margin in Permian and Triassic Times

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We present three palinspastic maps (Late Permian around 265 Ma, Middle Triassic around 235 Ma and Late Triassic around 210 Ma) showing the Arabian margin of the Neo-Tethys.

Although a general agreement exists concerning the general topology of the margin, the detailed organization is still the subject of debate. We discuss hypothese and alternative solutions concerning the relative position of several constitutive elements of this margin, as for example the original location of the depositional environment of the ammonotico-rosso " Hallstatt " type facies and the Baid exotic block.

#9 New algae and problematica of algal affinity from the Permian of the Aseelah Unit of the Batain Plain, East Oman

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Permian microfloras occur in limestone boulders of the Aseelah Unit at the lower part of the Batain Group (northeast Oman). The boulders are composed of bioclastic limestones deposited during the Permian on a shallow-marine warm shelf environment. They yield several rich associations of Dasycladales, Tubiphytids and Archaeolithophyllaceae indicating a Yakhtashian to Dzhulfian age. The algal-bearing boulders, with a sandy matrix, conformably overlay the Permian Qarari Unit deposited on the distal slope of the Arabian carbonate platform. The conglomerate and sandstone sheddings of the Aseelah Unit indicate the end of a major transgressive-regressive cycle at the Permian/Triassic boundary. The oldest age of the depositional event is given by the Dzhulfian age of the youngest reworked boulders. The age of the sandy matrix is not well established, it is post-Dzhulfian, probably Lower Triassic on the basis of some palynological indications. Several new taxa are described: *Aphralysiaceae* nov. fam., *Sparaphralysia orientalis* nov. sp., *Mellporellopsis corpulenta* nov. gen. nov. sp., *Aseelahella granieri* nov. gen. nov. sp., *Claracrustinae* nov. subfam., *Claracrusta ungdarelloidea* nov. sp. and *Sphairionia galinae* nov. sp.

#10 Middle Permian (Midian/Capitanian) Fusulinid assemblages from the Aseelah Unit (Batain Group) in the Batain Plain, East Oman

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Some exceptionally rich reworked Middle Permian (Midian/Capitanian) microfaunas occur in the Aseelah Unit at the lower part of the Batain Group. The Permian fusulinid-bearing conglomerates and sandstones overlie conformably the Qarari Unit, also dated as Middle Permian (Murgabian/Wordian) based on ammonoid assemblages. The boulders of the Aseelah Unit are composed of Permian bioclastic limestones deposited on a shallow marine shelf environment. They may indicate different facies on an extensive shallow carbonate shelf from the southern Neo-Tethys, whereas the Permian Qarari limestone is interpreted as a hemipelagic shelf sediment, deposited on the distal slope of the Arabian carbonate platform.

The Midian foraminifers of the Batain Group are similar to some assemblages of Transcaucasia, of the Iranian Abadeh area and of northwest Turkey. Surprisingly several species, especially the Neoschwagerinids, exhibit eastern Tethys affinities with the terranes of the Kobayashi's Province C of Japan; they have never been found in the adjacent Oman Mountains, nor in the Taurus Mountains. Moreover, as in some terranes of Japan, *Afghanella* and *Sumatrina*, typical of Kobayashi's Provinces A and B, are absent from the Batain Plain.

A systematic revision of various genera and species of smaller foraminifera and fusulinids is given. The fusulinid genus *Codonofusiella* (?) spp. (superfamily Schubertellacea) is analysed, and the presence of agglutinated walls in Palaeozoic foraminifers is discussed, as Ataxophragmacea and atypical *Neoendothyra* occur in the Middle Permian of the Batain Plain.

#142 350,000 years of climate variability recorded in speleothems from Oman

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The Indian Ocean monsoon is one of the major weather systems on earth, bearing rain during Northern Hemispheric summer in North Africa, Southern Arabia, India and East Asia. Years with lower monsoonal rainfall can cause catastrophic droughts in these densely populated regions. Knowledge of the mechanisms responsible for monsoon variability is essential to forecast droughts and to weaken their effects in such areas. One important hindrance to monsoon prediction is a lack of long, continuous, high resolution records, such as varved lake sediments and tree rings, which could provide information about monsoon variability on timescales ranging from annual to millennial and longer. Speleothems, especially stalagmites and flowstones, found in a number of caves in northern and southern Oman are a potentially rich source of information about the monsoon and climate variability in general. Most of our samples were found in Hoti Cave near Al Hamra in northern Oman. Today, the climate in this area is arid to semi-arid, with an average rainfall of 100-200 mm/yr. Rainfall originates mainly from cyclonic low pressure systems coming from the Mediterranean Sea during the winter months and local thunderstorms during the summer months. Except the Dhofar region, Oman is not affected by the Indian Ocean monsoon.

We mainly use four different methods to get information about palaeoclimate from speleothems: (1) precise Uranium-series age dating; (2) stable isotope composition (oxygen and carbon isotope ratios); (3) stable isotope composition of speleothem fluid inclusions (hydrogen isotope ratios); and (4) thickness of annual growth layers. A total of 60 U/Th-ages on different speleothems indicate five periods of speleothem growth in Oman: 6.2 and 10.5 ky, 78-82 ky, 117-130 ky, 180-210 ky and 300-325 ky. During each of these periods, stable isotope composition of speleothem carbonate (oxygen isotope ratios) and fluid inclusions (hydrogen isotope ratios) exhibit highly depleted values compared to those of present-day speleothems. Present-day stalagmites exhibit oxygen isotope values between -1 and -2 ‰ (VPDB) and hydrogen isotope values between 0 and -15 ‰ (VSMOW), whereas stable isotope composition of fossil stalagmites vary between -12 and -4 ‰ (VPDB) for oxygen and -25 and -55 ‰ (VSMOW) for hydrogen. Such negative values are characteristic of monsoon rainfall, which implies that the limit of the monsoonal rainfall belt shifted far north of its present location. These northward shifts coincide with peak interglacial periods (early- to mid Holocene, Marine Isotope Stage 5a, 5e, 7 and 9). The Hoti cave speleothem record also show that transitions between a wet, monsoon type climate, and an arid to semi-arid climate, comparable with that of today, took place within a few decades.

#175 Magmatic evolution of the Tethyan Permo-Triassic Oman margin

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Permian and Triassic submarine basaltic flows sampled from various occurrences within the Oman margin units have been analysed by ICP-AES for major and trace elements. Their large ion lithophile element contents are highly variable and do not reflect primary magmatic features. Data on rare earth elements (REE), Th and high field strength elements show that the Permian lavas are either of MORB type (Rustaq, Buday'ah, several Al Ajal tectonic slices, Al Hillo dolerites) or alkali basalt-related (Saih Hatat, Baid - Wadi Wasit, some Al Ajal units). Normal (depleted) MORB have not been found, and the studied samples range from transitional MORB (with flat REE patterns) to enriched MORB, the latter type being the most common. Although the occurrence of transitional basalts is consistent with the development of an oceanic domain, these seem volumetrically minor with respect to rift-type lavas.

The Triassic lavas analysed display the usual characteristics of intra-plate (enriched) magmatic series, as proposed by previous authors. They range from intra-plate tholeiites (Sinni, Aqil, eastern part of Jabal Buwaydah) to alkali basalts (Misfah, West of Buwaydah).

#306 Permian conodont provincialism: Significance in global correlation and climate change

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Distribution patterns of Permian conodonts suggest that *Vjalovognathus*, *Gondolelloides* and *Merrillina* are cool water residents, whereas *Diplognathodus*, *Sweetognathus* and *Iranognathus* are warm water residents. *Neostreptognathodus* is more common in temperate zones than in the equatorial zone. Neogondolellids, *Hindeodus* and *Sweetina* are cosmopolitan and the most temperature tolerant. Permian conodont provincialism in the Asselian to Artinskian is only indicated by rare endemic elements indicative of cool water such as *Gondolelloides* and *Vjalovognathus*. Provincialism during the Kungurian is marked by differences at the species level for *Mesogondolella*, *Neostreptognathodus* and *Sweetognathus*. Finally, provincialism becomes very distinct with differences at the generic level during the Guadalupian and Lopingian. Neogondolellids persist as *Mesogondolella* with a big cusp and low and discrete blade in bipolar temperate zones during the Kungurian through Lopingian. In the equatorial zone they are differentiated into *Mesogondolella* with a small cusp, a tightly spaced to fused carina, and a high and fused blade during the Kungurian, *Jinogondolella* during the Guadalupian and *Clarkina* during the Lopingian. Conodont provincialism patterns reflect glaciation in Gondwana during Asselian and Sakmarian, widespread warming during Artinskian, cooling in North Pangea during the Artinskian and especially during the Kungurian and later Permian, slight amelioration during the Guadalupian, warming during the Wuchiapingian, and cooling during the Changhsingian in peri-Gondwana. Climate changes may ultimately be related to the northward movement of Pangea and the resulting alteration of oceanic circulation patterns. An Early Permian conodont crisis is associated with the Artinskian warming and the extinction of *Neostreptognathodus* is probably associated with Guadalupian warming. However, the progressive apparent extinction of *Neostreptognathodus* from North Pangea during the Late Artinskian and Kungurian results from cooling in that region. The replacement of *Jinogondolella* and *Sweetognathus* respectively by *Clarkina* and *Iranognathus* is associated with the Wuchiapingian warming and the extinction of *Iranognathus* is probably associated with Changhsingian cooling. Permian conodont lineages ended during a late Griesbachian conodont crisis, which is associated with Early Triassic global warming.

Middle and Upper Permian conodont zones established in the Equatorial Warm Water Province (EWWP) can not be correlated precisely with those recognized in the North Cool Water Province (NCWP) and the peri-Gondwana Cool Water Province (GCWP) because of the marked provincialism. Four horizons, which define the boundaries of five conodont evolutionary stages during the Permian, have potential for inter-provincial correlation. They are in ascending order: (1) the first appearance of *Sweetognathus whitei*, which is closely related to the last occurrence of Carboniferous-type conodonts such as *Streptognathodus* and *Adetognathus*; (2) the first appearance of *Neostreptognathodus pequopensis*; (3) the base of the *Jinogondolella nankingensis* Zone; and (4) the base of the *Clarkina postbitteri* - *Iranognathus erwini* Zone. Permian Series and Stage boundaries should be defined at horizons close to the above-mentioned horizons so that they are as correlatable as possible outside the type area. A study on geographical clines in morphology for each index conodont is also necessary and will be the key to improve inter-province correlation.

#17 The geology of the late Proterozoic crystalline basement of the Salalah area, South Oman

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East of Salalah (Dhofar) part of the late Proterozoic Arabian crystalline basement and its intra-Cambrian sedimentary cover are exposed beneath the Mesozoic and Tertiary sequences. The history of this basement begins around 1,000 Ma with the deposition of clastic sediments in an accretionary prism environment, the protoliths of the mica gneisses of the Juffa Group. Around 850 Ma, mantle derived melts started to intrude the base of the prism. The continuos injection of melts produced the first dioritic and tonalitic intrusives and a thermal anomaly able to sustain partial melting of the prism sediments. During this stage the Banded Migmatite Complex of the Sadh Group formed. 50 my later (800 -790 Ma), a suite of dioritic to tonalitic calc-alkaline plutons intruded the migmatites (Mahall meta-intrusives, Fusht Complex, Hasik Gabbro Complex, Hadbin Complex and Mirbat Complex). Around 750 Ma, during the uplift to shallower levels, a huge mass of granitic dykes intruded along a conjugated set of compressional brittle faults. Then, over a 200 my period, the basement remained inactive until, around 550 Ma, extensional tectonism favoured the emplacement of a dyke suite composed of calc-alkaline basalts, andesites and rhyolites.

On the fluvial deeply-eroded crystalline, the upper Proterozoic Mirbat Sandstone Formation was unconformably deposited.

#53 1:50,000 scale geological map of northeast Saih Hatat: Geometry and significance of internal windows and regional isoclinal folds

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Northeast Saih Hatat consists of fold interference between regional-scale, sheath-like, recumbent isoclines and more open, upright NW-, N- and NE-trending fold sets. These early recumbent folds are subparallel to, but cut by, a major shear zone (upper - lower plate discontinuity) that separates lower plate eclogites/high P rocks exposed from less metamorphosed upper plate rocks containing carpholite and lawsonite. The upper plate rocks correspond to the blueschist region II of Coleman and El-Shazly (1990), whereas the majority of the lower plate rocks correspond to their region III, part of which reached eclogite facies metamorphic grade. The shear zone is delineated by a marked gradient in strain in the upper plate, but is cut by a brittle fault with bleaching alteration and localised occurrences of Pb-Zn and Cu mineralisation. The outcrop trace of the fault in map view defines two ovoid shaped windows (As Sifah and Hulw windows). The two windows are essentially foliation domes within the flat-lying layering and foliation of the early recumbent fold sets. Parts of this fault had been mapped or speculated upon previously to explain the variation in metamorphic grade across Saih Hatat. The décollement appears to have had more than one generation of movement, and locally along the southernmost segments there is imbrication and infolding of upper and lower plate sequences, resulting in fault-bounded slithers of upper plate units surrounded by lower plate units (i.e. klippen). This reactivation is associated with the development of N- and NE-vergent asymmetric crenulation cleavages, and occasionally the development of macro-scale asymmetric closures. Our mapped relationships and structural observations agree with Bureau de Récherches Géologiques et Minières mapping that recognised fold-nappes in this part of the Oman Mountains. Upper plate nappes are controlled by proximity to the mapped shear zone interface. The upper limb of the regional anticlinal closure that encompasses the majority of Saih Hatat is defined by a large asymmetric closure that encompasses the entire hillside of Jebel Qirmadil (hills north of Wadi Adai). Below this anticlinal hinge zone is a major recumbent syncline that is the dominant structure in this region of the upper plate. A large expanse of Hatat schist and Hijam dolomite defines the overturned limb of this syncline on the most southwestern extremity of Wadi Meeh. The lower limb of this closure is truncated by the upper - lower plate discontinuity. The lower plate closures below the discontinuity have formed independently in an intense zone of non-coaxial shear. This has produced schistose L-S tectonite fabrics, sheath-folds at all scales, C- and C'- shear bands, asymmetrically sheared clasts and pressure shadows around porphyroblasts. These early folds reflect a major NE-movement of the para-autochthonous rocks at the same the ophiolite is being emplaced over the top to the southwest. The interpretation is different from proposed S-directed thrusting scenarios. S-directed faulting and shearing is later, and superimposed on the early structures of the mountain range.

#220 The Ruwaydah Unit: Volcanic and limestone deposits of a dismembered sea mount. Batain Plain, Sultanate of Oman

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The Ruwaydah Unit is made up of an elliptically shaped WSW-ENE elongated outcrop displaying a seamount relic. An association of volcanic and clastic carbonate rocks build up the outer rim of the outcrop, neritic and pelagic limestone successions with pillow lava and basaltic extrusives the central part of the seamount.

The clastic successions with partly basaltic interbeds consist of conglomerates, calciturbidite with radiolarian-bearing interbeds. They contain abundant strongly recrystallised and micritised shallow-marine fossil debris, peloids and volcanic clasts. The clastic carbonate succession is of late Callovian–Oxfordian to Berriasian–earliest Valanginian age dated by Jurassic radiolarians and Lower Cretaceous calpionellids.

The neritic and pelagic facies of the central part of the Ruwaydah Unit is made up of an association of pillow basalts, ammonite-hosting limestones of the "Ammonitico rosso" type and crinoidal limestones. The red fossil-rich "Ammonitico rosso" limestones interbedded with pillows yield aptychi, belemnites and gastropods (*Discohelix* sp.) and a ammonite assemblage with *Phyloceras*, *Perisphinctes*, *Taramelicera*s, *Lytoceras* and *Nebrodites* cf. *macerrimus* indicating a middle Kimmeridgian age. The "Ammonitico rosso" limestones are overlain by trachybasaltic flows, volcanic breccia, pillow basalts and finally by 15 m of trachyandesitic flow-breccia. Isolated outcrops of micrites and radiolarian-bearing porcellanites from the western part of the Ruwaydah outcrop were dated as late Tithonian based on the radiolarians.

The volcanic series displays magmatic differentiation, trending from basanite over tephrite and trachyandesite to trachyte in chemistry. They appear to belong to the alkali-basaltic series. The volcanic deposits within the calcareous sediments indicate specific temporal volcanic activity. Further the co-occurrence of different facies indicates either strong relief, or enormous vertical tectonic movements. We suggest two compressional phases: A first phase, directed S-N, appears to coincide with India drifting to the north during the Hauterivian-Barremian time span. A second phase which is E-W directed, contemporary with the obduction of the Batain nappes at the Cretaceous/Tertiary boundary.

#231 From Pele's tears to caldera collapse: the impact of terminal Proterozoic volcanicity in Oman

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The Huqf Supergroup of Oman provides an unrivalled glimpse of volcanism and its effects on the environment during the terminal Proterozoic-Cambrian transition. Past research on the Huqf succession has concentrated on the hydrocarbon play potential of the clastic - carbonate cycles. However, volcanic sequences are now beginning to yield crucial paleo-environmental and tectonic information pertinent to such exploration, as well as providing the chronostratigraphic means with which to accurately pin and calibrate basin evolution models.

Subsurface in central west Oman, seismic, gravity and magnetic data reveal a 50 km wide downsagged caldera bounded by ring fractures and situated against a major N-S lineament. A well penetration (Abu Butabul-1) on the outer rim demonstrates the presence of mixed volcaniclastics 1.2 km thick, much of it as delicate millimetre-sized trachybasalt to andesitic flow-glass. Modelling this structure on analogous geophysical and outcrop data from the Cretaceous of Namibia helps to resolve the complex history of the Abu Butabul caldera. The interfingering of the volcaniclastics with salt from the Ghaba Basin to the east suggests an age of youngest Proterozoic to Cambrian.

In the Jebel Akhdar of north Oman, new detailed outcrop mapping and 3-D facies analysis of the Fara Formation indicates that it consists of over 600 m of volcaniclastics and catastrophic debris flows. The Fara overlies carbonate platform and ramp facies of the Buah Formation and marks a sudden appearance of volcanic ash plus dramatic increase in accommodation space. Prograding wedges built out on a steeply inclined surface from a marked break in slope to the southwest, which may represent the fault responsible for rapid basin subsidence. The subsidence, slumping and fill style of the Fara basin raises the strong possibility that it represents a small exposure located just inside the rim fracture of a drowned Abu Butabul - like caldera.

Terminal Proterozoic to Cambrian age volcanic ash horizons are beginning to be found in many cores from the South Oman Salt Basin. Of particular interest is a currently unique 60 m thick cored interval in Ghafeer-2 well which is entirely composed of delicate vesicular spherules and teardrop-shaped pyroclasts. Electron Probe and SEM analysis confirms that spheres were originally a glass 'foam'. Their internal structure and devitrified composition indicates that they are likely to be the product of a subaqueous trachybasalt eruption within the salt basin, implying the close proximity of a further active vent in the south of Oman.

The volume of pyroclastic debris and ash erupted at both Abu Butabul and the Fara dominated their respective basinal environments and could have caused local biosphere collapse, having major implications for potential hydrocarbon source rock formation. Perhaps even more intriguing is the effect that may have accompanied emplacement of units such as the Ghafeer spherule horizon. Eruptions that involve melting and vapourization of evaporites are known from recent examples to have the potential to pump large volumes of acid aerosols into the stratosphere and cause rapid global cooling.

#95 Accretion of the Oman Ophiolite: A new structural map

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This presentation relies on the structural map of the Oman-United Arab Emirates ophiolite and presents a new synthesis at the scale of the entire belt. We discuss the various constraints introduced by these data in view of a synthesis of the ophiolite belt in terms of an ocean floor spreading system. Because they are the link between the factual results summarised in the maps, and the ridge models, these constraints are critical (and are central to the structural analysis of ophiolites). They introduce severe limits to possible ridge models such as those proposed in the conclusion. After being reassembled in a best geometrical and structural fit, the belt is parted into three domains. The southeastern and central domains (from Wadi Tayin to Haylayn and possibly Sarami massifs) incorporate a

40-50 km-wide and possibly over 200 km long new ridge segment, oriented NW-SE, which is opening into a 1-2 my older lithosphere oriented NE-SW. The northern domain (from Khawr Fakkan to Hilti massifs) is well explained by a model of propagating (Aswad) and failing (Fizh) ridge segments of nearly parallel NNW-orientation which are separated by a 10-20 km-wide transform zone covering the north of Fizh massif. This new synthesis illustrates the contrast between locally simple ridge segments organised around mantle diapirs and the tectonic complexity of the two larger domains, with, as an example, sheared mantle, vertical Moho and dismembered lower crust with hydrous contamination, near the tip of ridge propagators. The relation between the northern and central-southern domains is obscure because the paleomagnetic results suggest that, with respect to the central-southern domain, the northern domain should have rotated 130° clockwise. Such a large rotation of a 200 km long domain is difficult to explain, inasmuch as the age constraints seem to restrict the possible duration of the rotation to a couple of million years. The preferred model consists in a progressive clockwise rotation during tectonic accretion of increasingly larger blocks. This is initiated in the northern massifs, progressing over 1-2 my, southward to finally integrate the entire ophiolite.

#236 Structural map of the Oman-United Arab Emirates Ophiolite

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The new structural maps of the Oman-UAE ophiolite, scale 1:400 000 are presented. The set includes 3 maps, in press in a special issue of 'Marine Geophysical Researches'. They concern the internal structures of the ophiolite units: planar structures, linear structures and dikes. This long-term mapping which represents 20 years of continuous scientific activity included the contribution of 15 scientists (PhD students and collaborators) and was achieved thanks to the permanent concern and help of the Directorate of Minerals of the Sultanate. One principal result of this mapping is an unexpected structural complexity, but altogether a structural continuity accross the different massifs and the evidence that nearly all structures result from a tectonic activity at the paleospreading axis of origin. These stuctural data introduce new constraints on ridge segmentation which is presented and discussed in the joined oral presentation.

#149 Palynology of the Misfar Formation, Oman and its correlation with sequences in Saudi Arabia

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Re-evaluation of the hydrocarbon potential of the Devonian Misfar Formation in the South Oman Salt Basin is supported by new palynological evidence which suggests the formation has a wider distribution than previously suggested.

Palynological assemblages recovered from core, SWC and drill cutting samples from 21 wells yielded commonly well preserved populations of miospores accompanied in some cases by marine microplankton. The presence in the assemblages of both simple single walled commonly retusoid genera including *Retusotriletes*, *Emphanisporites*, *Acinosporites* and *Dibolisporites* together with numerous zonate and camerate genera including *Samarisporites*, *Grandispora*, *Rhabdosporites* and *Ancyrospora* suggest an age assignment to the late Emsian - early Eifelian.

Direct correlation with other Arabian sequences is impeded by the absence of a regionally specific palynozonation scheme. Reliance is frequently placed on long range correlations with the Devonian reference sections of western Europe without exploiting the full potential of endemic Gondwanan taxa with restricted ranges.

The general character of the Misfar assemblages allows potential correlations to be drawn with the upper part of the Jauf and the lower part of the Jubah formations of eastern Saudi Arabia as reported by Al-Hajri et al. (1999). The boundary between the Jauf and Jubah formations in the Ghawar field coincides with the boundary between two operational palynozones, designated D2 and D3 with the latter being subdivided into two sub-biozones D3A and D3B. The D3B sub-biozone is characterised by prolific monospecific leiospherid assemblages which represent a major flooding event in the Hammamiyat Limestone Member of the Jauf Formation. Similar microplankton events are present in the Misfar sequences of Oman with comparable but specifically different monospecific assemblages being recorded. Further work is required to establish the precise relationships between the Jauf and Misfar events and to determine whether these are the same event with species composition of the microplankton assemblages being controlled by palaeoecological criteria.

#11 The developpment of the western Indian Ocean and the northeast Arabian continent

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The geologic history of the Batain Plain has to be viewed within the context of the continental margin of the southeastern Tethys as well as the formation of the western Indian Ocean and the eastern continental margin of Arabia. As part of Pangea it was situated at the junction of Arabia, Greater India and Eurasia/Iran until the opening of the Neo-Tethys in the Early Permian. The opening of the Neo-Tethys was preceeded by a WNW-ESE-trending rift. An embayment of the Tethys between Arabia and Greater India does not necessitate a N-trending eastern Oman rift system as proposed by Stampfli et al. (1991) and Le Métour et al. (1995). Sedimentation, differing from that on the Arabian Platform in this embayment, designated herein as Batain Basin, is recorded by the mid Permian Quarari Unit. For this unit, their is no equivalent in the Hamrat Duru Basin, indicating that this basin formed after the rifting stage at the Permian/Triassic boundary when uplifted shoulder parts of the Permian platform shed the conglomerates of the Aseelah Unit into the Batain Basin. From the Early Triassic onwards, sedimentation in the Hamrat Duru

Basin and in the Batain Basin is similar, but not the same. The breakup of Gondwana around 155 Ma is only registerd in the Batain Basin, where a strong phase of alkaline magmatism led to volcanic activity and seamount building similar to that of the Ruwaydah Unit. Further south, in the West Somali Basin, E-W trending spreading ridges, connected by large numbers of N-trending transform faults, opened. The spreading ridges probably continued into the North Somali Basin, but it is not clear whether they continued further north. The N-trending transform faults, however, must have continued along the African/Arabian Plate into the Batain Basin enabling the Indian Plate together with Madagascar to move southwards. The Eastern Oman Ophiolites formed at this time on one of these spreading ridge segments. It is uncertain whether the K-Block stayed attached to India and also moved southward or whether it continued to form the eastern margin of the Batain Basin. In the first case, oceanic crust formed north of the K-Block in the Neo-Tethys, in the second case it would have formed beween the K-Block and India. In either case, the sedimentation of radiolarian cherts continued during the Cretaceous. The influx of manganese during the Valanginian was registered in both the distal Hamrat Duru Basin and the Batain Basin. The pelagic radiolarian chert sedimentation in the Hamrat Duru Basin stopped with the beginning of the Cenomanian, possibly as a result of the start of intra-oceanic thrusting of the Semail Ophiolite, but continued into the Batain Basin. Sedimentation in the Hamrat Duru Basin stopped at the Coniacian/Santonian boundary with the emplacement related thrusting. Simultaneously, the influx of continent derived siliclastic deposits started in the Batain Basin and continued into the late Maastrichtian. At the Cretaceous/Tertiary boundary, a tranpressional movement caused the emplacement of the Ophiolite Nappes and Batain Nappes onto the Arabian continental margin as the Indian Plate passed this region. After the emergence and lateritic weathering during the Palaeocene, the marine transgression reached the region of the Batain Plain with intermittant deposition of platform carbonates up into mid Late Miocene. Normal faulting with the extrusion of olivine alkaline basalts during the Late Eocene is related to the rifting of the Red Sea. The blockfaulting and the thinning of the Ophiolite Nappes and continental crust below the Owen Basin is related to the opening of the Gulf of Aden since the mid Miocene, causing an anticlockwise rotation of Arabia resulting in extensional tectonics in the Owen Basin. On the other hand, this movement caused a compression towards Eurasia, resulting in the gentle folding of the Tertiary and underlying Batain Nappes.

#29 Emplacement of the Semail Ophiolite: Paleomagnetic results from the volcanic sequence

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Many paleomagnetic studies have been carried out on the Semail Ophiolite in order to better define the cinematic of the nappe and large rotations have been proposed (Thomas, 1991). An analysis of the volcanic sequence sampled in the Salahi Massif, has shown (Perrin et al., 1994) that the movement could be modelled by a single and large rotation of about 145-150° around an Euler pole located close to the nappe (less than 200 km away). The paleo-location and paleo-orientation of the ridge in hotspot coordinates could be estimated, as well as the linear velocity of the nappe between the period of accretion at the ridge, and the end of the obduction. However, the Oman Ophiolite is divided into structural massifs, each several tens of kilometers long and therefore a question arises: are the Salahi results representative of the entire nappe?

In order to answer this question, 32 flows (247 cores) were sampled in the first two volcanic episodes (V1 and V2) of the Oman Ophiolite, from the Aswad, Fizh, Hilti, and Sarami massifs in the northern part of the nappe, the Wuqbah Massif on the western front of the complex and the Wadi Tayin Massif in the south. Paleomagnetic analysis of the samples was complicated by a large overlap of the two components of magnetization carried by the rocks: a recent crystalline remanent magnetization (CRM) acquired in the present day field, probably during weathering of the rocks, and a older CRM probably produced by dissociation of the original titanomaghemites during hydrothermal event(s). If the magnetization carried by the V1 samples was acquired during the hydrothermal event related to the emplacement of these lava, e.g. during and/or shortly after cooling, the tectonic unity of the northern domain has to be questioned and a differential rotation considered between the Aswad and Hilti-Sarami Massifs but, by the time of emplacement of the V2 serie, this northern area seems to behave as a whole. As only one set of data is available for the southern Wadi Tayin-Sumail Massif, a conclusion would be premature but a possible relative rotation on the order of 90° can be suspected between the Hilti-Sarami and Wadi Tayin-Sumail Massifs, rotation which would have occurred after emplacement of the V2 series.

#331 Biostratigraphy and Microfacies of the Jafnayn Formation (Late Palaeocene-Early Eocene) of northern Oman

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The biostratigraphy and sedimentology of the “Jafnayn” Formation are described. The formation is divisible into two members separated by a sedimentary hiatus. The lower member is dated as Late Palaeocene (Thanetian) based on the occurrence of the foraminifera *Lockhartia diversa*, *Daviesina persica*, *Kathina* sp. and *Nummulitoides margaretae*. It comprises low energy, inner shelf, lagoonal marls and wackestones which pass upwards into massively-bedded pseudonodular, bioturbated wackestones and packstones and then into marls at the top of the member indicative of deposition in a shallow, normal salinity, inner shelf environment. The upper member is dated as mid Early Eocene (Ypresian) based on the occurrence of the foraminifera *Sakesaria cotteri*, *Heterostegina ruida* and *Nummulites* *globulus*. It comprises coral and red algal-rich, well-bedded, occasionally rudaceous, nodular packstones-grainstones and cross-bedded calcarenites deposited in a shallow (<10 m), fairly high energy open marine shoal environment with nearby patch reefs supplying coral debris.

The base of the upper member is marked by a distinctive thin (3 m) pebble bed, rich in metamorphic and vein quartz pebbles and rarer weathered ophiolite clasts together with occasional reworked clasts of the underlying member. The pebble bed immediately overlies a distinctive depositional hiatus corresponding to the upper part of the Late Palaeocene and lower part of the Early Eocene, i.e. approximately two nannoplankton zones (NP9-NP10) representing the upper part of the *Alveolina (Glomalveolina) levis* zone to the lower part of the *A. cucumiformis*/*A. trempina* zones. Although this hiatus is recognised lithologically and biostratigraphically at Wadi Rusayl, at other localities it is only detected through detailed micropalaeontological analysis, the lithological differences between the upper and lower members being less distinct. To the southeast of Wadi Rusayl several distinct pebble beds are present in the lower part of the Jafnayn representing multiple minor unconformities related to syndepositional uplift of the Siah Hatat area.

The base of the studied interval, i.e. base of the Umm er Rhaduma Formation, represents a regional unconformity known across much of the Arabian Peninsula and Gulf (Jones and Racey, 1994). The general lack of any Early Palaeocene across the Arabian Peninsula and Gulf is thought to be due to non-deposition or erosion associated with major regional inversion (Jones and Racey, 1994). The depositional hiatus between the redefined upper and lower Jafnayn is of major sequence stratigraphic significance in that it represents the base of the transgressive systems tract (TST) which encompasses the Upper Jafnayn and the overlying Rusayl Formation.

#332 Micropalaeontology of the Early-Middle Eocene Rusayl Formation of northern Oman

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New micropalaeontological data are presented for the Rusayl Formation of northern Oman. This formation comprises a lower restricted marine marly-argillaceous member, a middle inner shelf limestone member (partially hypersaline in origin) and an upper interbedded sandstone and marl-rich member rich in terrestrial material (including coals) representing shallow high energy barrier facies and restricted to normal inner shelf lagoonal environments respectively. Locally the formation is separated from the underlying Jafnayn Formation by a fluvial package. The formation is dated using foraminifera from both within and from the over- and underlying formations as latest Early to earliest Middle Eocene (NP13-NP14).

The presence of the larger foraminifera *Linderina rajastahnensis* in the upper member indicates a Middle Eocene age whilst the underlying middle limestone member has produced a fauna comprising *Alveolina agerensis, Somalina hottingeri* and *Opertorbitolites* cf. *gracilis* which together would indicate a late Early Eocene age. Calcareous green algae including *Ovulites maillonensis*, *O. morelleti*, *Furcoporella diplora* and *Neomeris* together with the red alga *Distichoplax biserialis* were noted in the limestones within the lower member. Together with the larger foraminifera *Orbitolites*, *Alveolina* plus textulariids and miliolids. Within the Middle member in addition to the foraminifer mentioned above were *Orbitolites*, miliolids, peneroplids and textulariids plus calcareous green algae including *F. diplora*, *Trinocladus perplexus* and *Cympolis elongata*.

The palynology indicates a dominantly restricted marine palaeoenvironment with two distinct periods of strong marine influence, during which dinocyst abundances increase markedly. The pollen and spore assemblages indicate a dominantly mangrove flora (*Spinozonocolpites*) until near the top of the formation. The abundance of *Spinozonocolpites* is a notable event correlatable over a large area (at least as far as South America). Horizons rich in algae similar to *Scenedesmus* and abundant algal filaments, may represent a tidal zone assemblage. Palynofacies are dominated by cuticle and membrane material (probably leaf debris) and brown pseudoamorphous wood, indicating a very shallow marine palaeoenvironment. The ostracod and foraminiferal assemblages support these interpretations. The ostracods permit the identification of a number of distinct environments within an overall lagoonal to infralittoral shelf setting with the dominant taxa comprising *Neocyprideis*, *Stigmatocythere*, *Xesteloberis*, *Phalcocythere* and *Paracypris*. Overall the foraminiferal assemblages support a dominantly lagoonal (partially restricted) setting being generally dominated by *Discorbis*, *Cibicides* and miliolids except for the middle member which dominantly represents deposition in a carbonate shoal setting.

#335 Eocene nummulite reservoirs: A review

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Nummulite accumulations, often referred to as nummulite "banks", form important hydrocarbon reservoirs in North Africa Eocene carbonates (Tunisia and Libya) and may represent potential exploration targets in other parts of the Mediterranean and Middle East (Oman). Porosities commonly average 10-20% and permeabilities 10-50 md within these nummulite accumulations.Within these reservoirs nummulites may constitute up to 98% of the bioclasts and are often restricted to only one or two species. The general absence of associated fauna is taken to indicate an oligotrophic environment. The palaeoecology of *Nummulites* is discussed and depositional models are outlined for the Lower Eocene El Garia of Tunisia and Libya, the Middle Eocene Seeb

Limestone of Oman and the Middle Eocene Mokattam Formation of Egypt. The nummulitic El Garia and Seeb Limestone formations are shown to be deposited in ramp settings and comprise a series of amalgamated sheets to low relief banks. In the case of the Hasdrubal field, offshore Tunisia, it is demonstrated that much of the El Garia has been redeposited into deeper-water. These accumulations often show ample evidence for both physical (scouring, winnowing and imbrication) and biological processes (reproduction strategies and bioturbation) leading to their formation. These processes are discussed and a general model for discriminating various physically and ecologically produced biofabrics, together with their implications for reservoir quality, is provided.

#78 Early Holocene paleolakes of the Wahiba Sands

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The Wahiba Sands cover an area of approximately 16,000 sq km in eastern Oman bordering the Indian Ocean. Its central part is dominated by linear mega-ridges up to 70 m high with a spacing of approximately 2 km. The aeolian sediments are characterised by 30 to 50% marine bioclastic grains reworked from the underlying “aeolianite”-paleodunes (Gardner, 1988).

Lacustrine sediments crop out in the interdune-swales between linear mega-ridges. They form a veneer of variable thickness (60 to 130 cm) resting discordantly on poorly-cemented “aeolianite” ranging in age from 30 to 70 ka. The lacustrine deposits consist of middle to coarse grained silty sand containing freshwater and land snails, ostracods, trace fossils of burrowing insects and plant remains. The sediments were dated by optical stimulated luminescence to ages from 8.4 ± 1.4 ka to 10.5 ± 1.5 ka. This is consistent with a calibrated 14C-age of 11.0 ka measured in shells of the prosobranch freshwater snail *Melanoides tuberculata* from the uppermost layer.

$\delta^{18}O$ in three species of freshwater snails (*M. tuberculata*, *Hydrobia* sp. and *Gyraulus* sp.) decreases from between + 2‰ to + 4 ‰ at 50 cm depth, to 0 ‰ at the surface whereas $\delta^{13}C$ values decrease from - 4 ‰ to - 6 ‰. In contrast the pulmonate freshwater snail *Gyraulus* sp. shows an increase from - 8 ‰ to - 4 ‰ in $\delta^{13}C$ values.

The decrease in $\delta^{18}O$ values in the shells of freshwater snails from 11 to 9 ka reflects the onset of the early Holocene wet period which is related to stronger monsoon activity. This period has extended until 6 ka (Burns et al. 1998), an age which is in place supported by the presence of Neolithic artefacts on the erosional surfaces of the outcropping lacustrine sediments.

#63 Diagenetic controls on Haushi Group reservoir quality, Sultanate of Oman

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The late Westphalian to early Artinskian Haushi Group is one of the most important hydrocarbon bearing reservoir units in the Interior Oman Sedimentary Basin. It consists of the glaciogenic Al Khlata Formation and the Gharif Formation, which contains marginal marine, coastal plain and fluvial sediments.The sediments presently range in depth from outcrop in the Huqf-Haushi area to almost 5,000 m in the northwest. This large depth range results from a varied subsidence, uplift and erosion history across the basin.

Sandstones at shallow depth are characterized by good reservoir properties, with intense dissolution of alumosilicates and carbonate minerals, combined with minor kaolinite and authigenic quartz precipitation, and little compaction. In contrast, deeply buried sandstones are highly compacted and tightly cemented by quartz, carbonate and sulfate minerals. This varying degree of diagenetic overprint is caused by regional differences in the heat flow, by surface-water infiltration during the Late Triassic to Early Jurassic, basin inversion and uplift in the Late Cretaceous along the southeastern basin margin, and obduction of the Oman Mountains in the Late Cretaceous.

Authigenic quartz, forming zoned syntaxial overgrowths, plays the crucial role in reducing the reservoir quality of the Haushi Group sandstones as it varies from trace amount in outcrop samples to almost 25% of the bulk composition in sandstones buried below 4,000 m. The timing of quartz cementation, constrained by burial/temperature history modeling and minimum trapping temperatures of primary fluid inclusions, suggests that the first detectable stage of quartz precipitation took place during the obduction of the Hawasina Nappes/Semail Ophiolite of the Oman Mountains in Late Cretaceous times. The volumetrically most important phase of quartz cementation occurred in the Early Tertiary in conjunction with the obduction of the Batain Nappes onto the east Oman margin.

In summary, the primary control on extensive quartz precipitation and therefore reservoir quality was tectonism, which induced pressure solution and stylolitization as the main silica sources.

#259 River systems and Arabian Basement subsidence relationship in Khuzestan Plain of southwest Iran, a Neotectonic example

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River migration can occur under influence of many factors. One of these is the tectonic activity that presently is happening in the Khuzestan Plain, a portion of Zagros foreland basin of southwest Iran. In this area many rivers such as Karkheh, Karun, Dez, Marun, etc. are flowing and under the force of Neotectonism continuously change their course. To map out the pattern(s) of the river migration, the morphotectonic elements such as plaeochannels, compressed meanders, river terraces (paired-unpaired), cut off meanders, etc. were identified on the satellite TM output data.

The study indicates that the pattern(s) of river migration is in accordance to tectonic behavior of the Zagros structural belt and its Arabian basement beneath. This can be well seen in the configuration of Karkheh River plaeochannels that show clockwise rotation of river system from east to west, which under normal condition should flow towards east and southeast.

The Paleogene Margin of the Arabian Carbonate Platform in the Oman Mountains (Sur Area)

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The most complete succession of Paleogene depositional sequences is exposed along the southeastern Arabian Platform margin, in the Oman Mountains, in the Dank–Buraymi area to the north, and in the Sur area to the east. Results presented here are centred on this latter region. A remarkable succession of depositional sequences can be observed which, through their stratigraphical configuration, morphology and their varied tectonic settings, demonstrate the transition between platform carbonate or mixed deposits to hemipelagic and gravitational deposits of the slopes and basins.

Stratigraphical and sedimentological analysis of these continental margin-type successions enables: (1) the tectono-sedimentary evolution of the Arabian Plate Tertiary paleomargin to be understood in terms of its main characteristics, based on almost continuous stratigraphic recording; and (2) the sedimentary dynamics to be analysed at the transition between platform and basin, and thus to understand the evolution of predominantly carbonate gravitational systems with regard to the structural evolution of the margin.

The structural and sedimentological evolution of the continental margin can be defined within three major sedimentary cycles summarised here in five stages:

1. ***Late Maastrichtian – Early Paleocene:*** This multistage tectonic period involved uplift and emergence of the Arabian Platform, tectonically-controlled subsidence and drowning of the Arabian Plate margin, and retrogradation of platform to basin depositional sequences. Carbonate debris flows occured during shelf-margin aggradation along high angle clinoforms and during the forced-regressive progradational stage of the platform at the end of the cycle.

2. ***Thanetian – Ilerdian:*** This period involved widespread subsidence and extensive transgression over the Arabian Platform, aggradation of the first Paleogene carbonate platform (*Umm Er Radhuma*/*Jafnayn formations*). At this stage, the Sur area corresponded to a passive platform margin open to the east. Slope to basin area were dominated by carbonate hemipelagic sedimentation (*Abat Formation*). Some gravity flow deposits are observed in lowstand and early transgressive system tracts of 3rd order depositional sequences.

3. ***Cuisian:*** Extensional tectonic activity and a correlative major relative sea level drop were responsible for a wide emergence of the Arabian carbonate platform and forced regressive prograding carbonate wedges, at the Plate margin. At that time, the eastern and southern borders of the Abat basin were uplifted along the Qalhat and the Ja'alan faults resulting in a trough configuration of the Abat basin. An important turbiditic sedimentation associated with large slumping and sliding phenomena, developed along a more inclined carbonate platform margin (*Fitah Formation*).

4. ***Lutetian – Bartonian:*** Regional subsidence of the Arabian Plate was accompanied by extensive transgression and aggradation of the second Paleogene mixed carbonate-siliciclastic platform (*Rus and Dammam/Seeb formations*). Thick deltaic deposits accumulated along the subsiding eastern border of the Abat basin controlled by the Qalhat Fault (*Musawa Formation*). The massive carbonate resedimentation along the margin continued during platform aggradation until the first maximum flooding event recorded on the platform. Above the flooding surface, poorly-efficient axial siliciclastic channel-lobe turbiditic systems and scarce lateral carbonate debrites are intercalated in the thick argillaceous prodelta to deep marine deposits in the Abat basin.

5. ***Late Bartonian to Oligocene:*** The main extensional tectonic phase is related to the opening of the Gulf of Aden, progressive uplift and emergence of the Arabian plaform, further block faulting at the margin. Forced regression and shelf margin platform progradation/aggradation developed at the edge of the Arabian Plate (*Shama Formation*). Carbonate platform collapse and resedimentation along the margin occured at the beginning of this stage. Then, chaotic gravity flow sedimentation, including basement olistoliths eroded along the bypass slope, accumulated on the down-faulted marginal blocs (*Tawah Formation*).

The Paleogene major transgressive-regressive cycles show a depositional partitioning between platform and basin that can be directly related to tectonic activity. The period of tectonic relaxation reflected by regional subsidence are characterised by aggradation of the carbonate platforms onlapping the Arabian craton. The periods of extensional (or strike-slip?) tectonism are marked by uplift and emergence of the Arabian Platform, while slope and gravity deposition are restricted to the reactived faulted Plate margin.

#160 Oil exploration in a late Precambrian intra-salt hydrocarbon system: The Ara Group of the South Oman Salt Basin

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During the past decade, a major exploration campaign by Petroleum Development Oman (PDO) has been underway to unlock hydrocarbon reserves from the deep, unconventional oil plays of the Ara Group of the South Oman Salt Basin. The Ara consists of a cyclic sequence of carbonates, siliciclastics and thick evaporites of late Precambrian to Early Cambrian age. Exploration activities have focussed on the intra-salt Athel silicilyte and the Carbonate stringers plays located at depths between 3 and 6 km.

Being completely encased in salt, the prolific reservoirs represent classical stratigraphic traps. They are considered self-charging systems with reservoirs and source rocks in close proximity to each other. The carbonates have been deposited on rimmed shelf and/or carbonate ramp settings within the overall restricted setting of the Ara Salt Basin. They represent cycles of marine freshening, onlapping and progressively backstepping transgressing over the tilted and block-faulted basin flank from WNW to ESE. The deeper parts of the basin were periodically anaerobic, resulting in the preservation of rich hydrocarbon source rocks (e.g. Athel Silicilyte). Subsequent halokinesis due to the deposition of overlying Haima Group clastics and regional tectonism has deformed the original depositional setting of the Ara cycles.

Commerciality of the carbonate stringer play was established following the discovery of the Birba field in the late 1970s. However, due to technical limitations of 2-D seismic data and the high drilling costs at the time, the play remained largely dormant for the following 15 years. During this period, the Athel silicilyte play was discovered at Al Noor and oil production, from this technically challenging play, was achieved in August 2000, barely 10 years later.

The carbonate stringer play has experienced a major revival since 1997, as a result of new 3-D seismic data coverage, new geological concepts, more cost-effective well designs and an integrated, multidisciplinary exploration effort. Since then four new oil discoveries have been made and plans for commercial development are actively being pursued. Presently the intra-salt carbonates constitute a significant part of PDO's undrilled prospect portfolio. Key critical success factors for exploring this play are: (1) high-quality 3-D seismic data and imaging; (2) prediction of reservoir facies based on a comprehensive geological understanding, and from seismic data; and (3) lowering well costs.

When generating predictive exploration play models, a main challenge is the identification and interpretation of Precambrian-specific lithofacies and depositional environments. By integrating data from outcrop analogues with subsurface log, core, and borehole-image data, key stringer carbonate lithofacies have been recognized. Reservoir facies include shallow-water ooid/peloidal grainstones, thrombolite buildups and laminated source-rock facies, where primary porosity has been preserved. Carbonate source rocks were deposited as sapropelic laminites and laminated mudstones in basinal settings. Stacking patterns of lithofacies in the various carbonate cycles differ based on sediment flux and available accommodation space, resulting in a set of facies models. These facies models can be tied to seismic geometry's, allowing a better pre-drill risk assessment.

#196 A preliminary evaluation of burial history and thermal modeling in the Fars Area, South Iran

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Fars area is a part of large Zagros Basin, covering about 150,000 sq km of the northeast margin of the Arabian Plate. This area has attracted the attention of petroleum geologists due to its huge gas reservoirs.

In this area the Silurian Shale is recognized as gas a source rock. It was recently defined as the Sarchahan Formation and is equivalent to the Silurian Qusaiba Member of Saudi Arabia.

The Sarchahan Formation does not extend regionally to all parts of the Fars area because of non-deposition or due to pre-Permian erosion. This Formation is deep and very few wells penetrate it. Therefore, determination of the level of maturity and source rock potential is not possible by routine geochemical studies. Instead, burial history reconstruction and thermal modeling was attempted to evaluate thermal maturity and determine timing of oil generation and accumulation.

The study is based on geological and geochemical data, chiefly obtained from 50 wells. The predicted maturity using thermal modeling appears to fit much closer to the maturities obtained by measuring vitrinite reflectance.

Geohistory of wells and isoreflectance maps for the potential source rocks were constructed. Maturation calculations, derived from geohistory analysis, indicate the onset of oil generation in the north Fars area began during the Jurassic. At present, in this area the source facies is gas mature but toward the southeast (south Fars) onset of oil generation is later, and in some parts of south Fars it is oil mature.

#123 Upper Permian to Lower Triassic carbon isotope record: A review and new data in the Oman Mountains, from the shallow platform to the basin

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The Oman Mountains expose a segment of Neo-Tethyan southern margin interpreted as an upper plate flexural margin. In the present study we examined the $\delta^{13}C$ and $\delta^{18}O$ isotope stratigraphy in various sections from shallow to deep-water facies zones for the Upper Permian-Lower Triassic carbonate sequences [(bulk rock, new data and data from Atudorei, (1998)]. The shallow-water environment occurs in the Jebel Akhdar Mountains (Wadi Sathan section, Saiq and Mahil formations), the slope carbonates of the platform margin crop out in the Sumeini area (Wadi Maqam section, Maqam Formation). Drowned carbonate platform (Oman Exotics) and deep-water deposits occurring in the basinal sector of the margin belong to the thin-skinned Hawasina Nappes [(Wadi Alwa, Wadi Wasit and Wadi Musjah sections, (Pillevuit, 1993; Atudorei, 1998; Baud et al. 1999)].

There is apparently no sedimentary gap between the Permian and the Triassic in the Wadi Maqam slope deposits and in the Wadi Sathan carbonate platform but these sections lack good biostratigraphic control. There is a better biostratigraphic calibration on the other sections proving significant gap in sedimentation. In the Wadi Alwa section at least the Changhsingian to Griesbachian sediments are missing, in the Wadi Wasit sections the gap is between the Wordian and the Griesbachian and in the Wadi Musjah between the ?Wordian and the Dienerian limestones.

Wordian carbonates are present in all sections with high $\delta^{13}C$ values between +3‰ and +6.6‰. These high values are still present in the Capitanian to Wuchiapingian carbonates.

The Changhsingian carbonates are present probably only in the Wadi Sathan and Wadi Maqam but without biostratigraphic constraints.

New $\delta^{13}C$ values on Griesbachian limestones from a block dated by conodonts (L. Krystyn) in the Wadi Wasit area are presented.

Dienerian to Smithian limestones comprise low positive $\delta^{13}C$ values (1.6‰ in Wadi Alwa2 section) to low negative values (-0.7‰ in Wadi Wasit) with positive peaks up to 3.5‰. In the Wadi Musjah section, Dienerian carbonates $\delta^{13}C$ values are surprisingly high, between 2.5‰ and 3.5‰. Higher up in the section (Smithian?) values lowered to more common values (1.6‰).

The biostratigraphically poorly-constrained Lower Triassic dolomites of the Mahil Formation in the Wadi Sahtan show low positive $\delta^{13}C$ values between 0.9‰ and 1.6‰ in the lower sequence with values increasing up to 4 ‰ in the overlying cycle.

Within the Lower Triassic limestones of the Wadi Maqam C member, the negative $\delta^{13}C$ values vary between -0.5‰ and -2.5‰.

Thus, if the Upper Permian carbonates are relatively constant with high $\delta^{13}C$ positive values, the Lower Triassic $\delta^{13}C$ with commonly low values shows a great variability with up to 3‰ positive peaks.

Despite this variability within paleogeographic domains and the poor correlation control, we can observe after the worldwide large negative shift of the $\delta^{13}C$ at the Permian-Triassic boundary, an increase of the values in the Dienerian followed by a negative trend in the Smithian limestones.

If these variations, over a range of 4.5‰, stay high, we believe that the great variability of $\delta^{13}C$ values is a characteristic of the Lower Triassic carbonate sediments. This may be related to global short-term variations in seawater chemistry or local variations of $\delta^{13}C$ values of the seawater related to particular paleoceanographic settings.

#124 Lower Triassic carbone isotope stratigraphy of the Sumeini slope deposits, (Maqam C) northwest Oman

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Platform-derived carbonates represent the major source for a thick sequence of slope deposits (the Sumeini Group) near the platform margin, cropping out in the Sumeini area near the border between Oman and the United Arab Emirates. The lower part of this Group (about 1,700 m thick) is included in the Maqam Formation (Upper Permian to Upper Triassic) which is divided into 6 members (A, B, C, D, E and F; Watts and Garrison, 1986). This study provides new stratigraphic and isotopic data for members A, B and C.

The fossiliferous member A, Wordian in age (Pillevuit, 1993), is made up of thin gray and black limestone beds alternating with marls and subordinate sandstones. Member B consists of thin-bedded to massive dolomites with numerous calcirudite intervals and locally abundant breccia. Corals recovered from the lower part and skeletal bedded cherty dolomites rich in sponge spicules with bryozoans in the upper part indicate a Late Permian age for this member. Deep microbial platy limestones (basal member C) abruptly follow it. Member C is a very thick unit (900 m) essentially of platy limestones, calcarenites and calcirudites. An Induan age (Early Triassic) of the lower part is given by *Cyclogira* and *Earlandia* type foraminifera found about 50 m above the base. The location of the Permian-Triassic boundary (PTB) is not precisely known and will be discussed.

This study builds up the $\delta^{13}C$total isotopic curve of member C and confirms preliminary results on members A, B and the lower part of C (Atudorei, 1998).

The highest $\delta^{13}C$total values (+5.5‰) are recorded in members A and B. At the boundary between B and C, $\delta^{13}C$total values drop from +4.9‰ at the top of the member B to near 1‰ at the bottom of member C and then decrease until -2.3‰. This drop of around 7‰ in the $\delta^{13}C$total values is one of the strongest known in the Phanerozoic and at least the strongest within the PTBI in the Tethys.

In numerous sections along the Tethys (Baud et al., 1989), it is observed that following this PTB drop, a positive shift to values between +1 and +2‰ occurs in the upper Induan. But throughout member C of the Maqam Formation, $\delta^{13}C_{total}$ values remain at low values between -0.5‰ and -2.2‰.

If diagenetic effects lowering values can not be completely excluded, we assume that this negative trend represent original variations.

It is to note that with each thick turbiditic event occuring in the platy limestones, a 0.5‰ positive shift in the isotopic curve is recorded. As shallow-water limestones have higher $\delta^{13}C_{total}$ values than their equivalent in deep-water, we can suppose that this change is due to the massive input of the platform carbonate in the slope system.

#232 The influence of major linear trends of the Al Dhaid area, United Arab Emirates

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The discharge, recharge, and quality of groundwater in the Al Dhaid area, United Arab Emirates (UAE), are largely controlled by three major linear trends, which include the NE-trending Diba Zone, the NW-SE Wadi Ham Line, and the E-W oriented Hatta Zone.

Although large amounts of groundwater are withdrawn for agricultural purposes, the hydraulic head in several lineament-affected wells remained nearly constant while many others, away from linear trends, experienced a sharp decline in groundwater levels during the last two decades.

It seems that the aquifer recharge is accelerated along the dominant linear features, which act as conduits for groundwater flow from the northern Oman Mountains (recharge area) in the east towards the Arabian Gulf (discharge area) in the west.

The Wadi Ham Line seems to have a major influence on the existence of inland sabhkas which represent local discharge areas in which groundwater reaches the surface and evaporates.

Due to their influence on available groundwater, it was also observed that the intersections of lineaments are favorable sites for existing water-well fields of the Ministry of Electricity and Water, urban centers and major farms.

The traces of identified linear trends, especially their intersections, represent preferred locations for construction of high production water wells and construction of water-well fields in the future.

#337 Overview of the tectonic setting and emplacement of ophiolites bordering the Arabia/North African margin: Oman and the Eastern Mediterranean compared

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This paper focus on comparisons between the Semail Ophiolite and ophiolites in the Eastern Mediterranean of mainly Jurassic and Late Cretaceous age. Comparisons with the settings of modern oceanic lithosphere indicate that the various Eastern Mediterranean ophiolites have differing origins and formed in a variety of tectonic settings. The widespread occurrence of andesitic extrusives, “depleted” tholeiites and highly magnesian lavas (boninites) favour formation of most, or all, of the large Late Cretaceous ophiolites in the Eastern Mediterranean region (e.g. Troodos, Baer-Bassit, Hatay, Lycian, Pozanti-Karsanti, Guleman, intra-Pontide) in an above subduction zone setting, rather than at a mid-ocean ridge. Such ophiolites formed by spreading during the initial stages of intra-oceanic subduction, prior to the emergence of any major related oceanic arc. Such supra-subduction-type ophiolites typically formed during short-lived periods (<5 my) of regional plate re-organisation. By contrast, most MOR-type oceanic crust was almost entirely subducted, or preserved only as dismembered thrust sheets or blocks in ophiolitic melange, including as blueschists. MOR-type ophiolites are very preserved (e.g. Jurassic Western-type Albanian Ophiolite). Seamounts were preferentially accreted and record the subduction of large tracts of oceanic crust. “Volcanic-sedimentary” units of mainly Triassic age, including alkaline to MOR-type extrusives and radiolarites record rifting transitional to spreading of Neotethyan ocean basins. Back-arc, intra-continental marginal basins of Triassic and Late Jurassic age developed within the northerly (Eurasian) continental margin (e.g. Jurassic Guevgeli Ophiolite, north Greece); the present-day Black Sea is a Late Cretaceous-Early Tertiary example. In addition, transform influenced ophiolites are occasionally preserved (e.g. Late Cretaceous Tekirova Ophiolite, southwest Turkey). Metamorphic soles reflect tectonic displacement of oceanic lithosphere while still hot, near a spreading centre (whether of mid-ocean ridge or subduction type). The Eastern Mediterranean subduction-type ophiolites, of both Jurassic and Cretaceous age, were rooted in several coeval Neo-Tethyan oceanic basins, separated by microcontinental fragments, and cannot be interpreted as vast, far-travellel thrust sheets derived (at different times) from a single, palaeogeographically simple Tethyan oceanic basin.

#245 Late Oligocene-Early Miocene rifting of the northeastern Gulf of Aden: Basin evolution in Dhofar, Southern Oman

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Most recent international work has focused on the northern Oman Mountains and it is often overlooked that southern Oman (Dhofar) borders the Gulf of Aden. This is a narrow, obliquely spreading, small ocean basin that is one of world's best analogues for Red Sea-type spreading basins, whose former existence is commonly invoked in regional tectonic interpretations. The purpose of the present paper is to outline the evidence of continental rifting preserved within the onshore Neogene successions of southern Oman (Dhofar). In this area, a narrow coastal plain is backed by a major fault escarpment, rising to 1,800 m. In the west, Quaternary alluvium conceals a major E-trending rift basin, the Ashawq Graben (90 km long by <20 km wide). This structure is infilled with Oligo-Miocene, mainly carbonate sediments that record rifting prior to initiation of seafloor spreading in the eastern Gulf of Aden. An initial rift pulse in the Early Oligocene (Rupelian; c. 33 Ma) resulted in accelerated subsidence, with marginal facies in the northwest, patch reefs on a high in the south and shallow open-marine deposition in the east (Nakhlait Member). A latest Early Oligocene (late Rupelian) rifting pulse (c. 29 Ma.) then created a steep-sided asymmetrical rift basin, the Ashawq Graben, in which pelagic carbonates and calciturbidites, c. 1,000 m thick accumulated in water depths of c. 400 m (Mughsayl Formation). Limestone talus was shed from master faults in the north, near the present the Jebel Qara Escarpment, and debris flows, slumps and detached blocks of shallow-water limestone were also fed northwards into the rift basin from a marginal rift high to the south, the Aquabat Horst. In addition, carbonate was redeposited eastwards within channels into deeper water. In the southwest, the extension of the Aquabat Horst is marked by a zone of E-trending coastal fault blocks stepping down into deep water. Following partial infill, the Ashawq Graben was cut by NE-trending normal faults, correlated with the landward projection of a major oceanic fructure zone (Alula-Fartak Fracture Zone). This faulting coincided with the onst of seafloor spreading in the eastern Gulf of Aden around middle Burdigalian time (c. 18-19 Ma.). Associated flexural deformation of the continental margin gave rise to a prominent break-up unconformity and development of a major fault escarpment bordering the coastal plain. The rift basin itself was uplifted by c. 400 m, whereas its northern flank was upfaulted by around 1,500 m. Tertiary and older units were eroded during the early Miocene, giving rise to shallow-marine clastics, consisting mainly of limestone conglomerates. Erosion continued after marine regression and red alluvial conglomerates accumulated on the coastal plain during the Pliocene (N'ar Formation). Fluvial downcutting continued during the Quaternary in a tectonically quiescent post-rift setting. Despite the oblique spreading of the Gulf of Aden, the rift morphology in Dhofar is more akin to orthogonally rifted (Atlantic-type) margins than to strike-slip dominated rifts, as most structures show evidence of dominantly normal faulting.

#246 Interpretation of the break-up and spreading history of the Neo-Tethyan Ocean from Oman to the Eastern Mediterranean region

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The tectono-stratigraphy of the northern Oman Mountains is recognised to exemplify the history of rifting, spreading, passive margin evolution, ocean crust genesis, ophiolite obduction and plate convergence of the Neo-Tethys Ocean. In Oman, Glennie et al. envisaged two alternatives in which rifting and oceanic spreading began, either as early as the Late Permian (first model), or alternatively not until the Late Triassic (second model). The Open University Group later favoured rifting in the Late Permian, but spreading delayed until the Late Triassic. Later discoveries of Late Permian MORB and radiolarites and the presence of Late Permian base-of-slope sediments (Sumeini Group), favoured Glennie's first model. Support for regional Late Permian break-up also came from north India (Panjal Traps and Late Permian base-of-slope successions in Ladakh). However, it still remains unclear how extensive spreading actually was in Oman until the Late Triassic when large-scale, alkaline volcanism (of hot-spot type?) occurred, recorded in the Late Triassic Oman Exotics (oceanic or continental margin?). Some light can be shed on these aspects by comparisons with the Arabian/North African margin evolution extending as far as the Eastern Mediterranean region. Little new data are available on the intervening Iran area; however, further northwest in Baer-Bassit region, north Syria, base-of-slope to basinal deep-sea facies preserved in melange beneath the dismembered Baer-Bassit Ophiolite document a passive margin established by Late Triassic time. Evidence from the Levant margin further South is suggestive of spreading by Early Jurassic time. The Late Triassic allochthonous terranes of Mamonia (southwest Cyprus) and Antalya (southwest Turkey) include Late Triassic pelagic sediments and MORB, but no evidence, as yet, of Late Permian deep-sea sediments or oceanic volcanics of this age. On the other hand, Late Permian and younger deep-sea sediments are present in Crete (metamorphosed) and Sicily (unmetamorphosed), but whether these represent remnants of a Late Permian spreading oceanic basin (which was later destroyed without trace) or instead a deep-water rift basin remains open to question. A possible scenario is that following Late Permian continental break-up and minor ocean crustal genesis in Oman, spreading dominantly occurred in Late Triassic time in this area. The Late Permian narrow basin terminated westwards against a continental margin transform fault (e.g. Dibba Zone). By contrast, in the Eastern Mediterranean region, rifting in the Late Permian was followed by initial spreading in Late Triassic time. Participants are challenged to provide supporting evidence for any alternative tectonic scenario: at stake is the validity of the recent concept of a wide Late Permian Neo-Tethys stretching from Oman to southern Italy.

#203 Geodynamic evolution of the Hawasina basin based on a sequence stratigraphic analysis of the Triassic to Cretaceous turbiditic systems

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The Hawasina Basin is a deep-sea basin, filled by differents types of turbiditic systems from Triassic to Cretaceous, lower part of the Tethyan passive margin of Oman. The Mesozoic turbiditic succession has been studied. The biostratigraphic correlations are based on radiolarians, according to the principles of sequence stratigraphy. Four major cycles have been defined. They record facies changed along a turbiditic depositional profile based on the Mutti's model (1992) from proximal sediments to distal and proximal again.

(1) Late Permian – Early Liassic (Aljil to Matbat 2 Formation): The most distal facies occur within the radiolitic facies (low density turbidity currents) of the base Matbat 1 Formation (lower Ladinian). The Triassic/Jurassic boundary is a major facies shift with onlaps, coeval with deposition of high density silicoclastic turbiditic facies (Matbat 2).

(2) Early Liassic – Dogger (Matbat 2 – Guwaysa Formation): The most distal facies occurs within the radiolaritic facies (low density turbiditic currents) of the top Matbat 2 (Toarcian to Aalenian). The base Dogger is a major facies shift with the development of high density carbonate facies (Guweysa).

(3) Dogger – Early Cretaceous (Guwaysa – Sid'r 2 Formation). The most distal facies occurs within the Sid'r 1 Formation (low to medium density turbidity current age). The distalisation hemicycle is underlined by a large debris flow (around the Jurassic/Cretaceous boundary) with truncation of the unerlying sediments. The boundary between the Sid'r 1 et Sid'r 2 (around Hauterivian) is a major shift with onlap.

(4) Early Cretaceous – Late Cretaceous (Sid'r 2 – Naid formations): The most distal facies occurs at the base of the Naid (low to medium density turbidity currents, around Albian/Cenomanian boundary).

The geometry of the different shifts and the lateral facies changes have been studied carefully. The relative importance of tectonics, eustasy and sediment supply/productivity on the control of this cycles will be discussed.

#354 Tectonic Development of the Ghaba Salt Basin, Block 3, Oman; A thrust model for the development of the Ghaba Salt Basin

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Seismic data over Block 3, Oman, demonstrates that the tectonic history of the Ghaba salt basin is dominated by compressional events ranging in age from Late Precambrian to Tertiary. Thrusting began during deposition of the Abu Maharah Group. Opposite verging thrust belts can be seen under the western margin of the salt basin and under the Huqf Arch. The initial phase of compression ceased in the early Cambrian (intra-Nimr times i.e. contemporaneous with cessation of movement on the Najd Fault System in Saudi Arabia). The Ghaba Salt Basin is best described as a push-down basin and is compressional in origin. Several phases of reactivation occurred in the Cambro-Ordovician during the deposition of Andam and Ghudun sediments and many thrust structures were modified by salt movement.

Little evidence for thrust reactivation is then apparent on seismic data until the Late Cretaceous to Tertiary phase of deformation. Well data indicates large scale erosion at the Hercynian Unconformity but the angular unconformity is barely apparent on seismic data. This is possibly a consequence of the position of Oman at this time, remote from the main focus of the Hercynian event in Egypt.

Major reactivation occurred in the Late Cretaceous and Tertiary. First, loading of the Oman Mountains led to the development of a Late Cretaceous foreland basin. Loading from the north resulted in a regional dip in that direction on which the Mesozoic carbonate section began to slide, resulting in a series of extensional faults of WNW orientation. This event allowed reactivation of the salt and many diapirs developed. It was followed by renewed uplift of the Huqf Arch, probably due to the obduction of the Masirah ophiolite in intra-Fiqa times. The thrusts beneath the western margin of the salt basin were reactivated and a major inversion, the Afar high oriented NNW in the north of the block, developed at this time. The uplift was buffered to the west by the Maradi Fault Zone. The present-day structural configuration of the block is thus related more to transpressional events along the east coast than to the more obvious mountain building to the north.

#256 The Late Triassic Kawr Platform, Sultanate of Oman: An analogue to the Dachstein Platform, Northern Calcareous Alps, Austria?

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The Kawr Platform is hundreds of meters thick and tens of kilometers in diameter, composed of shallow-water, bedded limestones deposited on a volcanic seamount. The interval of this study is Norian and Rhaetian in age according to the foraminiferal and algal associations in the bedded and in the coeval reefal facies. Coral and sponge framework reefs dominated the platform margins. Some areas at the present northern front of Jabal Kawr show reef facies attached to inner platform facies. This facies is interpreted as rim of the platform (cf. Bernecker, 1996).

Facies of platform interior is present in the sections Ala and Amqah that we measured east of the Kawr Platform. It is composed of bedded limestones, laminites, and various dark and red partings:

- The bedded limestones consist of 20 to 150 cm thick beds of pale gray, often burrowed wackestones and packstones. They are rich in the giant clam megalodonts. Smaller bivalves and gastropods are common. Ostracodes and low-diverse benthic foraminifers occur. Rare beds are rich in coprolites. Lithoclasts and peloids are present in c. 60 % of the measured intervals. These limestones are interpreted as subtidal deposits.

- Laminated layers are a few to 40 centimeters thick, often dolomitic mudstones and, rarely, wackestones. They display multiple fenestrae, stromatolites, and tepee structures. Many of these layers are eroded, with fragments of laminites in the subtidal beds. The depositional environment is typically intertidal and supratidal.

- Various red and dark partings occur within the sequences: layers of breccia, commonly at top or base of subtidal beds; reddish to pink, cm-scale volcaniclastics; large lithoclasts occurring predominantly in fracture fillings; reddish horizons with alveolar texture and circum-granular cracking indicative of subaerial exposure.

Subtidal facies alternates with intertidal layers, along with paleosols and volcaniclastics. Both shallowing and deepening trends are present. The surprisingly short-distance lateral facies variations are conspicuous, with subtidal horizons interfingering with intertidal beds. Thus different cycle patterns occur.

Facies and cyclic patterns show close similarities to the classical Dachstein Platform, Northern Calcareous Alps, Austria (Fischer, 1964). Lateral facies changes are common on both platforms, pointing to a general rather local phenomenon. Megalodonts, occurring in both platforms, are generally larger in the Oman sequences; their patchy occurrence characteristic to Kawr Platform is encountered only in the upper part of the Dachstein Platform (Enos and Samankassou, unpubl.). Corals and algae are common in the Dachstein Platform; however, they occur only in the northern part of the Kawr Platform and in the uppermost part of Ala and Amqah sections. Lithoclasts are more frequent in the Kawr sequences compared to Dachstein Platform.

Patterns of Late Triassic "Lofer Cycles" in the Dachstein area are controversial (cf. Enos and Samankassou, 1998). Comparative studies on the Kawr Platform are thus of interest questioning controls of platform cycles.

#254 Stratigraphy and environmental conditions of the Proterozoic-Cambrian interval in Oman: evidence from sulfur and strontium isotopes

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The Neoproterozoic-Early Cambrian Ara Group contains a six-fold, cyclic sequence of evaporites and organic-rich dolomites. In each cycle, evaporites represent a period of important basinwide restriction. Subsequent flooding by waters of normal salinity led to carbonate formation, followed by slowly increasing restriction which ultimately terminated carbonate deposition. Despite halite recrystallization, bromine values in whole-rock halite samples are suggestive of a marine water source. Carbonates contain fossils regarded as marine.

The mean $\delta^{34}S$ sulfate is +38.0 ‰ (range +32.4 ‰ to +42.1 ‰), and the mean $\delta^{34}S$ pyrite is +1.4 ‰ (range -10.8 ‰ to +11.4 ‰). Relatively heavy sulfur isotopes characterize the complete Ara Group section and do not show significant variation between individual wells or cycles.

Sulfur isotope values are likely to reflect the isotopic composition of their respective parent waters. The heavy values of $\delta^{34}S$ sulfate and the difference of about 35 - 40 ‰ to time-equivalent pyrite deposits are related to important bacterial sulfate reduction (BSR). BSR led to the formation and burial of reduced sulfur, and operated throughout Ara deposition. Pyrite in deep anoxic parts of the basin and organic species were major sinks for the reduced sulfur.

The Neoproterozoic-Cambrian, in general, was a period of important worldwide BSR. Ara sulfates and pyrites are relatively enriched in ^{34}S relative to values from roughly coeval basins, although some overlap exists. Waters in these basins probably had a similar oceanic-sourced sulfur isotopic signature, but BSR was perhaps most important in Oman. High organic content, a prolonged history of sulfate reduction and/or progressive ^{34}S enrichment in a larger basin complex are possible factors that seem to have contributed to the observed sulfur isotopic signature.

$^{87}Sr/^{86}Sr$ ratios have been measured on both dolomites and evaporites. Dolomites have a much greater scatter (0.70819 to 0.70883) compared to evaporites (0.70836 to 0.70854). Evaporites have less radiogenic average values than dolomites. As with sulfur isotopes, strontium isotope ratios of Ara deposits do not show significant trends in space and time.

The data scatter in dolomites reflects partial diagenetic modification of the original signal, but evaporites provide an alternative record which is less affected by $^{87}Sr/^{86}Sr$ changes during diagenesis. While pre-Ara sediments in Oman record rising $^{87}Sr/^{86}Sr$ ratios which are generally attributed to increased continental erosion, Ara values are less radiogenic. A general decrease of continental erosion and/or an increase in hydrothermal activity are possible explanations. Despite basin isolation during evaporite deposition, the less radiogenic values and their constancy in space and time suggest that clastic input was not important during that phase of deposition.

#342 A theropod caudal vertebra from the Maastrichtian Al-Khod Conglomerate, Sultanate of Oman

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Although dinosaur remains are known from all over the world, in the Middle East only a few dinosaur localities have been described so far. The recent discovery of a proximal caudal vertebra of a theropod from the Maastrichtian of the Sultanate of Oman represents the first dinosaur occurrence in the Sultanate and constitutes the first evidence of large theropod dinosaurs from the Arabian Peninsula (Schulp et al., 2000).

The vertebra was collected in the Al-Khod area, close to the Sultan Qaboos University, at the type section of the Al-Khod Conglomerate Formation (Nolan et al., 1990). The formation consists of a series of conglomerates interbedded with sandstones and shales.

The specimen is housed in the collections of the Sultan Qaboos University (registration number SQU-2-7); a cast is in the collections of the Natuurhistorisch Museum Maastricht (NHMM 1997113).

The centrum, with a diameter of 12 cm, is platycoelous or very slightly amphicoelous, with an excavation not deeper than 7 mm on both sides; the axial length is 92 mm. The ventral surface features a prominent axial ridge up to 20 mm wide. Chevron facets are barely recognisable on the anterior margin, and are absent on the posterior margin. No pleurocoels are present.

The ventral ridge and the laterally excavated and almost platycoelous character are typical of proximal caudal vertebrae of theropod dinosaurs. A direct comparison of our specimen with the Late Cretaceous theropod record of the Afro-Arabian Plate is difficult, since the Middle East dinosaur record is extremely poor, as is the latest Cretaceous record in Africa. Assuming an allometry comparable to *Allosaurus*, the total length of the Omani animal would have been between 6 and 7 m.

#358 Environmental care and stakeholder relations in offshore operations: Shell's experience in deepwater block 18 (Oman)

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In 1999 Shell Deepwater Oman B.V. (SDO) as Operator of Deepwater Block 18 (Gulf of Oman) acquired some 3,000 km of 2-D seismic data . Prior to this survey, a formal application for the Environmental Permit was submitted and a detailed Environmental Impact Assessment (EIA) study was carried out. Recommendations of the EIA were applied throughout the survey and during the close-out of the project.

The main experiences gained from the project's pre-survey, the actual survey and the close-out phase were the following:

Extensive and timely consultation of all potential stakeholders involved in the project proved to be very useful for a successful and minimal impact execution of the project. Main stakeholders included Government Bodies (3 Ministries), Royal Navy, University, Local Communities and Fishing Community. Making use of internationally acknowledged and local, expert Contractors contributed to the effective execution of the project.

Main precautionary measures during the actual survey included

- Avoidance of natural reserves
- 'Soft start' procedures,
- Removal / re-positioning of fish traps and artificial reefs
- Cutting short of seismic lines in case of risk of excessive interference
- Operating with two chase boats
- Operating with dedicated environmental observer on board of survey vessel
- Operating with local representative on board of survey vessel
- Post-survey efforts included extensive consultation with stakeholders - Ministries and Fishing Community in particular

- in order to arrive at a mutually agreed compensation plan. The project was closed out with a comprehensive close-out report (including summarised learnings) that was shared with and distributed to all stakeholders.

In conclusion, it can be stated that the project was executed following best environmental and operational practice, complying with local as well as UK government guidelines (relating to minimum disturbance to marine mammals). The survey was executed with minimum impact to the marine environment in general and to the local socio-economic environment in particular. The money spent for the 'environmental effort' ($110,000) was considered as money well invested.

#202 Surface to subsurface structural mapping of Block-30, Hamrat Duru Range, Sultanate of Oman

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A surface geological evaluation of Gulfstream's Block-30, northcentral Oman, was undertaken in late 1998. The purpose of this study was to identify and map surface features which relate to possible subsurface structural culminations and exploration targets in the Wasia Group. Block-30 covers the eastern part of the Hamrat Duru Range in the foreland fold and thrust belt of the southern foothills of the Oman Mountains. The subsurface Cretaceous carbonate target reservoirs in Block-30 lie below the allochthonous, thrust imbricate stack of Hawasina sediments belonging to the Hamrat Duru Group. This allochthonous assemblage was emplaced upon Upper Cretaceous Aruma foreland sediments which form the sealing caprock for the Natih Formation reservoirs of the Wasia Group.

Subsurface structural culminations were drilled at Hafar, Al-Sahwa and Nadir, in the southwest part of Block-30, on the leading edge of the Hawasina Nappe, whose surface expression seem to influence erosion patterns. Seismic data deteriorates quickly overtop the nappe and thus the requirement for surface mapping as a tool to identify subsurface structural highs and areas to focus future exploration activity.

Surface structural mapping was facilitated by a satellite image interpretation of the Hawasina in Block-30. Major lineaments and lithological boundaries were identified from the satellite interpretation and this preliminary work was augmented by Block-30 seismic and well data. The surface geological evaluation not only served to proof the satellite interpretation but also provided detailed structural and stratigraphic analysis for the identification of subsurface structures.

Two mapped surface features which may relate to subsurface structural culminations below the Hawasina Nappe in Block-30 are: (1) an increase in thrust frequency of the Hawasina Nappe, which represents a thin-skinned tectonic response to an existing structural high during allochthon emplacement; and (2) the incorporation of Aruma Group sediments into the Hawasina assemblage, which involve thick-skinned tectonism and possibly the development of Cretaceous structures. In addition to these two features, structural reversals and surface drainage reveal patterns which may also indicate subsurface structural highs and exploration targets in Block-30.

#240 The geochemical distinctiveness of Precambrian petroleum - more questions than answers

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Oils and bitumens from Precambrian strata have a number of distinctive geochemical features that differentiate them from Phanerozoic petroleum samples. For example, the Huqf oils of Oman are among the most isotopically depleted oils known and they contain unusual patterns of steroid, triterpenoid and branched alkane hydrocarbons. Globally, Oman oils have very few counterparts but they do share their uncommon features with probable Neoproterozoic samples from eastern Siberia, Kazakhstan, India and Australia suggesting that the geochemistry is diagnostic for the microbiota, paleoenvironment and the paleogeographic settings of source rocks deposited in a narrow time window. This paper reviews what we currently understand (and don't understand) about the chemistry of the Huqf oils and source rocks and how this chemistry might relate to Neoproterozoic biogeochemical processes.

Carbon isotopic depletion is common in Precambrian hydrocarbon samples but the Huqf petroleum is the most extreme example known. This ^{13}C pattern likely records a combination of global secular isotopic shifts in the ocean-atmosphere carbon reservoir together with biological and paleogeographic influences. The overt preference for C_{29} sterane hydrocarbons is likely due to the radiation of a particular clade of algae in the Neoproterozoic and this is almost certainly the major factor in the Huqf Group sediments being the earliest known occurrence of a world-class petroleum source rock. Although putative source rocks as old as 1,600 Ma have been recorded in Australia, these latter sediments contain mainly bacterial organic matter which is mostly generative for gas and condensate. Besides the important algal source organic matter, the Huqf biomarker patterns also reveal inputs from other biota including cyanobacteria and sponges or their protist predecessors. Accordingly, the Huqf oils and confining sequence of organic rich sediments are an important source of information about Neoproterozoic biology.

The distinctiveness of biotic inputs, along with lithological indicators of unusual water chemistry and diagenetic conditions combine to make the Huqf oils and their source rocks unique. Consequently, the modelling of hydrocarbon generation and expulsion in these sediments cannot be based on Phanerozoic proxies. New measurements of the kinetic parameters for hydrocarbon generation will lead to an improved appreciation of the controls on hydrocarbon generation in this enigmatic oil province.

#103 High resolution, global correlation of the Permian-Triassic interval

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In recent years, many significant advances have been made in accurate dating of the Permian-Triassic interval. Much of this work has taken place at the well studied Meishan section (the proposed global stratotype). Several of the most recent results from China and elsewhere have shown that the disappearance of the Late Permian taxa probably occurred over a very short interval of time (less than 50,000 years).

Unfortunately, all of these well studied sections are highly condensed. For example, recent estimates suggest that for the transitional beds at Meishan, 1cm of rock represents 30-35,000 years. Effects of biotic mixing, sedimentary processes and non-deposition in such condensed settings mean that rapid events (such as the end-Permian crisis) are below the stratigraphic resolution of these sequences.

Thus, it becomes imperative to find localities where sedimentation rates are much higher. In addition, we need to be able to correlate between such sections. Traditional correlation by macrofossils (e.g. ammonoids) is often unsatisfactory because of vagaries of preservation, abundance and palaeogeographic distribution. Microfossils (e.g. conodonts) are superior due to their greater abundance in the rock record. However, first appearance datums (FADs) of zonal fossils are often diachronous (at the time resolution we need). Isotope changes, such as the negative shift in $\delta^{13}C$, appear to be much more reliable.

However, a problem with extrapolating from condensed sections, such as Meishan, is that in such sequences all changes (isotope and faunal) appear to happen at the same time. Thus the sharp negative shift in $\delta^{13}C$ occurs at the exact same level as the apparent extinction event. Recent results from East Greenland (one of the most expanded sections documented to date) show that here the $\delta^{13}C$ shift happens after the biotic crisis. Estimates of sedimentation rate for the East Greenland section shows that 1m of rock represents 8-17,000 years and that ecosystem collapse took place over c. 0.5 m.

Thus it is always best to combine as many methods as possible. For example, recent results suggest that using a combination of conodont and strontium isotope stratigraphy is a very useful (and currently under-employed) method for correlating sections throughout the extinction-recovery interval. In addition, new data from East Greenland allow us to directly compare the terrestrial palynomorph record with marine events and isotope changes. It will shortly be possible to correlate the marine and terrestrial records at sub-zonal level.

#276 Middle Cretaceous sedimentation patterns and chemostratigraphy of the eastern Arabian Plate, north Oman

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Well exposed, mid-Cretaceous successions (Barremian to Turonian) in northern Oman have been studied for both their stratigraphic architecture (van Buchem et al., 1996; Immenhauser, 2000; van Buchem et al., 2000), and chemostratigraphic signature (C and O stable isotopes; Immenhauser et al., 1999; van Buchem et al., 1999). We present a synthesis of this work, and propose a reference carbon and oxygen isotope curve of the mid-Cretaceous for the Arabian Platform in relation to the main trends in sedimentation pattern.

Three stratigraphic patterns have been observed in this interval: carbonate ramp systems (Lower and Upper Kharaib; Barremian), mixed carbonate/clay ramp systems (Nahr Umr Formation of Albian age, and the mid-Cenomanian Natih C and D members), and carbonate platforms with intra-shelf basins enriched in organic matter (Shu'aiba Formation in the Aptian, and the Natih Formation in the Cenomanian/Turonian).

Striking trends in the ecology of the carbonate producing organisms have in particular been observed in the Barremian to Aptian. A gradual increase in the volumetric importance of benthic foraminifera (orbitolinids) is observed during the Barremian and Aptian, leading to a climax in the Albian, where it is the dominant and rock forming component of the Nahr Umr Formation. Another significant ecological observation is the occurrence of microbialites (automicrites), as the dominant platform builder in the Shu'aiba Formation, and abundant organic matter production at that time in the adjacent Bab Basin. In addition, towards the top of the studied interval, a major change in the rudist communities takes place at the boundary of the Cenomanian/Turonian (Philip et al. 1996).

A composite C stable isotope curve for the mid-Cretaceous was measured in Wadis Muyadin, Bani Kharus, Nakhr, and in Jebel Madar and Salakh. Worldwide recognised deviations in the C isotope curve ('oceanic anoxic events'), such as in the early Aptian, and around the Cenomanian/Turonian boundary, are also recorded in these shallow-water platforms. A number of additional positive and negative anomalies were observed that probably have a more regional (plate-wide) correlation potential. These results will be discussed against the background of variations in the stratigraphic architecture, lithological composition, and ecological change of the shallow water carbonate systems of the southern Arabian Plate.

#161 Stratigraphic Architecture of the Cretaceous Carbonate Platform, Oman

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Extensive carbonate platforms covered the Middle East during Mesozoic times. The interior parts of these platforms are often visualised as undifferentiated, extensive shallow-water areas, where carbonates accumulate by aggradation. This view was based on the fact that individual shallowing-upward carbonate packages are laterally extensive.

However, with the improvement of seismic quality and resolution, internal geometries are revealed within the carbonates. This is illustrated by an example of the Lower to Middle Cretaceous carbonate platform of Oman, for which the seismic shows a complex internal architecture, rather than a 'layer-cake' configuration. Recognition of these stratal geometries has important implications for hydrocarbon prospectivity and development in these sequences.

The Lower to Middle Cretaceous carbonate platform was initiated in Central Oman during the major transgression over the top-Jurassic unconformity. After a rapid progradation of some 250 km to the north, the platform edge aggraded, leading to the development of a 1,200 m thick platform.

A well developed clinoform system occurs at the prograding lower part of the platform sequence. This clinoform belt consists of a series of laterally stacked stratigraphic packages of some 20 km wide, each showing a change from low- to high-angle clinoforms. These packages are thought to represent third-order sea level cycles superimposed on a second-order regressive trend. The difference in inclination is associated with variations in sediment fabric: the high-angle clinoforms are composed of thick sequences of shallow-water grain- and packstones, whereas the low-angle clinoforms represent muddy, deeper-water calcareous shales.

Within the 'layer-cake' platform interior carbonates, seismic data reveal the presence of similar but smaller-scale clinoform complexes and the occurrence of intra-platform basins. Mapping of clinoform belts and directions of progradation in the Natih-E platform interior carbonate unit shows that this extensive carbonate member consists of a number of separate platforms, which merged by lateral accretion. The platforms started to grow in areas with relatively low subsidence rates, such as basement highs and salt domes, following a regional rise in sea level. Merging of the platforms was not complete and in the intervening areas relict intra-platform basins developed, which were later filled with shales. Similar to the large clinoform system at the base of the platform, the clinoforms in the platform interior show cyclic variations in slope angle, associated with variations in sediment composition, and related to relative sea level changes. This leads to the suggestion that dip angles in these carbonates can be used to predict reservoir and seal facies.

The top of the platform was terminated by a period of uplift, karstification and erosion. An extensive system of deeply-incised meandering channel systems is observed on 3-D seismic data.

Recognition of inclined stratal geometries and the diachronic character of lithological units has important implications for hydrocarbon prospectivity and reservoir development in these sequences. At exploration scale, it allows the definition of stratigraphic trapping potential. At development scale, the understanding and prediction of reservoir heterogeneities, sweep efficiency, early high watercut, water flood, etc. will help to optimise field development plans.

#265 Early Permian blastoids and crinoids from northeastern Oman

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Three genera of cladid crinoids, two of them endemic and one known from Australia and North America, were reported from Oman by Jell and Willink (1993). The blastoids Timoroblastus and Deltoblastus and the crinoid Platycrinites are here reported from an interbedded marly shale and limestone sequence containing an abundant marine invertebrate fauna with brachiopods and trilobites from an unnamed jebel approximately 3 km west of Jebel Qarari, west of Al Ashkharah, northeastern Oman. These beds are considered to belong to the Sakmarian Bih (=Gharif) Formation. These records double the number of Permian echinoderm genera known from Oman.

This is the first report of Timoroblastus and the first confident identification of Deltoblastus from outside Timor. Platycrinites is a stratigraphically long ranging genus which occurs at a number of localities of differing age in the Permian of Timor, in late Sakmarian or early Artinskian strata of Western Australia, in late Artinskian or early Roadian strata of eastern Australia and in Artinskian strata of the Ural Mounatins of Russia. The Oman fauna shows relationship with Tethyan faunas of Timor and supports an Early Permian age for part of the Basleo fauna of Timor. These discoveries show that some elements of the Timor Permian echinoderm faunas were widespread within the Tethys. Reconstructions of palaeogeography show that the Oman fauna would have been distributed between 58° and 66° south latitude in the Early Permian.

#12 Mixed carbonate-siliciclastic sediments of the Permian Haushi Group, Central Oman: Outcrop analog model for marine, cold-water reservoir rocks?

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After glaciogenic deposits of the Permo-Carboniferous Al Khlata Formation, mixed carbonate-siliciclastic sediments of the Saiwan Formation (formerly the lower part of the Gharif Formation) marked the onset of the transgression onto the Arabian craton. Following an indistinct unconformity, fluviatile, lacustrine, and shallow-marine siliciclastic sediments of the Gharif Formation were deposited and overlain by a thick limestone-marl sequence of the Khuff Formation. These sediments form important reservoirs in the Arabian Gulf region. However, reservoir development is at risk due to internal heterogeneities.

The Saiwan Formation consists of 50 to 65 m cross-bedded or horizontally bedded, partly laminated mixed carbonate-siliciclastic sediments of varying grain size. Fossiliferous float- and rudstones consist of brachiopods, bivalves, gastropods, bryozoans, and crinoids. Jell and Willink (1993) described cold-water crinoids. The biotic composition resembles the heterozoan association defined by James (1997), which forms a productive carbonate factory in non-tropical settings. The sediments of the Saiwan differ therefore from time-equivalent, tropical counterparts of the Tethys and are interpreted as cold-water deposits. This interpretation is confirmed by a paleogeographical position of the Arabian craton outside the tropical belt during the Early Permian. The cross-bedded facies of the Saiwan was deposited by migrating carbonate dunes in a subtidal environment. Beds with horizontal bedding represent storm events, a common phenomenon of modern cold-water shelfs. The depositional environment is the middle and outer shelf in an upwelling region. Oolites reported from the Haushi Limestone may be the result of warm water above a land-connected thermocline. Potential reservoir units form either thin (tempestites) or sigmoidal to lens shaped reservoir units (dunes), which are in their dimensions below the resolution potential of seismic data sets. Diagenesis of the Saiwan cold-water sediments is characterized by absent to moderate syn-sedimentary cementation (epitaxial bladed or blocky calcite and syntaxial echinoderm rim cement). Consequently, early diagenetic compaction of the unlithified sediment reduced open porosity. Significant percentage of open pores resulted from intraparticle porosity (bryozoans), shelter porosity (brachiopods and molluscs), as well as leaching of metastable, probably phosphoritic skeletal grains. Grain size of bryozoans and shells is therefore an important factor controlling reservoir properties.

The Saiwan in the Huqf area may serve as an outcrop analog for productive subsurface hydrocarbon reservoirs with cross-bedded, mixed carbonate-siliciclastic composition. In contrast to tropical carbonate reservoirs, intense synsedimentary cementation, meteoric dissolution or dolomitization are absent. Reservoir properties of cold-water sediments greatly depend on coarse-grained primary texture of bioclasts and fabric selective dissolution of specific grains. In addition, fracture-related porosity may be important. The combination of cold-water sedimentation in connection with regional upwelling also suggests a complex intercalation of source and reservoir rocks in the Arabian-Gulf region. The data show, that consideration of the importance of cool-water carbonates may help to better understand heterogeneities of mixed carbonate-siliciclastic reservoirs.

#257 Geological features of the ophiolites along the Yanbu and Bir Umq sutures in Saudi Arabia

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Ophiolites of Saudi Arabia are amongst the less abundant and presently lesser-known ophiolites of Proterozoic age. Ophiolites of Saudi Arabia mostly outcrop discontinuously along the suture zones in-between the tectono-stratigraphic terranes that compose the Precambrian basement. They mark structural lineaments along the Arabian Shield basement when it was being accreted. The ophiolites are generally intensely altered, multistage deformed and metamorphozed to greenschist facies assemblages. Unlike most Phanerozoic ophiolites, the Saudi Arabian ophiolites lack significant chromite deposits. Segregated chromite is more abundant in the western ophiolites in the sutures of terranes of oceanic affinity; compared to the eastern ophiolites that bound terranes with mixed oceanic-continental lead-isotopic signatures.

The NW-trending Bir Umq Suture joins the Hijaz and Jeddah terranes; and hosts the Bir Umq and Jabal Dherwah Ophiolites. The younger, NW-trending, Yanbu Suture joins the Hijaz and Midyan terranes; and hosts the Jabal Ess and Al-Ays Ophiolites. Outside of the suture zones, the Nabitah-Hamdah Ophiolite belt follows the N-trending Nabitah Fault within the Asir terrane.

Ophiolites of the Yanbu and Bir Umq Sutures abound in isotropic gabbros with very little presence of layered gabbros. They possess more refractory chromite compositions (with higher Cr / (Cr+Al)) compared to those from the Nabitah-Hamdah Ophiolite belt, reflecting heterogeneity of their mantle sources.