AL HAJAR

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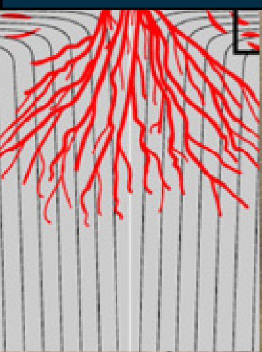
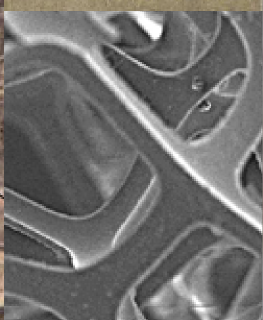
this issue





President's Address

My Fellow GSO members,

It is a great pleasure to introduce to you the all new Al Hajar newsletter. Al Hajar has evolved into its new shape in and out, thanks to the efforts of its editor, Caroline. This issue of Al Hajar contains geo-scientific articles and geology news updates from Oman and the world. This is really a milestone for GSO towards establishing Al Hajar as a reputable scientific publication where members can publish their articles and views on various geosciences topics. And from here I would like to extend my invitation to all members to contribute articles and research findings in his/her field of interest to be published In Al Hajar.

I'm also glad to let you know that the society has completed the shooting of the documentary film on the geology of Oman. The film is currently in the montage stage and it should be ready for viewing by the end of this year "Insha Allah". Tremendous time and efforts have been put into this film and we think it will be a significant contribution from the society towards preserving the geologic heritage of the country and promoting Geo-tourism.

Along the same line we have established a link with Al-Watan daily newspaper by which Al-Watan will give us a space in its English version "Al Watan Tribune" and in the main Arabic newspaper where we can publish society news and geology articles about Oman. The aim of this collaboration is to increase public awareness of Oman's geology and the importance of preserving its heritage, and the role that GSO plays in that regard. Any member who would like to contribute can send his/her English or Arabic articles to the society and we will compile them and publish them with their names.

And another bright side, the geological conservation committee is making good progress in preserving endangered geological specimens and localities. Very soon you will hear some news in this front. This step is very crucial stage for preserving many of the rare fossils, minerals and rocks that would otherwise vanish. Many of you have been involved in this project and I'm sure that this effort will bring relief to all us all.

At the same time, I mentioned in my last message that the geology museum is currently being considered by the Ministry of Heritage and Culture. The Ministry is aiming at rebuilding the Natural History museum with a significant section on the geology of Oman. GSO have submitted a proposal for the geology section to the Ministry and it has been incorporated in the museum's theme. We hope that the project will see light very soon.

Finally, I would like to extend my warm greetings to all GSO members and I encourage you to take an active role in the society. I also would like to express my thanks to Oman TV and all the companies and individuals for their generous contribution towards the documentary film on the geology of Oman.

By putting our hands together we can excel the society towards internationalism.

Regards,
Dr. Mahmood Saif Al Mahrooqi
GSO – President

Note from the Editor

Welcome to the July edition of Al Hajar. The theme for this issue is ‘Research in the Sultanate’. The response from those contacted was overwhelming with many high-quality, detailed and richly illustrated articles so much so that we have decided to split the edition into two parts, the second one will follow in September after the summer break. In Part 1 we concentrate on the Ophiolite; how the Oman ophiolite was pivotal in helping establish the character of such features and providing an analogue for other localities; how it has provided the evidence for a new model of flow in mantle melt and how, with an eye on the future, it may be able to help with the storage of CO2 (see Lecture note at end for another upcoming event in the same theme). We also have a summary of papers published last year – a handy reference list to keep abreast of current research in the Sultanate.

As usual we also provide an industry news round-up courtesy of IHS and alongside a detailed piece on current activity in the Bay of Bengal.

As a taster, Part 2 will comprise articles on the Farah Formation, Mesozoic Carbonates, Silicified Wood and the Quaternary Dunes of Ras al Hamra. We'll also provide the winter lecture series and more field trip locations and dates at that time too.

As regards housekeeping, we have listened to your feedback and have simplified the on-line design to enable easier printing. As always, if you have any further comments or suggestions concerning Al Hajar or GSO in general, please do not hesitate to contact me or any one of the ExCom.

I hope you enjoy the read and once again thank you to all of our contributors.

Best regards,

Caroline

Reinhardt's Ophiolite

Prof. Bill Church

2009 is the 40th anniversary of the publication of Ben Reinhardt's classic paper on the oceanic origin of the Oman ophiolite (Reinhardt, 1969), which opened up the way to the finding of sheeted diabased in Newfoundland and to Bob Stevens' 1969 paper on the Oman model as applied to the West Newfoundland ophiolites (Stevens, 1969)- and consequently to a profound revision of the tectonics of the whole Appalachian-Caledonian system. Reinhardt's contribution to geoscience, particularly as it concerns Oman and our early ideas on the development of oceanic crust, is I think vastly underestimated and undervalued.

During the winter of 1961, when I was a Post-Doctoral fellow at Columbia University in New York, Harry Hess came up to Columbia from Princeton to promote his idea that the world's oceans were entirely young, his war time experiences as a submarine commander having convinced him that there were no ‘ancient’ rocks in any of the major ocean basins. Other than my recollection that Maurice Ewing, who ran the Lamont-Doherty Geophysical Observatory of Columbia University, was extremely sceptical of Hess' claim, I equally short-sightedly didn't see much connection between Hess' ideas and the fact of ‘polyphase deformation’ in orogenic belts such as the Caledonides and Appalachians!, my subject of interest at that time.

In 1963, after having moved to the University of Western Ontario in Canada, I travelled to Newfoundland to start a study of polyphase deformation in psammites of the Burlington Peninsula, with a more distant hope that I might also find eclogites similar to those I had found in polydeformed psammites of the ‘orthotectonic’ Moinian of Western Ireland. The ultramafic ‘intrusives’ associated with the overlying lower-grade and less deformed ‘paratectonic’ Baie Verte sequence were only of marginal interest to me. ('Orthotectonic' and 'paratectonic' were buzz words that I borrowed from de Sitter's book on Structural Geology.) I didn't find any eclogites in the summer of 1963, but two years later, I found eclogites at four localities along the Westport and Bear Cove roads. This allowed me at least to justify "a correlation of the Fleur de Lys metamorphism and tectonism of Newfoundland with that of the Moine-Dalradian of the British Isles, thus supporting the concept of Continental Drift".

In 1963 Rodgers and Neale had reinterpreted the Humber Arm Group of Western Newfoundland as two large klippen, thereby bringing to fruition the allochthon concept planted long ago by Logan, and subsequently developed by Ulrich (1902), Ruedeman (1909), Keith (1913), and, in the early 1960's, E-An Zen working in the type area of the Taconic klippen. They drew a detailed stratigraphic and structural analogy between the Newfoundland klippen and the Taconic klippe, and suggested that the Newfoundland klippen were emplaced by gravity sliding from a source to the east of the Long Range. These authors were the first to include the igneous rocks of the Bay of Islands and Hare Bay in the transported rocks, although they assumed that the igneous material intruded the sediments of the Humber Arm, a relationship that had apparently been confirmed by the detailed mapping of Smith (1958).

In 1967 a new element was introduced into the equation by R.K. Stevens, who noted the presence of detrital chromite in Lower Ordovician (Arenig) quartzo-feldspathic fore-basin flysch associated with the allochthons of Western Newfoundland, and this led in turn to the finding of detrital chromite in back-basin sediments overlying the east-facing ophiolitic sequences located along the eastern margin of the eclogite-bearing high grade metamorphic belt (Fleur de Lys Supergroup) of the Burlington Peninsula. This led us to propose that the allochthonous flysch sediments were originally laid down as a carpet in front of the over-riding "allochthonous ophiolites" and their substrate of Cambro-early Ordovician continental margin deposits. We knew therefore that the ophiolites were allochthonous relative to the underlying sediments, which were themselves allochthonous relative to the underlying rift margin sequence, and that they both came from the East; but we were not aware that the easterly source of the ophiolites was the 'Proto-Atlantic' ocean.

In 1968 I met Hugh Davies at the Prague IGCP where we discussed his idea that the allochthonous ophiolites of Papua - New Guinea represented displaced samples of Pacific ocean crust and that the same idea might apply to the Bay of Islands ophiolite, and that same year Ian Gass' paper 'Is the Troodos Massif of Cyprus a fragment of Mesozoic oceanic floor' appeared in Nature. Neither paper contained or tried to mount a persuasive argument in favour of their formation by 'spreading' at an oceanic ridge, or how such oceanic crust might be different from any common garden fractionated ultramafic-mafic intrusion.

Where does Oman fit in? Well, because of my interest in eclogites, and because they were not an unusual rock type in the European Alps, I was in the habit of perusing relatively exotic Swiss and Italian journals for articles on eclogites. In the Spring of 1969 I struck lucky, not with respect to eclogites as it turned out, but because the Swiss journal Schweizerische Petrologische Mineralogische Mitteilung published in February of that year a paper by Shell geologist Ben Reinhardt on the oceanic nature of the Oman ophiolite. Reinhardt described 'sheeted diabases' as a distinctive unit within the ophiolite, and explained their formation in the context of the tensile steady-state formation of oceanic crust. This was the first major geologic contribution (as distinct from a geophysics contribution) to our understanding of the mechanism of sea-floor spreading, and I think the importance of this paper in this respect has been considerably underestimated by the geological fraternity. However it was certainly the impetus that led us to conclude that "The large amount of ultramafic detritus in the Lower and Middle Ordovician sediments of Quebec and Newfoundland indicated that the ultramafic rocks exposed at present are mere remnants of a much larger sheet, perhaps comparable to those of the Circum-Pacific belt or the Oman." Even better!

In the summer of 1969 Bob Stevens and I started mapping along the east coast of the Burlington Peninsula, and saw for the first time the spectacular 'sheeted diabase' unit of the Betts Cove ophiolite. Base on our reading of Reinhardt's paper we immediately recognised that the ophiolites of Newfoundland indeed represented oceanic crust formed at a spreading centre within Wilson's Proto-Atlantic ocean. The allochthonous oceanic origin of the Newfoundland ophiolites thus became fixed as a point of reference for all future tectonic studies of the Appalachians. We did not appreciate at this time that the ophiolites represented spreading centres within the fore-arc portion of an island arc. It would be another four years before Miyashiro would stir up the geological world in this regard.

Forty years on from the publication of Reinhardt's seminal paper it is now possible that even the Fleur de Lys eclogites were formed as boyant ‘core complexes’ in the same manner as the HP rocks of Oman, Papua, Cuba, and elsewhere. Dating of the Papuan and Oman ophiolites (Baldwin et al., 2004, and Warren et al. 2005, respectively), their dynamothermal aureoles, and the exhumed eclogites has shown that the ophiolites were tectonically emplaced shortly after their formation, thus confirming the earlier contention of Church and Stevens (1970) with respect to the Newfoundland ophiolites that the ophiolites may have been “emplaced during the closing of the Appalachian ocean, while the ridge was positioned close to the continental margin or was newly developing within the margin.” Whether the eclogite-bearing Fleur de Lys and Ox Mountain/ Lough Derg rocks, and the Belvedere Mountain (New England Appalachians) terrain also represent random post-obduction “spot extensions”, or whether they are related to periods of more generalized late Taconic or Siluro-Devonian extension and exhumation, remains yet to be argued.

Prof. Bill Church
University of Western Ontario, Canada

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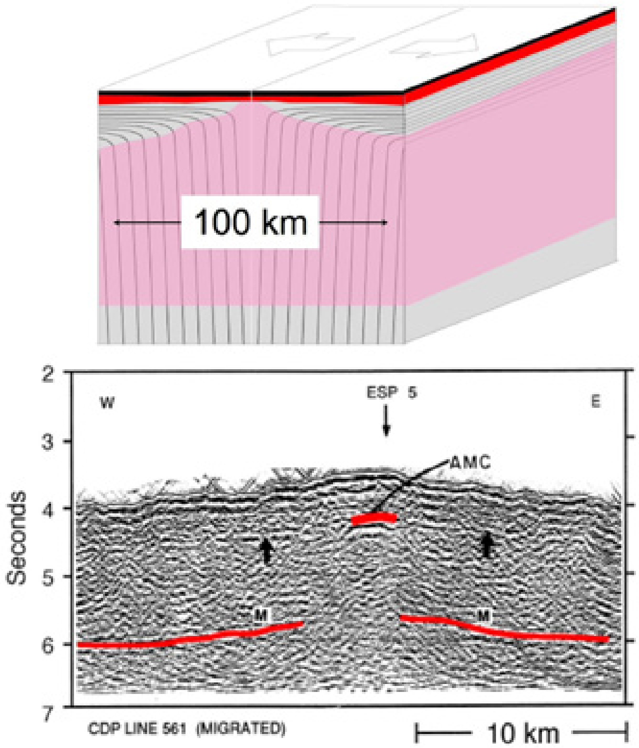
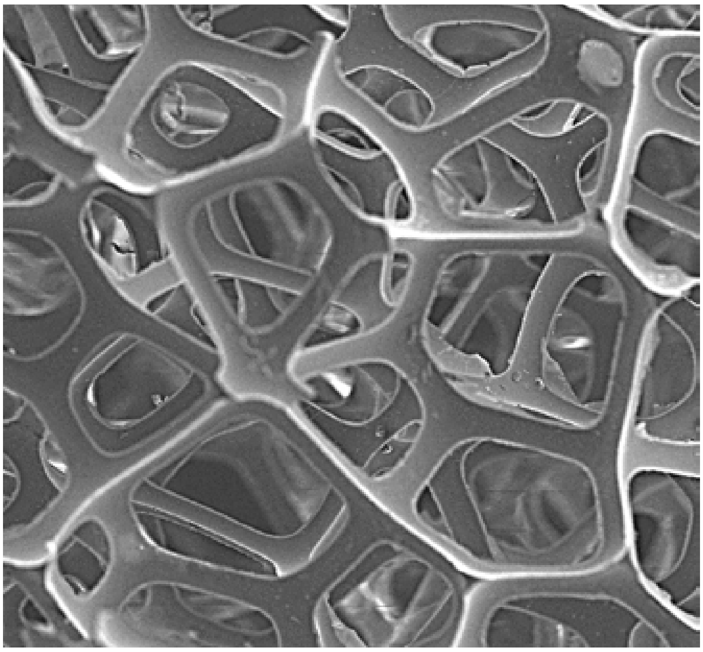
Melt Transport in the Mantle and Formation of Igneous Ocean Crust:
Theories Developed via Observation in the Oman Mountains

Peter Kelemen

At the dawn of the modern theory of plate tectonics in the 1960s, scientists realized that the ~7-kilometer-thick slabs of crust underlying the oceans were created entirely from basaltic lava erupting along chains of seafloor volcanoes known as mid-ocean ridges. Later, the same scientists strove to understand how and where this lava forms within the solid rocks of the mantle beneath. Basic theories suggested that because the oceanic plates pull apart at the volcanic ridges, new material must rise to fill the gap. As it rises, partial melting of the Earth's mantle will occur, and the resulting basaltic melts rise still higher to form the oceanic crust. The melting process occurs over a range of pressures and depths. The compositions of lavas erupted on the seafloor preserve the compositions of melts formed over a range of depths from more than 100 km to less than 10 km, recording an average depth of about 40 kilometers.



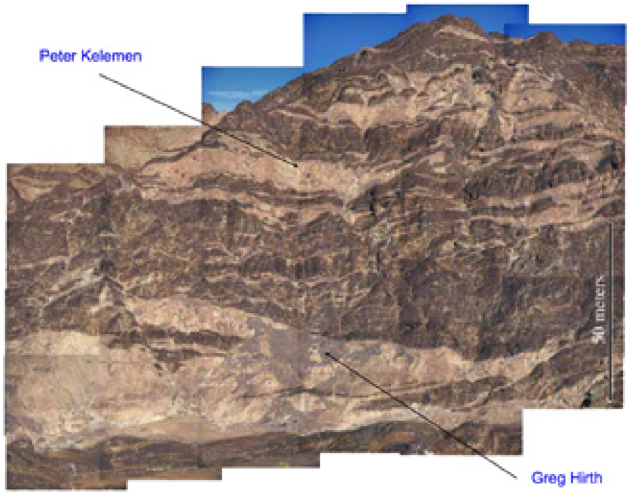
Top: schematic image of mantle flow (thin black lines in grey mantle rocks) and melting region (pink) beneath an oceanic spreading ridge. The melting region, pink region extends for 100's of km laterally on either side of the ridge, beyond the edge of the diagram, and melt forms in micron-scale pores (Top right) throughout that region, igneous oceanic crust (red and black) forms from volcanism that is almost entirely confined to a very narrow region around the spreading ridge. Bottom: Figure from Vera et al., Journal of Geophysical Research, 1989, showing a seismic reflection image of the East Pacific Rise oceanic spreading ridge, showing a shallow "axial magma chamber" (AMC) and the crust-mantle boundary (M). These are the kind of data that reveal that the igneous rust reaches >95% of its future thickness within a few km of the spreading ridge, despite the fact that it is fed by porous flow of melt in a region of upwelling mantle that is hundreds of kilometers wide.



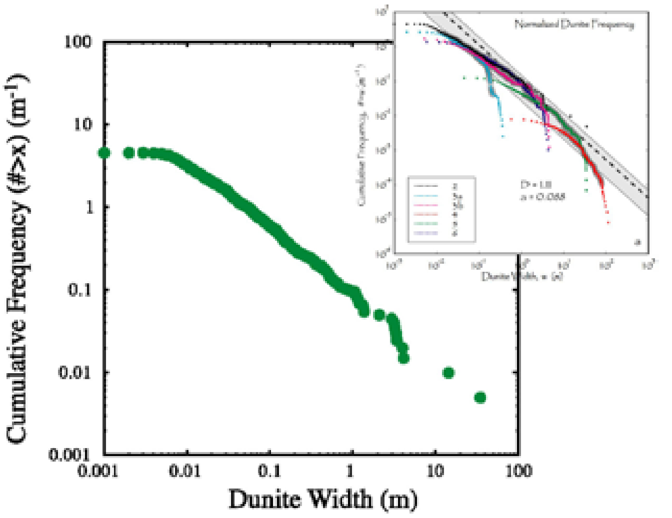
Partial melt forming in the mantle occupies crystal edges in a network resembling this one formed by volcanic glass and gas bubbles. In the mantle, melt pores would be a few microns (millionths of a meter) in width. (See Wark et al., Journal of Geophysical Research 2003, for an extensive discussion). Remarkably, melt forming over a region hundreds of kilometers wide flows through these tiny pores, and somehow aggregates to form 7 km thick oceanic crust at oceanic spreading ridges, in a narrow zone just a few kilometers wide.

To explain how this happens, scientists have come up with step-by-step hypotheses describing the formation of the ocean crust–some 70 percent of the Earth's surface. The largest exposed thrust block of oceanic crust and upper mantle underlies most of the mountains of northern Oman, stretching from Ibra past Sohar and Wadi Jizi into the UAE. Field observations in Oman have played a key role in deciphering the plumbing system that feeds seafloor volcanoes at mid-ocean ridges, in what Harvard geologist Charlie Langmuir calls "the Rosetta Stone of igneous processes". The process turns out to be quite different from the layman's view of massive chunks of mantle rock melting, filling enormous chambers and then raging toward the seafloor along jagged cracks. Instead, the system is much more like river systems on the planet's surface, which in turn implies that all fluid flow in natural systems may follow the same basic rules of physics.

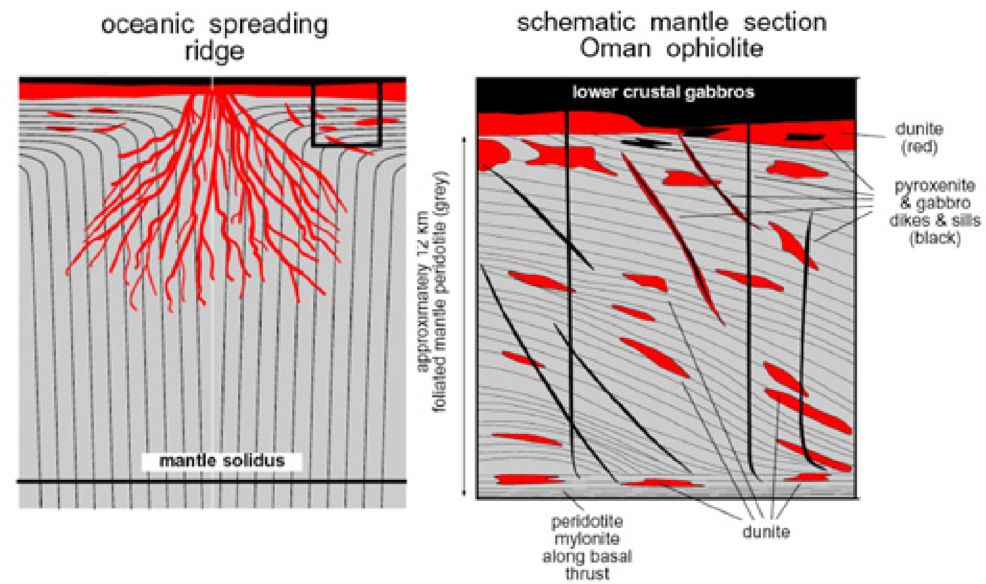
The process starts with melting of the mantle, beginning some 100 kilometers beneath the seafloor. Melt forms in microscopic pores along the boundaries of individual crystals, as though the rocks were sweat-



Conduits of focused porous flow of melt through mantle peridotites (composed of the minerals olivine and pyroxene) become dunites, composed only of the mineral olivine, because rising melt dissolves pyroxenes and precipitates some additional olivine. Small conduits coalesce to form larger ones. This image is a photomosaic from the Muscat massif in the Oman ophiolite, showing tan dunites hosted by brown mantle peridotites. Figure from Braun & Kelemen, G-cubed 2002.



Measurements of dunites within residual mantle peridotite in the Ingalls ophiolite (Kelemen et al., G-cubed 2000) and the Oman ophiolite (Braun & Kelemen, G-cubed 2002) demonstrate that dunites show a power law relationship between width and frequency, as predicted for a coalescing channel network. This result does not prove that dunites do form a coalescing network, but it is certainly consistent with that idea, and confirms a central prediction of our hypothesis. River systems form similar coalescing networks.



Mantle peridotite in grey, with thin black lines indicating trend of foliation in peridotites, dunites in red, gabbro and pyroxenite in black. Summary of observations in Oman (right) and interpretation (left). Foliation in mantle peridotites (approximately parallel to solid flow lines) is generally parallel to the base of the igneous crust, and to the paleo-seafloor. This is interpreted as the result of corner flow in the rising mantle beneath a spreading ridge and then spreading outward beneath newly formed oceanic crust. Black gabbro and pyroxenite dikes cut the mantle foliation, and so must have formed off axis; they cannot be the conduits for chemically isolated transport of melt from the upwerlling mantle at an average depth of 40 kilometers to feed seafloor volcanoes. Red dunites were deformed along with host peridotites, and thus formed in the upwerlling mantle beneath a spreading ridge, prior to corner flow rotation. Their chemical characteristics indicate that dunites were conduits for chemically isolated flow of melt from an average depth of about 40 km in the decompressing, partially melting mantle beneath the spreading ridge. Informed by geochemical observations, field measurements, and theory, we construct the hypothetical dunite network in the left hand diagram, with many coalescing dunite channels converging upward toward an oceanic spreading ridge. Because the dunites form about half way up the ~ 100 km tall melting region, they preserve melt compositions in equilibrium with peridotite at an average depth of ~ 40 km.

ing. This "sweating" occurs within widespread regions of the mantle about 100 kilometers wide and about as thick. However, the melt is somehow focused into only a five-kilometer-wide zone at a depth of 7 kilometers beneath the mid-ocean ridges, where the entire section of new oceanic crust is formed, and massive lava flows emerge. These observations introduced two perplexing questions: How does the lava get channeled from tiny pores in a broad region of melting into such a narrow region of volcanism on the seafloor? And how does melt rise through tens of kilometers of overlying rock while preserving the composition of melts formed at greater depth?

A simple answer to the second question, extensively developed by Prof. Adolphe Nicolas at the Université de Montpellier and his colleagues, was that melt rises in cracks, and moves so rapidly that it does not have time to equilibrate with its surroundings during ascent. Because melt is less dense than the mantle rocks in which it forms, it was proposed that the buoyancy of melt might drive fracturing. This explained many observations, and must be valid in some circumstances. However, at the high temperature and pressure of the partially melting mantle, solid rocks can flow plastically in response to small, local pressure increases due to melt buoyancy, making it difficult to crack the rocks. Imagine pushing on peanut butter – it is difficult to cause peanut butter to crack, because instead it flows out of the way; the harder you push, the faster it flows.

As a result, my colleagues and I began to develop an alternative hypothesis, in which melt in the upwelling mantle beneath ridges is transported by focused, porous flow of melt. Where collisions between tectonic plates have thrust rocks from the oceanic mantle to the surface, as in the mountains of northern Oman, geologists observe dunite veins, composed almost entirely of the mineral olivine. The nature of contacts between dunites and host rocks indicates that most or all dunites replaced the surrounding rocks. Melt moving by porous flow through the mantle dissolved some minerals and precipitated olivine. About ten years ago, we measured mineral compositions in Oman dunites, and found that they were in equilibrium with melts formed at great depth, whereas the surrounding mantle rocks recorded melting processes at much shallower depths. From field evidence, it was evident that the dunites were conduits for porous flow of melt that formed at depth, through the shallow mantle to the surface.

Outcrop of sheeted dikes in the Oman ophiolite near Wadi Jizi, formed about 1 km below seafloor volcanoes. Eruptions are fed by these dikes, which intrude each other as the new seafloor forms and spreads apart. John Delaney likes to call these dikes the "quantum event" of oceanic crustal formation.

Systematic light and dark colored mineral layering in igneous rocks forming the lower oceanic crust in Oman, near the village of Samrah, not far from the Muscat-Ibra highway. These periodic features are probably the result of a magmatic system in which crystallization of melt in pore space forms barriers to porous flow. Beneath these barriers, melt accumulates at increasing pressure in a kind of "melt lens". Eventually, the balloon pops, sending a dike upward toward the seafloor. The sudden change of pressure in the lens changes the proportions of minerals crystallizing from the melt, causing the layering.

Melts rising through the hot mantle will partially dissolve minerals around them. This can gradually enlarge the pores at the edges of solid crystals, creating a more favorable pathway through which melt can flow, in a positive feedback mechanism that quickly forms elongate, high porosity channels. In turn, similar feedbacks drive the coalescence of several small channels to form larger ones. Once dunites become more than about one meter wide, they are big enough to preserve chemical disequilibrium between melt flowing within them, and minerals in the surrounding rock. Maps and statistical studies of the dunite networks exposed in Oman show that they have characteristics similar to a coalescing river network, and that there are enough large dunites to explain the formation of the oceanic crust via porous flow of melt through these features (see page 7).

However, as always, one answer leads to new questions. If melt flows through the mantle in tiny pores along the boundaries of crystal grains, where does it accumulate to form massive lava flows at spreading ridges? And, if porous flow is a continuous, gradual process, what causes periodic eruptions of lava on the seafloor?

Again, field geology in Oman guided our intuition, and Adolphe Nicolas led the way. In a large outcrop of oceanic crust and mantle in the Sultanate of Oman, exposed during the ongoing collision of the Arabian and Eurasian plates, Nicolas and his colleague Françoise Boudier showed that melt accumulated in lenses, a few meters to tens of meters high and tens to hundreds of meters wide, within the shallowest part of the mantle, just below the base of the oceanic crust. We infer that porous flow is partially blocked at these shallow depths by crystallization of cooling melt in pore space. Due to cooling by conduction to the overlying seafloor, the overlying rocks are also too stiff to allow viscous relaxation of the pressures induced by melt buoyancy. Under these circumstances, the constant, gradual porous influx of melt from below is blocked, melt lenses form, and melt pressure rises. As a result, like a metronome, the overlying rocks periodically crack to form dikes that feed oceanic crust and sometimes erupt as lava flows on the seafloor (page 8, Top). We've proposed that another regular, periodic feature of oceanic crust exposed in Oman, repeated layers of light and dark colored minerals in layered gabbro rocks that crystallized below the seafloor to form the lower crust, also form as a result of periodic pressure rise and release in sub-surface melt lenses (page 8, Lower). Thus, this diking process – that University of Washington oceanographer John Delaney calls "the quantum event of oceanic crust formation" – is driven by the transition from dissolution and porous flow in the hot mantle at depth, to precipitation and fracture flow through the cold rocks near the seafloor.

Conveniently, all of these steps going on in the mantle can be explained using the more familiar analogy of water flowing on the earth's surface. Consider water flowing over a sandy beach. Where the slope is steep enough, moving water begins to form channels. As the channels grow, water flows faster, leading to more vigorous erosion of sand at the leading edge of the flow. When the slope decreases downstream, the water begins to deposit sand grains that it was carrying. The deposited grains construct barriers that block flow and force the water to diverge away from the main channel, creating a branching effect (see figure right). Water accumulates behind the barriers, but these temporary lakes periodically overflow the old channel and create new pathways, which in turn are clogged and abandoned. Analogous processes occur beneath the seafloor as rising melt cools, forms crystals that block pore spaces, causes flow to diverge and accumulate, and periodically bursts through these barriers to form fractures that give the melt a new conduit to the seafloor.

The similarities between chemical erosion forming coalescing melt transport conduits in the mantle, and mechanical erosion forming converging stream channels on the surface, suggest to me that there are fundamental physical limits that govern the evolution of both types of focused transport networks. Similarly, the structures formed by precipitation of minerals in pore space are similar in a fundamental way to those formed by deposition of sand grains in a river delta. In both cases, only one or two channels is active at a given time, they gradually become blocked with material transported by the moving fluid, and then they rapidly – sometimes catastrophically – cut a new channel. Because of the limitations of my training, I've concluded that I will not be able to elucidate the underlying, quantitative principles governing the geomorphology of fluid transport networks during my career, so I always end talks on this subject with an appeal to the younger generation: here is a fundamental problem in Earth Science, waiting for you to solve it.

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Sapping channels form on beaches when the tide goes out below the level of the ground water table in the sand. At this point, ground water comes to the surface, and flows down the beach. In some places, these beautiful and very simple channel networks form twice a day. In the upper part of this photo, channels are being eroded by flowing water emerging on the beach. As inferred for dunite channel networks in the mantle, the newly formed beach drainage network contains many small channels coalescing to form a few large ones. All of the channels are active at once, and flow rates are fairly constant. In the lower part of the photo, a decrease in the slope is causing sand to be deposited in fans, as in a river delta. Over time, this forms a diverging structure that seems symmetrical to the erosional channels above, but at any given time, there is only one active channel in each fan. As the active channel fills with sediment, there are sudden discontinuous changes in the position and flow rate of the outflow channel. This is very analogous to the formation of dunites and melt lenses in the upper part of the volcanic plumbing system at mid-ocean ridges, where crystallizing melt forms barriers to flow that are periodically breached by dikes.

Mineral Carbonation in Peridotite

for CO2 Capture and Storage (CCS) in the Context of other CCS Techniques

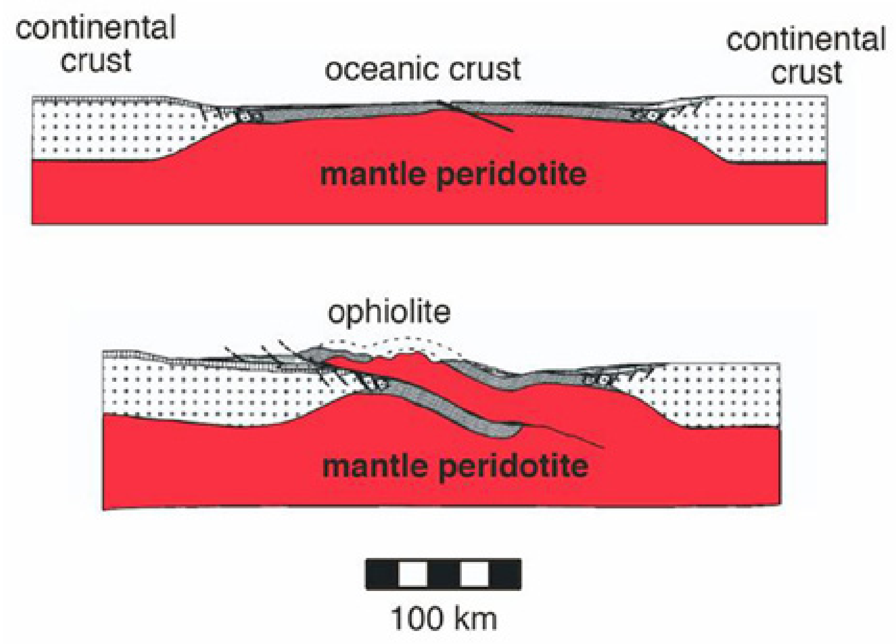
Peter Kelemen, Jürg Matter and Dr.Salim Al-Busaidi

In a recent paper in the Proceedings of the (US) National Academy of Sciences, we proposed that a common rock type in Oman could be used to react with carbon dioxide (CO2) dissolved in water to capture and store CO2 in solid, inert, stable carbonate minerals. This is desirable because human emissions to the atmosphere have led to concentrations of CO2 higher than any time since human beings appeared on the planet, causing chemical changes such as acidification of the oceans and contributing to climate change, particularly global warming. At the same time, power plants and vehicles burning fossil fuels - and emitting CO2 - are a vital part of the 21st century economy. By speeding up natural processes, we suggested that rocks from the Earth's deep interior, exposed on the surface by plate tectonics and erosion, may be able to capture and store billions of tons of CO2 per year. Compare this to the total human output of CO2 to the atmosphere, currently about 30 billion tons of CO2 per year, and you can see that this could make a significant difference in the overall CO2 budget of the planet.

Since 1990, scientists and engineers have considered using naturally occurring minerals that react with CO2 to form different, carbonate minerals, as a means to capture CO2 from the atmosphere and store it in solid form where it will remain stable and inert for thousands or millions of years (Seifritz, Nature 1990). Since then, the mineral olivine (Mg2SiO4) has been the focus of the most research. Olivine forms the carbonate mineral magnesite via reactions such as Mg2SiO4 (olivine) + 2 CO2 (from gas or fluid) = 2MgCO3 (magnesite) + SiO2 (quartz)

Olivine is abundant, has more magnesium than silicon, and reacts readily because it is far from equilibrium with the atmosphere and surface waters. For these reasons, olivine is particularly efficient for forming solid carbonate minerals.

Olivine forms 60 to 80% of the Earth's upper mantle, which in turn comprises about ¼ of the Earth. However, mantle rocks are ordinarily shielded from reaction with the atmosphere and surface waters by a shell of continental crust, 40 km thick, or oceanic crust 7 km thick. Collisions of tectonic plates cause mantle rocks to be thrust onto the continents, where they are later exposed by erosion in mountain belts. The world's largest exposures of olivine-rich mantle rocks are in the Sultanate of Oman, New Caledonia (Nouvelle Caledonie), Papua New Guinea, and the Baltic countries. In North America, some large deposits occur in northern California, southern Oregon, Montana and eastern Canada (See figure below).



About 25% of the Earth is the upper mantle, composed of a rock called peridotite which in turn is composed of 60 to 80% of the mineral olivine; mantle peridotite is far from equilibrium with the atmosphere and surface waters. Normally, the mantle is separated from the atmosphere and surface water by ~ 7 km of oceanic crust, or ~ 40 km of continental crust, but where continental plates collide, mantle peridotite is exposed on the Earth's surface and reacts readily with air and water. The mountains of northern Oman are composed largely of one such slice of oceanic crust and mantle, thrust onto the Arabian continental platform from 95 to 70 million years ago. Diagram redrawn after Coleman, 1971.

Initially, engineers focused on using olivine to capture and store CO2 via "ex situ" methods. Olivine-rich rocks were to be quarried, transported to power plants, ground to a fine powder, and mixed with water plus purified CO2 in reaction vessels at high pressure and temperature. These methods for

Ground water, modified by reaction with peridotite, returns to the surface in alkaline springs, rich in Calcium and almost completely devoid of CO2. On the surface, these alkaline waters combine with atmospheric CO2 to form carbonate deposits, like this travertine terrace near Nizwa.

olivine carbonation "at the smokestack" have proved to be relatively expensive, in both financial and energy terms, though engineers continue to seek methods to improve their efficiency (Mazzotti et al., Chapter 7, in Metz et al., IPCC Special Report on Carbon Dioxide Capture and Storage, 2005). Meanwhile, most proposed CO2 capture and storage methods rely on injection of pure CO2 in dense, supercritical liquid form into pore space in subsurface rocks, or even into "puddles" of dense CO2 on the seafloor. There, scientists hope, the supercritical CO2 will stay.

There is an incentive to look for alternatives to storing supercritical CO2 liquid in pore space, since storage of CO2 in inert, solid carbonate minerals could be safer, and easier to monitor and verify, than storage in pore space. Thus, over the past decade some scientists have focused on "in situ" mineral carbonation, leaving rocks in the ground and using methods such as injection of CO2 to increase reaction rates. Much of this work has been on carbonation of an abundant type of lava, basalt, which contains minor amounts of olivine together with large proportions of alumino-silicate minerals such as plagioclase feldspar. At optimal conditions, plagioclase carbonation is hundreds of times slower than carbonation of olivine, but basalt is abundant near many large power plants (e.g., Goldberg et al Proc. Nat. Acad. Sci. 2008). The idea is to pump CO2 into pore space in basaltic lava, with the expectation that over decades the CO2 will combine with olivine and plagioclase to produce solid carbonate minerals

Recently, we turned our attention to in situ carbonation of rocks rich in olivine (Kelemen & Matter, Proc. Nat. Acad. Sci. 2008). Such rocks are abundant where collisions of the Earth's tectonic plates have thrust rocks from the mantle to the surface; the largest such thrust slice forms much of the mountains of northern Oman, stretching from Ibra northwestward past Sohar and into the UAE. As we started our project, we were lucky enough to make two key observations. First, natural carbonation of olivine proceeds much more rapidly than geologists had previously guessed. In Oman, our samples of solid carbonate terraces ("travertine") forming from spring water emanating from mantle rocks (figure left), and of carbonate veins that formed within mantle rocks beneath the surface (figure above) and were later exposed by erosion, have an average age of about 25 thousand years, dated using the 14C method, whereas scientists in the past guessed that the veins were 95 to 40 million years old. Second,

Magnesium carbonate veins (light colors) formed in sub-surface peridotite (darker blocks, in lower part of the photo, with pencil for scale) as a result of reaction of ground water with the peridotite. Precipitation of these veins causes the CO2 concentration in the water to drop to almost zero, while Calcium concentration rises. Waters pass upward from these veins to form the alkaline springs shown in Figure top left, and precipitate Calcium carbonate terraces, known as travertine, on the surface, and in the top half of this photo, of an outcrop south of Nizwa, near the village of Jill.

we found that the olivine carbonation process can be "self-heating". Carbonation of olivine gives off thermal energy - basically because it involves condensation of CO_2 gas or liquid to form CO_2-bearing solids. If the carbonation reaction is fast enough, the evolved heat can offset cooling due to diffusion from hot rocks into their cold surroundings, and cooling due to flow of cold fluid through the rocks. At elevated pressure, about one kilometer below the Earth's surface, the carbonation reaction goes fastest at about 185°C. Under such conditions, the rock volume could become "self-heating". We calculated that cold CO_2-bearing fluid can be pumped into the rocks at about 4 centimeters per second without cooling the rocks and slowing the reaction. Thus, we propose that one method of speeding up olivine carbonation would be to "jump start" the process by drilling, fracturing, and heating a rock volume at depth to about 185°C, and then pumping purified CO_2 plus water, at surface temperature, into that heated rock volume. Energy emitted by the carbonation process would heat the cold fluid to 185°C, maintaining the rock volume at the optimal temperature for rapid reaction. Such a process would convert billions of tons of CO_2 into solid carbonate minerals per cubic kilometer of rock per year.

Such an in situ process might be less expensive than ex situ olivine carbonation, "at the smokestack", for several reasons. First, it avoids the cost of quarrying, transporting and grinding rock reactants. Once a rock volume is heated, the energy to sustain high temperature at depth would be provided by the carbonation reaction itself. Sustained pressure would be provided, to some extent, by the presence of overlying rocks. It is likely to be about the same cost as injecting CO_2 into underground pore space, since the technology for drilling, and pumping CO_2-water mixtures, is approximately the same for both methods. However, the cost of most CO_2 capture and storage methods is dominated by the process of CO_2 capture at power plants, and this proposal is no exception. Further, a globally important process of this type would involve transportation of really large amounts of CO_2, comparable to the amounts of oil, gas and coal currently being consumed.

Thus, in addition, we are beginning to consider an alternative possibility. In its pure end-member, it goes like this: Perhaps shallow seawater, rather than purified CO_2, could be used as a fluid to transport CO_2 into a volume of mantle rocks at depth. Shallow seawater maintains CO_2 exchange equilibrium with the atmosphere, so this would avoid the costs of industrial CO_2 capture and transport. As one goes deeper in the Earth, the rocks get hotter, so perhaps one could simply drill into rocks at about 185°C, rather than pre-heating a rock volume. Pumping might not be needed, since thermal convection might drive cold water to circulate down one hole, following hot water emerging from another. This end-member process using seawater would be thousands of times less efficient, in terms of kilograms of olivine transformed to solid carbonate per cubic kilometer of rock per year, than one using purified CO_2. However, in addition to CO_2 capture and transport, this simple end-member process would avoid the costs of preheating a rock volume, and pumping fluid at high pressure. If drilling holes and fracturing rocks at depth is 50 times less expensive than CO_2 capture and transport, then this end-member process could really stand out, as not only safer and easier to verify, but also less expensive than many alternatives. Certainly, this epitomizes the philosophy with which we began our project: Understand the processes of natural olivine carbonation, and then take only the minimum steps, doing as little as possible", to accelerate these processes so that they can consume globally significant quantities of atmospheric CO_2.

Dr. Salim Al-Busaidi, Director General of Minerals, in the Ministry of Commerce and Industry, is leading a group considering the first ever pilot experiment on this process, to be conducted in Oman. This would be a step-by-step process, with careful site selection followed by characterization of the sub-surface rock properties and evaluation of environmental impacts. It is important to find a location where olivine-rich rocks are abundant in the sub-surface, overlain by a "cap rock" of impermeable sediment. If all goes well, heating of a rock volume, followed by injection of CO_2 or seawater, might take place in about four years.

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Sultanate of Oman

Geoscience Publications 2008

John F. Aitken

Listed below are peer reviewed geoscience publications from 2008 concerning the Sultanate of Oman and from neighbouring countries that have a direct relevance to the Sultanate. General reviews and summaries, articles in trade publications and published conference abstracts are not included. Any omissions, corrections or additions will be gratefully received and should be sent to the compiler or through the GSO editor.

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John F. Aitken
Petroleum Development Oman

The Bay of Bengal

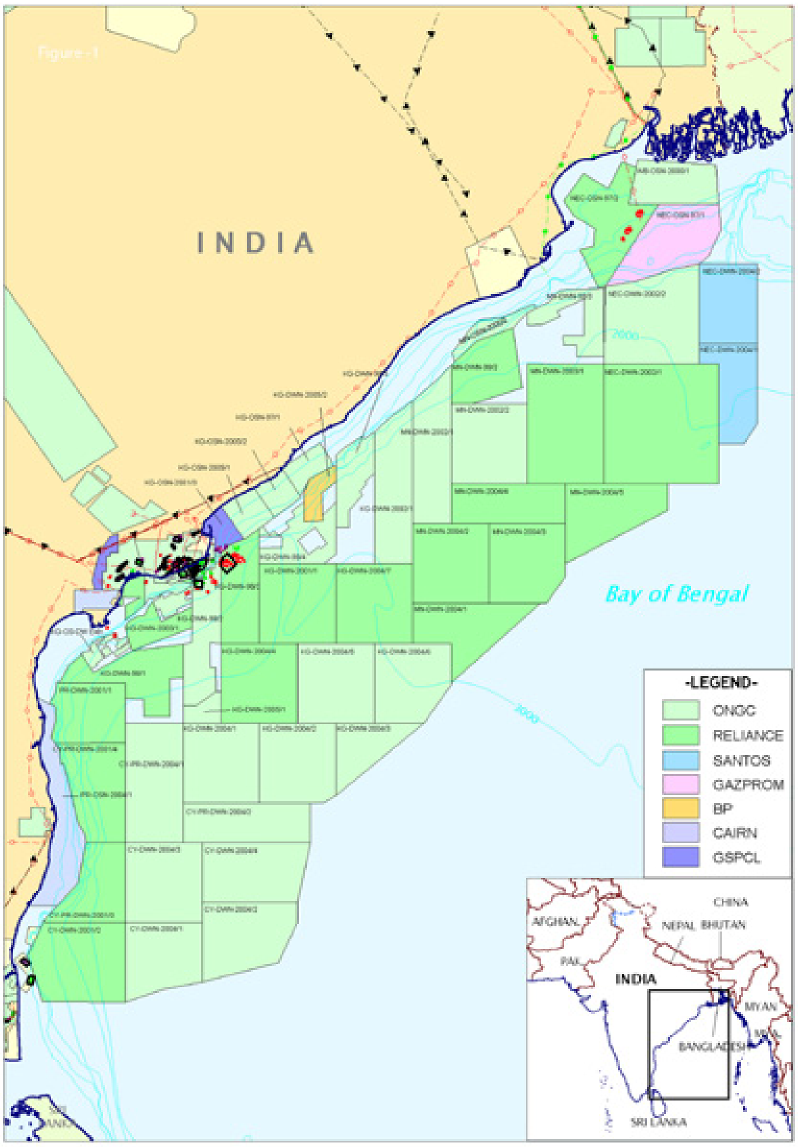
Ian Blakeley

A New Lifeline for South Asia?

Largely ignored by the international oil and gas community until the turn of the decade, the Bay of Bengal now finds itself to be an increasingly hot play as the ongoing search to discover offshore hydrocarbons gathers pace and regional energy security issues rise. The Bay of Bengal is a sweeping body of water in the north eastern part of the Indian Ocean and is effectively flanked by the vastly populated and energy starved countries of India, Bangladesh and Myanmar - each of which is pursuing its own path in an attempt to address its energy security concerns.

Having embarked on a programme to dramatically overhaul its hydrocarbon sector in the late 1990s through the New Exploration Licensing Policy (NELP), India now has more than 60 offshore exploration blocks under licence along its East Coast (Figure 1) and the country has been rewarded with a number of significant gas discoveries which threaten to transform the county's energy landscape.

Figure -1

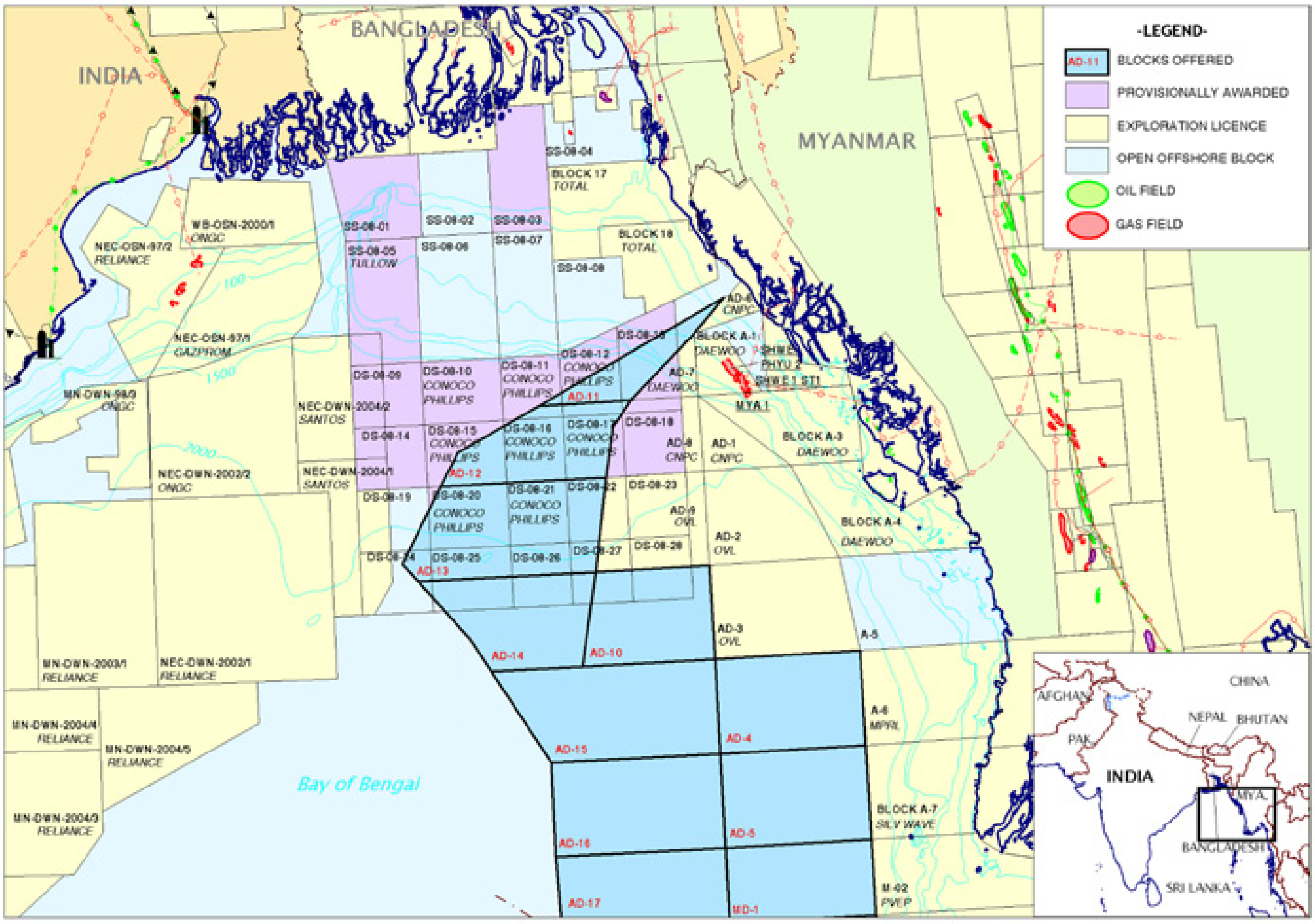


Although Cairn Energy was responsible for a number of small discoveries on the KG-DWN-98/2 deep water block in 2001 (Figure 1) prior to transferring operatorship of the acreage to ONGC as part of a wider asset swap, it was not until 2002 that the hydrocarbon potential of the Krishna-Godavari Basin finally caught the attention of some of the leading global energy players - India's largest private sector E&P company, Reliance Industries Ltd (RIL), being responsible for the world's largest gas discovery during the year.

Having discovered an in-place resource of 10 Tcf with its D6-A-1 (Dhirubhai 1) (Figure 1) well on the adjacent KG-DWN-98/3 (D6) deep water block, the company has been rewarded with further success from Pliocene-Miocene reservoirs in recent years - the in-place resource of the block currently standing at a hugely impressive 25 Tcf. With legal wrangles between the two Ambani brothers (owners of Reliance) having been resolved, gas production is expected to commence in March 2009 and facilities have been enhanced / re-designed from what was originally envisaged to accommodate the production of 2.8 Bcf/d within the first year of operations, which will effectively double India's current indigenous gas production. The Field Development Plan also provides flexibility in the critical portions of the facilities to allow for the production of up to 4.2 Bcf/d, which will radically change the domestic energy scenario if realised.

Not content with discovering a huge gas resource in the Krishna-Godavari

Figure -2



Basin, Reliance has also been responsible for finding an additional 3 Tcf in eight discoveries on its NEC-OSN-97/2 (NEC-25) shallow water block off the coast of Orissa (Figure 1), which it intends to bring onstream in 2012.

The reputation of the Krishna-Godavari Basin was further enhanced by Gujarat State Petroleum Corporation Ltd (GSPCL) in 2005 following its KG-8 (Deen Dayal) discovery on the KG-OSN-2001/3 shallow water block (Figure 1). Although wild announcements were made at the time declaring the well had discovered an in-place resource of 20 Tcf, a more realistic estimate of 3-4 Tcf has subsequently been assigned to the six discoveries that have been made on the acreage to date from Lower and Upper Cretaceous reservoirs.

Nevertheless, the success that Reliance, GSPCL, Cairn Energy and ONGC have had in exploring the East Coast of the country cannot be disputed and has resulted in an estimated in-place resource of over 40 Tcf, with significant upside expected from both the Krishna-Godavari Basin and Mahanadi Basin over the next few years. Reliance, in particular, has high expectations from its KG-DWN-2001/1 (D9) and MN-DWN-2003/1 (D4) deep water blocks, whilst ONGC is hopeful of increasing the in-place resource of its KG-DWN-98/2 and KG-OS-DW-IV deep water blocks from 6.5 Tcf through a committed appraisal programme - production from which is expected to commence in 2013.

Although much of the acreage under licence on the East Coast has been awarded to the two dominant upstream players, Reliance and ONGC, there are a handful of international E&P companies who have secured a position on the back of licensing rounds under the NELP. Gazprom was awarded the NEC-OSN-97/1 shallow water block from the First Round in 2000 and although the company has drilled two unsuccessful wells on the acreage, a 2D seismic programme is currently underway prior to the drilling of a third well later in the year. Santos, who was awarded the NEC-DWN-2004/1 and NEC-DWN-2004/2 deep water blocks from the Sixth Round in 2007, has recently completed the acquisition of both 2D and 3D seismic over the acreage, whilst BP was awarded the KG-DWN-2005/2 deep water block in the recently concluded Seventh Round.

It is worth noting, however, that several international E&P companies have gained a foothold on the East Coast through a number of farm-in deals and asset swaps conducted with ONGC in recent years.

Eni has acquired a stake in the MN-DWN-2002/1 deep water block, whilst BG has acquired a stake in both the KG-DWN-98/4 and MN-DWN-2002/2 deep water blocks. StatoilHydro and Petrobras have both acquired a stake in the KG-DWN-98/2 deep water block – Petrobras also picking-up equity in the MN-DWN-98/3 and CY-DWN-2001/1 deep water blocks, with Norwegian independent Rocksource recently acquiring a stake in the latter.

Whilst India appears to be making significant headway in its exploration efforts in the Bay of Bengal, what of its neighbour Bangladesh – home to the Bengal Fan, the largest fluvio-deltaic-slope fan complex in the world? With the country's current supply capacity insufficient to meet the projected growth in demand and new natural gas developments desperately needed to keep pace with the country's growth, the Bangladesh Government finally launched its long-awaited Third Licensing Round in February 2008 – a total of 28 offshore blocks (20 deep water, 8 shallow water) extending up to 200 nautical miles into the Bay of Bengal being offered for competitive bidding.

Although eight deep water blocks in the Central Bay Area and one shallow water block alongside the Bangladesh-India maritime boundary were recommended for award to ConocoPhillips and Tullow respectively (Figure 2), it remains uncertain whether the Ministry of Energy & Mineral Resources will finalise the signing of the Production Sharing Contracts (PSCs) and conclude the bid round as an interim government was in power at the time (elections only being held in December) and maritime boundary issues with both India and Myanmar remain unresolved. Although several high-level ministerial talks with India over the demarcation of the maritime boundary between the two countries have been held, there has been no definitive outcome and the matter may have to be resolved by the United Nations Convention on the Law of the Sea (UNCLOS).

The only Promotional Roadshow to market the Third Licensing Round was held in Dhaka and was attended by 28 international E&P companies including BP, Cairn Energy (Capricorn Energy), Chevron, CNOOC, ConocoPhillips, Nippon Oil Exploration, ONGC Videsh Ltd (OVL), Pearl Energy (Mubadala Development Company), Santos, StatoilHydro, Total and Tullow.

Exploration in Bangladesh has been relatively stagnant in recent years – international E&P companies effectively placing a moratorium on such in the late 1990s pending the development of a local gas market and a decision by the Bangladesh Government on the politically sensitive issue of gas export to India. The Bangladesh Government has long been reluctant to come up with a policy on gas export, choosing not to commit itself to gas supply contracts whilst reserve estimates remain uncertain, and a decision was subsequently made to retain the current gas reserve for domestic use and help combat the rising gas demand of the country.

Bangladesh has only one producing field in the Bay of Bengal – the Sangu Field operated by Cairn Energy (Capricorn Energy), which is on decline and producing just 55 MMcf/d. The offshore, however, remains a vastly under-explored landscape – the country having witnessed the drilling of only 15 new field wildcats in an offshore area spreading 63,000 sq km. Cairn Energy (Capricorn Energy) and recent joint venture partner Santos were responsible for the drilling of two multi-Tcf prospects (Magnama 3.5 Tcf, Hatia 1.5 Tcf) surrounding the Sangu Field in late 2007 / early 2008 – both of which were disappointing and require further evaluation / appraisal. The Magnama 1 well encountered a number of thin, normally pressured gas bearing sands (20-40m), which may thicken on the flanks of the structure, whilst the Hatia 1 well encountered non-commercial volumes of hydrocarbons – the well being suspended pending possible re-entry, with consideration being given to evaluating the up-dip potential. As such, it is understood that a 3D appraisal seismic programme will be undertaken over both structures later in the year.

The entry of Santos into Bangladesh represents a further step in its Asian growth strategy and follows on from its recent entry into India – the company having been awarded the NEC-DWN-2004/1 and NEC-DWN-2004/2 deep water blocks alongside the Bangladesh-India maritime boundary from the Sixth Round of the NELP in 2007.

Focus on the country's offshore has not only been stimulated by the success of E&P companies along the East Coast of India, but also by Daewoo Petroleum's recent gas discoveries in offshore Myanmar. Whilst a number of exploration campaigns were conducted in the area in the 1970s, it was Daewoo who unlocked the potential of the Rakhine Basin when it introduced the concept of a deep marine turbidite play – an initiative that resulted in the Shwe (2003) and Shwe Phyu (2005) discoveries on Block A-1 and the Mya (2006) discovery on Block A-3. The in-place resource of the Shwe structure is estimated to be 3.5 - 5.5 Tcf – the northern and smaller Shwe Phyu structure having an in-place resource of 0.5 - 1.2 Tcf, with the southern Mya structure having an in-place resource of 1.8 - 3.4 Tcf. The company is continuing to explore both Block A-1 and Block A-3 with mixed results

(Figure 2).

As a result of Daewoo's success in opening-up the Rakhine Basin, virtually all offshore western Myanmar is now under licence to international E&P companies – the most prominent of which are CNOOC, CNPC, Daewoo Petroleum, Essar Oil and ONGC Videsh Ltd (OVL).

As with India, however, talks on the demarcation of the maritime boundary between the two countries have been held with no definitive outcome – the situation first coming to light in November 2005 when the Myanmar Government offered five new deep water blocks to the west of the Shwe discovery into what Bangladesh claimed to be its territorial waters (AD-6, AD-7, AD-8, AD-9 and AD-10). To complicate the issue further, an additional eight deep water blocks lying further to the west were offered in March 2008 – four of which (AD-11, AD-12, AD-13 and AD-14) overlapped the deep water acreage being offered by the Bangladesh Government at the time – and the matter was brought to head towards the end of the year following a naval confrontation between the two countries as Myanmar commenced exploratory activities in the disputed area.

Despite its proximity to some of the fastest growing economies in the world, establishing a market for the gas has not proved straightforward. Both India and China have been vying for exclusive rights to the gas – Indian companies GAIL (India) Ltd and ONGC Videsh Ltd (OVL) both holding equity in Block A-1 and Block A-3. It appears, however, that the Chinese have ultimately been successful in securing access to such by pipeline.

Whilst it is clear to see the hydrocarbon potential of the Bay of Bengal from the discoveries that have been made to date, the area is fraught with both sub-surface and above ground challenges. The lack of an internationally recognised maritime boundary between India-Bangladesh and Bangladesh-Myanmar is beginning to have a major impact on exploration efforts and the situation is likely to be compounded unless demarcation of the disputed areas is officially established. Although the matter has not been a subject for discussion since the 1980s, the situation has escalated and intensified in recent years as both India and Myanmar have rushed headlong into offering offshore areas for oil and gas exploration – both countries having been rewarded with a string of high profile discoveries, which in turn has attracted considerable interest from international E&P companies.

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International News

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INDIA

A deepwater wildcat was spudded by Reliance Industries Ltd on 14 April 2009 on the KG-DWN-2003/1 (KG-V-D3) (Krishna-Godavari Offshore) block by the Transocean "Discoverer 534" D/S in 1,233m of water. The KGV-D3-G1 exploration well, which has a prognosed total depth of 2,510m, is the third to be drilled on the acreage during the current license term. It is designed to explore sands in the Pleistocene slope debris complex and Pliocene/Late Miocene deep water channel-levee-lobe complex. Located about 20km south-west of two recent discoveries on the acreage (Dhirubhai 39 and Dhirubhai 41), the well was drilled to a depth of 1,625m where 20" casing was set. It has now been suspended pending re-entry in the second half of 2009, while repairs continue on the blowout preventer.

Seventy exploration blocks are being offered in the first phase of NELP VIII, which was launched by the Indian Government on 9 April 2009. Those blocks are comprised of 24 in deepwater, 28 in shallow water and 18 onshore. Another 30-40 exploration blocks are expected to be offered in a second phase toward the end of the year, depending on industry reaction to the first offering. In further licensing news, it appears the last three blocks in NELP VII will not be awarded as GeoGlobal Resources Ltd and Interlink Petroleum Ltd have been unsuccessful in securing an extension for the signing of PSCs for the VN-ONN-2005/1 and VN-ONN-2005/2 blocks and CB-ONN-2005/1 block, respectively.

IRAN

Iranian oil minister Gholamhossein Nozari has announced two new discoveries: a new oil layer in the Band-e-Karkeh oil field in Khuzestan province and a new gas discovery with the Sefid Baghoun wildcat. Apparently exploration work on the Band-e-Karkeh field has revealed the Sarvak formation to be productive and as a consequence, reserves of the field have been increased to 4.5 billion barrels. After receiving formal approval of its commerciality report from National Iranian Oil Company (NIOC) in June 2007, OMV started work on the master development plan (MDP) for the Band-E-Karkheh field in late 2007. The MDP, which may include up to 12 development wells, was originally due to be agreed between OMV and PEDEC by end December 2007. This deadline was extended to May 2008, when the second 18-month extension to the original four-year exploration agreement finished. Nonetheless, talks with the company are understood to be ongoing and the MDP is yet to be submitted. Preliminary operations are believed to have started on the field, in order to prevent any further delays. With regard to the Sefid Baghoun 1 well, operator NIOC was last reported drilling ahead in a technical sidetrack below 3,765m in the Dalan Formation after having tagged the top of the Kangan Formation and set a 7" liner at 3,336m. The well was spudded in late April 2008, with primary objectives in the Lower Triassic, Kangan and Upper Permian, upper Dalan Formations of the Deh Ram Group and a planned total depth in excess of 4,600m.

With the government's frustration at the lack of foreign investment in the country brought further into the open via LNG issues, Mahmoud Zirakchian-zadeh, managing director of Iran Offshore Oil Company (IOOC) sees a more optimistic Iran. When interviewed by the state broadcaster, he said the country expects to finalize two energy contracts totaling US$ 7 billion but gave no indication as to when these would be signed. Also absent was the name of the European firm that had completed a development plan for the offshore Lavan natural gas field in the Gulf. The Lavan field, which was discovered in 2003, has in place reserves of around 10 Tcf. In February 2009, Polish gas monopoly PGNiG said it had signed a preliminary deal with the IOOC to cooperate on managing already-discovered gas reserves. The second energy contract was revealed to be a US$ 3 billion investment by ONGC, the company having concluded a development plan for the Farzad gas field, which forms part of the Farsi block in the Gulf. Zirakchian-zadeh also revealed ONGC had discovered an offshore oilfield, Binaloud, in the Farsi block with one billion barrels of in-place reserves of heavy (14° API) crude. The block is also estimated to hold recoverable gas reserves of 12.8 Tcf.

IRAQ

In March 2009, the Iraqi Oil Ministry distributed to bidding companies a revised draft of a model contract for the fields offered in the first Iraqi licensing round. The participating international oil companies were asked to submit any comments on the new model contract by 1 April 2009. Iraq's Petroleum Contracts and Licensing Directorate has now issued to the bidding companies a final model service contract and tender protocol for the fields offered in the first Iraqi licensing round. Companies must submit a bid bond of US$ 5 million to the oil ministry for each field on which they wish to bid by a deadline of 15 June 2009. A bidding and award session will then be held in Baghdad on 29-30 June 2009, where the companies will submit their bids, the contracts will be awarded and the winning bidders will be named.

Gulf Keystone has spudded its Shaikan 1 new field wildcat in the Shaikan Block, located in the Kurdistan Region of Iraq. Shaikan 1 is being drilled in a proven hydrocarbon area on acreage that lies directly between the Tawke and Taq Taq oil fields. The well is targeting multiple horizons ranging from 600m to approximately 3,000m, seeking potential Cretaceous Qamchuqa and Triassic Kurra Chine formation objectives. Reservoir potential may also exist in the Cretaceous Chia Gara, Jurassic Najmah and Permian Chia Zairi formations. In the event of a multi-horizon discovery in place reservoir volumes are expected to be in the range of two billion barrels of oil. The Shaikan structure is believed to reside in a play fairway that possibly extends across the region and includes the recent Tawke discovery in an adjacent block some 60km to the north-west. Upon completion of the Shaikan 1 well, the commitments under the first phase of the PSC will have been completed with an option to enter into phase 2.

KUWAIT

Kuwait National Petroleum Company (KNPC) has apparently suspended plans to build a fourth refinery at Al Zour at an estimated cost of US$ 15 billion. The suspension of plans for a fourth refinery, which was supposed to process 615,000 bo/d, came after the project was referred to the State Audit Bureau in 2008 when opposition members of parliament alleged that the contract awards did not comply with the tender procedures set by Kuwait's Central Tenders Committee. The Kuwaiti Government had plans to increase the country's refining capacity to 1.415 MMb/d and wanted the Al Zour refinery to replace the aging Shuaiba refinery. The scrapping of the Al Zour refinery comes just three months after Kuwait's parliament forced the closure of a planned US$ 18 billion joint-venture deal with US chemicals giant Dow Chemical Co.

On a more positive note, Saad al-Shuwaib, managing director of Kuwait Petroleum Corp. (KPC), has said that Kuwait has increased its crude production capacity to 3 MMb/d. In his view this is affirmation that the country is on schedule to meet its target of a production capacity of 4 MMb/d by 2020 however, there are doubts that this may be realised.

OMAN

Petroleum Development Oman (PDO) has confirmed the successful completion of the first phase of the Mabrouk field development project. The field development plan currently being implemented by PDO involves the construction of a major new production station and associated gathering system, the first phase of which has just been completed. The new facility can process 63,000 b/d of gross liquids (oil and water) and 2.5 MMcfg/d. Over the coming years, a total of 76 new wells will be drilled at the field. The second phase of the Mabrouk project, scheduled for completion in early 2010, involves the installation of powerful gas compressors capable of sending natural gas produced at the field to the Saih Rawl gas processing plant where it will enter the Government Gas System.

PAKISTAN

An exploration well targeting a 2 Tcf prospect is being drilled by Eni on the Badhra D&PL (Kirthar Foldbelt). Spudded on 24 March 2009, Bado Jabal 1 (Badhra Deep 1) has a proposed total depth of 4,400m. It is in the 230.25 sq km Badhra D&PL, which was awarded in 2004 over Eni's Badhra 2 gas discovery. That well, drilled in 1998-1999, was the first to successfully test the Cretaceous Mughal Kot Formation. It was tied back as a satellite development to the Bhit field 20km to the north-west in January 2008. An exploration well to evaluate the Cretaceous Pab Formation, Badhra 3, was abandoned at a depth of 1,260m in 2003. A 3D seismic program was undertaken over the acreage in 2005-2006. Eni has a 40% stake in the acreage, with Shell holding a 28% interest through its subsidiary company Kirthar Pakistan BV. Other partners are Premier-Kufpec Pakistan Kirthar BV with 12% interest and OGDC holding the remaining 20%.

QATAR

Total has inaugurated Qatargas 2, an LNG venture composed of two trains each capable of providing 7.8 million tons annually. Gas feed for Qatargas 2 is from two blocks in the North Field, which is located adjacent to the block and is assigned to the Dolphin project (Total 24.5% interest) and the producing Qatargas block (Total 10%, 20% upstream). This latest agreement follows the signing of a sale and purchase agreement for the export of up to 5.2 million tons of LNG from Qatargas II over a 25-year period, to supply markets in France, the UK and the Gulf of Mexico. Total will also gain an 8.35% interest in the South Hook LNG terminal in Wales, the largest in Europe. The other partners in train two are QP (65%) and ExxonMobil (18.3%) while train one interests are held by QP (70%) and ExxonMobil (30%), which equates to QP (67.5%), and ExxonMobil (24.15%) for the overall Qatargas II project and South Hook terminal. In January 2009, Qatargas shut in all production from Qatargas I due to a mechanical failure. Press reports suggested that "force majeure" had been declared however this has not been confirmed or denied by Qatargas. Qatargas I has a total combined capacity of 10 million tons per year.

SAUDI ARABIA

According to Lukoil, its Luksar joint venture with Saudi Aramco, which was to expire April 30, has been granted a six-month extension. The Saudi Government officially signed a modified EPSA with Luksar for Contract Area A on 7 March 2004. The license incorporates blocks 69, 71 and 73 and is believed to carry a maximum 10-year exploration phase (divided into three periods) and a 25-40 year production term, with no signature bonus or rental fee payable. In the event of a commercial discovery, the Saudi Arabian government will pay for the construction of a gas pipeline from the gathering station within a contract area to the country's Master Gas System (MGS), subject to a minimum supply volume of 350 MMcfg/d. The first five-year exploration period carries a minimum commitment to acquire 4,000km of 2D seismic and drill two exploration wells, following which there will be a 50% acreage relinquishment. In its 2008 year-end financial statement, Lukoil revealed its intentions to expand internationally as Russia offers fewer licenses. With regard to Saudi Arabia, the company spent US$ 122 million on drilling that failed to yield results.

SYRIA

Local media report that IPR Mediterranean Exploration Ltd (IPRMEL) a subsidiary of Improved Petroleum Recovery, has made an oil discovery with its Rashid 1 exploration well in Block 24, northeast Syria. According to Petroleum and Mineral Resources Minister, Soufian Allao, the well's production capacity will be 1,450 bo/d. The well was drilled as an offset of the Kasra 101 well. IPRMEL abandoned the Kasra North 1 wildcat in Block 24 as a dry hole in late April 2007 after reaching a total depth of 1,945m in the Albian Rutbah Formation. The company was reported in March 2007 to be looking for a workover rig to undertake three to four drillstem tests after logs had indicated gas and oil shows in the Cretaceous Shiranish and Judea formations.

With thanks to IHS Energy

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Lectures

We are still constructing the full lecture program but here is an early entry for your diaries.... Whilst in Oman to deliver his Distinguished Instructor Short Course, Professor Patrick Corbett has kindly agreed to give a talk to the GSO entitled Petroleum Industry Sustainability. The talk will be on December 12th at 7pm in the Oil & Gas Centre. The abstract is given below and looks to be a fascinating talk.

Petroleum Industry Sustainability

Prof Patrick Corbett
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Abstract

The oil industry, like all others, is concerned with its long term sustainability. Sustainability often means growth whilst leaving resources for future generations. In recent years the concept of "Peak Oil" has entered the public consciousness along with the realisation that release of carbon dioxide into the atmosphere is widely accepted as being responsible for rising global temperatures.

These drivers - concerning society and environment - have been incorporated into the sustainable goals of the major companies. Future growth in hydrocarbon demand - currently depressed as a result of the global financial slowdown - will soon recover due to development objectives in the developing world. The industry will hope to meet demand by the development of new resources - improving oil in conventional fields, heavy oil and tar sands, tight gas, shale gas and oil and possibly in the longer term, developing hydrate resources.

To mitigate against the environmental impact the industry is committed to reducing emissions in operations and using energy more efficiently. The oil industry has historically been a major player in the development of alternative energy sources - solar, wind, marine, biofuels - and this trend continues. There is recent evidence that the industry is cooling on alternative energy initiatives and concentrating once again on "core business". The contribution of the oil and gas industry to the development of alternatives is evidence of a commitment to long term energy sustainability.

Many oil and gas companies (and service companies) are involved in projects around the world which will lead to a new industry promoting carbon capture and storage (CCS). This is nearer to the core skills for oil industry and our industry can provide access the long term subsurface storage sites and provide all the necessary monitoring services.

When it comes to sustainability - it will be engineers "thinking out of the box" that provide the long term solutions. New resources, new technologies and new industries - thus, the industry faces a challenging and exciting future. To ensure the skilled workforce that we will need for the future - we mustn't forget the underlying demographic pressures and the need to "sell" the industry to a new generation. The long-term sustainability agenda is one that the industry ignores at its peril.

Field Trips

2009/2010 Season

Please note this is a tentative list and both dates & localities may change. Further, we expect to offer additional trips, which will be confirmed after the summer break (-Ed.)

October 8th & 9th	Sohar Copper Mines and Pillow Lavas of Wadi Jizzi	National Mining Company & Jan Schruers
October 22nd	The Late Pre-Cambrian Fara Fm. , Wadi Bani Awf	Carlos Fonseca & Jan Schruers
November 5th	Structural Geology & Carbonate Facie sin the Salakh Arch	Mohammed Kindy, Heiko Hill-gartner & Redha Al Lawatia
November 19th	Salt Stringers in the Salt Domes of Central Oman	Zuwena Al-Rawahi
December 3rd	From Snowball Earth to Hothouse - Oman's Distant Past	Joachim Amthor
December 10th	Paleogene Palaeoenvironments	Ru Smith
January 13-15th	The Al Khlata & Gharif of the Huqf	Alan Heward

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