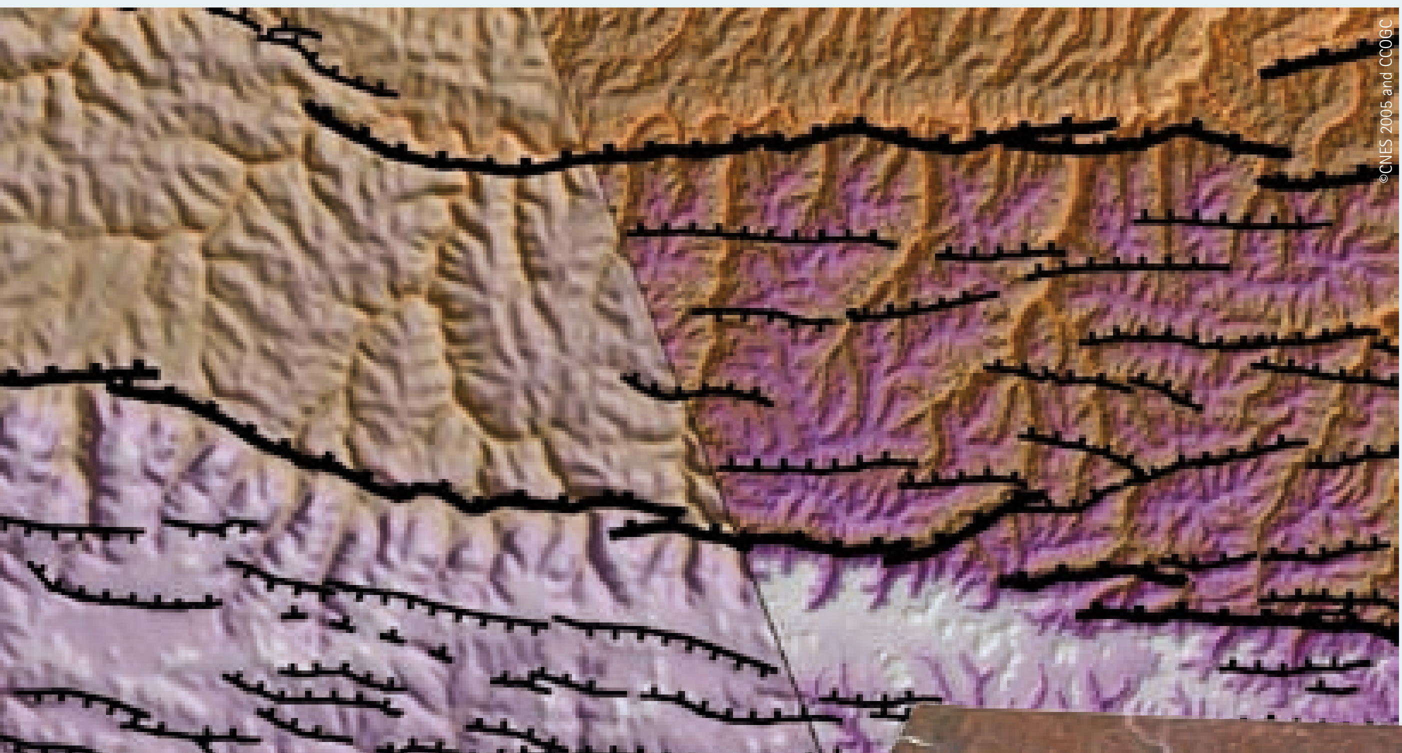
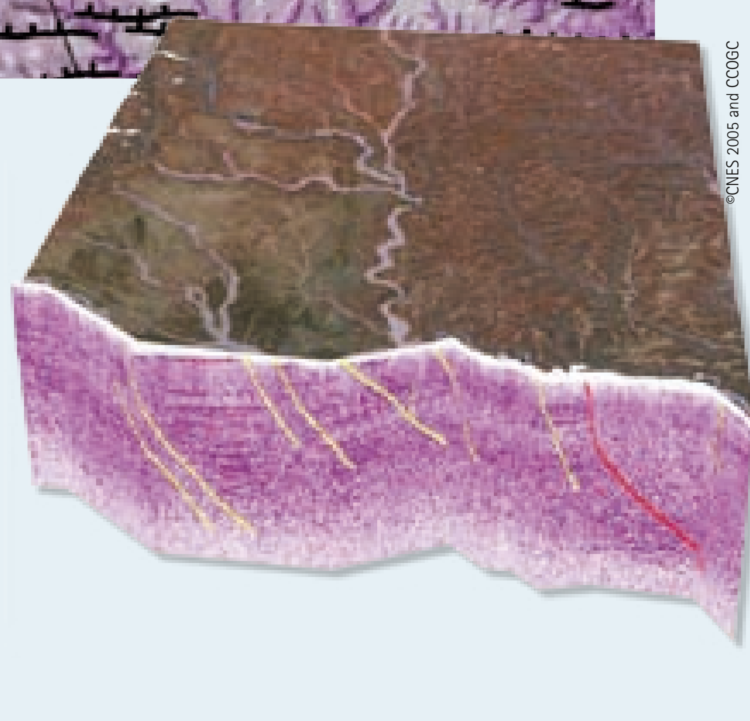
Visualising the subsurface: from 2D to 3D

"Improved resolution and clarity in remote sensing satellite imagery helps geoscientists to build models in hostile terranes, not only of the surface of the earth, but also the subsurface."



SPOT HRS data at a 20m resolution are used for block-specific studies. The amount of extra information provided by this level of resolution is illustrated by comparing the structural interpretation possible using SPOT data, on the right, with the coarser SRTM data (90m resolution) on the left. As can be seen, much more structural detail is revealed with the higher resolution data.



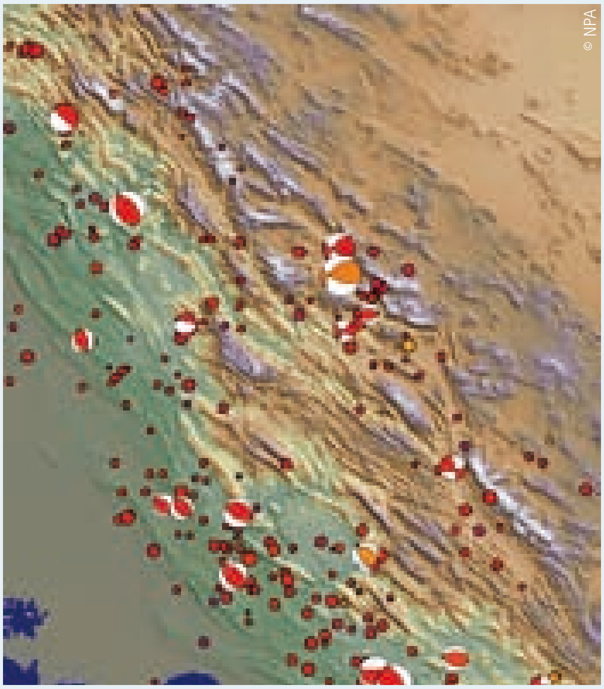
Satellite data is integrated with seismic information in the form of 'curtains' that hang from the geo-referenced surface thematic layers. This image shows that it is not always possible to drive nice straight seismic lines, in this case due to the challenging topography of Yemen. The line shows normal faults defining a half graben in the Masila region. Madbi Formation shales, the source rock of the petroleum system, exist in the Jurassic depocentres. River and Wadi systems flow parallel to and are controlled by the extensional structures. The relationships between surface processes and sub-surface geology are much easier to explain with this visualisation technique.

Jane Whaley, Associate Editor

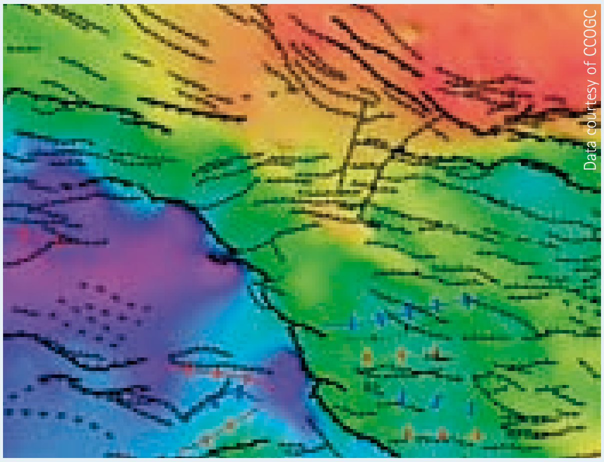
Various applications of remote sensing imagery have been used by the oil industry for a number of years, as discussed in GeoExpro last year (vol. 3, no. 3). It is an area where the technology is continually advancing and, as remote sensing companies collaborate with experts in other fields, new ways of using this data are constantly presenting themselves.

"These developments now provide geoscientists exploring in hostile onshore terrains the ability to visualise the structure of prospective reservoirs from the comfort of their desk, well ahead of any expensive deployment of a seismic crew. Money well spent," says Alan Williams, Oil & Gas Manager with NPA Group, which specialises in deriving geo-information from Earth Observation satellites.

"Extracting information from complex foldbelts is the most exciting aspect of this kind of work."



High resolution satellite imagery is used to interpret structural features such as faults and bedding. These interpretations are then integrated with alternative technology to augment the surface interpretation, before the exploration moves onto 3D visualisation. In this case the fault planes interpreted from satellite imagery of Iran were compared to the Harvard CMT database. In this view the size and angle of the ball indicates magnitude and direction of present day stresses, providing the remote sensing interpretator with some idea of the fault plane geometry at depth.



Structure contour map (rainbow colours) of Top Um Er Radhuma Limestone made entirely from remotely sensed data, including Landsat ETM, SPOT and SPOT HRS DEM.

Shuttle data covers the world

"Take, for example, Shuttle Radar Topography Mission (SRTM) data, obtained using a specially modified radar system on the Space Shuttle," explains Alan. "Data from this is free of the effects of clouds and has a resolution of 90m, creating the most complete, commercially available, high-resolution digital topographic database of the whole Earth."

"What I find so fascinating about using remote sensing imagery, " Alan continues, "is the way we can go from a broad brush approach, to focus in on an area and look in detail at, for instance, faults patterns and dip angles. By working at all scales with companies which have expertise in seismic imaging and 3D modelling, it is possible to really visualise both the surface of the earth and what lies beneath."

NPA have recently been using satellite imagery to successfully assess areas in Yemen and Iran, as Mike Oehlers, NPA's Chief Geologist, explains. "Model building with satellite data can have a number of objectives, including detailed geological analysis such as horizon mapping, recording dip data and even 3D structural mapping. We can work at various scales, using, for example, 90m resolution for regional work, 20m sample size for mid range use, or even airborne at 1 metre or less for more detailed studies."

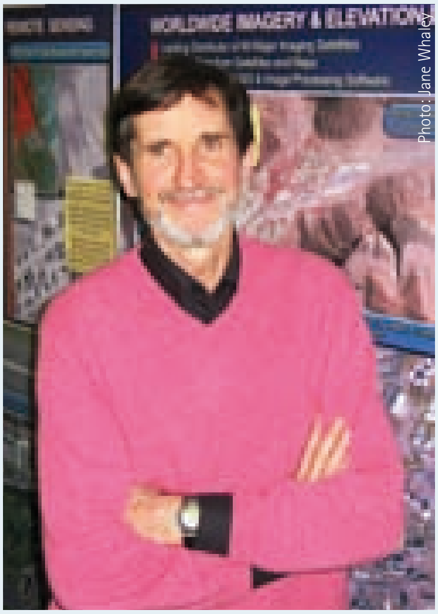
Seeing the subsurface in Yemen

"Having identified the regional tectonic elements, we can combine remote sensing data with other technologies such as 3D modelling, as we have successfully been doing in a remote area in Yemen."

"The thick Um Er Radhuma Limestone, which covers much of the Hadhramaut-Masilah region in the centre of the country, creates enormous logistical and technical problems," explains Mike. "It is deeply incised and locally dolomitised, the latter creating a rubble-strewn surface that impedes geophone coupling and thereby reduces our ability to see what is going on at depth with seismic data."

"This limestone is, however, a blessing in disguise, as it forms an essentially flat surface at outcrop throughout the region, allowing us to map the geology of the area and develop a feel for the degree of structural and stratigraphic control on the plateau," Mike continues. "We can identify the effects of the separate Tertiary, Cretaceous and Jurassic rifting episodes in the Gulf of Aden by examining the interaction of different fault populations."

For the more detailed interpretation at block level NPA use SPOT data, which enables the creation of geological maps to a scale of 1:10,000. By tracing and digitising the stratigraphic boundaries and compiling the results in a geographic information system, it is possible to map



Alan Williams, NPA's Manager, Oil and Gas, worked in the field of remote sensing for a number of years before joining NPA 8 years ago. He is involved in the interpretation and marketing of offshore seep detection projects world-wide, developing NPA's flagship Global Offshore Seep Database.

the top of the Um Er Radhuma formation by digitally relating it to the elevation model. "Because the plateau is vast and extensively dissected, there is a huge volume of points to control the surface," says Mike. "We can follow the outcropping surface and, since we can see individual beds, we can follow the trace of the layer and accurately measure dip and estimate bed thickness. This allows us to extrapolate downwards from the horizon into the subsurface and predict the depth and structure of the reservoir."

"Areas where the Um Er Radhuma is covered by younger Tertiary sequences are dealt with in the same way, by mapping the higher boundaries and subtracting their thicknesses from the model to restore down to the limestone surface. When compared to well tops data in this area we discovered that we had an error of only 6m in our estimation of Um Er Radhuma elevation", added Mike.

Using seismic with remote sensing imagery

Having created high-quality elevation models, and through them accurate structure and contour maps, the explorationist can move a step further towards successfully imaging the sub-surface by combining these with seismic data. "Seismic is integrated with the results of the remote sensing analysis in the form of manifolds, which hang like curtains from the geo-referenced surface thematic layers," explains Mike. "As seismic data has good positioning control, we can closely link the 2D satellite imagery through interpreted features such as faults and show all these relationships in 3D. Whole 2D surveys can be visualized in this way to aid regional interpretation and, if there is a degree of risk due to poor line spacing, incorporating and integrating surface geology helps tie between the lines."

"The fact that Mars is covered by better resolution publicly available data than Earth is most frustrating."

This technique has been used to great effect in Yemen, which has a history of extension and rifting stretching back to the early Mesozoic. Although the most recent extensional phase can be seen in the Palaeocene Um Er Radhuma and

Typical Yemeni countryside in the Masila region. The wadi is gravelly and in the foreground some of the uppermost Cretaceous units can be seen covered with screes developing on and above the wadi walls, which are formed by the massive Um Er Radhuma Limestone Member in the background.

younger sequences, it was the Jurassic and Cretaceous extensional events that defined earlier structure and palaeogeography. As a result, these are the structures that have had the most influence on hydrocarbon geology, including the source kitchens, reservoirs and seals, so it is important to attempt to image them accurately.

"It is also important to help identify superimposed, poly-phase deformation, as is often encountered in the Middle East", explains Mike. "Being able to view the 3D relationships between the surface and subsurface generates more confidence in the geological model. The relative position of these elements and timing of activation or re-activation is critical to exploration success. The ultimate aim, obviously, is to reduce risk."

Part of the toolbox

Using remote sensing imagery as an integral part of the explorationist's toolbox therefore has a number of benefits.

Firstly, it can be used to provide detailed surface, structural, dip and stratigraphic data. Secondly, the information can be further extended by using satellite data to map near-surface horizons, which are then projected into the subsurface with the help of modelling packages, in order to map deeper features, elements of petroleum systems and prospects.

Will this help you find oil? According to Alan, the answer is "not directly".

"The aim of any oil exploration project is to reduce the overall risk factor. 2D visualisation with remote sensing has traditionally been a successful tool to achieve this in well-exposed terrains where surface structures are assumed to mimic those at depth, such as fold and thrust belts. However, the ability of 2D combined with 3D to now accurately image structure at reservoir depth in areas of subtle dip and difficult surface access is impressive."

"This allows explorers to not only better plan their seismic grids but also gives them the confidence that valid traps will be present at depth at a very early, pre-seismic stage in the exploration cycle," concludes Alan Williams.

Acknowledgement:
Many thanks to Peter Bryant of CCOGC for permission to publish field photos and data from Yemen.

Another typical view of the rugged terrain near Wadi Masila. Here Qishn Carbonate beds in the hanging-wall rollover into a fault that runs along the wadi in the left of the photograph. Upper Qishn beds in the footwall are seen in the low hills to the left, mid-distance.