Dolomite-limestone alternations – from outcrop to 3D model

While rock climbers try to avoid the thin, porous and microfractured dolomites, geologists involved with reservoir characterization go to great length in order to give a detailed account of their distribution in carbonate reservoirs in relation to their tight limestone counterparts.

Photo: Wolfgang Blendinger

Wolfgang Blendinger and Edwin Meißner

The literature abounds with geological publications attempting to explain dolomitization qualitatively. Very few papers, however, address geometrical aspects of dolomite distribution in carbonate reservoirs for the purpose of reservoir characterization.

Quantitative mapping of dolomite distributions in carbonate reservoirs is important because dolomites often are porous, while limestones are tight. Unless densely spaced well data are available in a given field, geometrical data are best collected from outcrop analogues. This requires demanding fieldwork, excellent outcrops and tedious analysis on a bed-by-bed basis, which is why it is only rarely done.

A Triassic analogue

We have mapped the distribution of limestone and dolomite in a Triassic carbonate platform in the Dolomites, northern Italy. Edwin Meißner carried out the fieldwork in fulfilment of the requirements for his diploma thesis.

Not only are these platforms located in the type area of the mineral dolomite, they possess geometries similar to subsurface analogues. The platforms are high in relief, that is, they accumulated mainly vertically and were surrounded by deep water during deposition. Such platforms are known as hydrocarbon reservoirs in many areas, but are particularly common in the Paleozoic of the northern Caspian, such as the supergiants Tengiz, Karachaganak, Astrakhan and Kashagan fields.

Triassic isolated carbonate platforms

The Triassic isolated carbonate platforms have many characteristics of so-called mud mounds. The flanks are largely in-situ deposits, made up of cyanobacterial boundstone ; the platform tops were flat and consist mainly of aggregate grainstone. No reefs protected them from the deeper water. The calcareous parts of these platforms mostly show very poor porosity and permeability, which is mainly due to early plugging of the porous sediments by calcite cement soon after deposition. In spite of this, such platforms can host enormous hydrocarbon accumulations if porosity is created during burial and subsidence. One of these processes creating porosity is dolomitization. In addition, fracturing and poorly understood thermal karst formation plays a role.

The Pale di San Lucano massif (Seconda Pala di San Lucano) is a 1500 m thick carbonate platform of Middle Triassic age within the Dolomites of northern Italy. It preserves a well-developed prograding platform interior on top, whereas the platform core has been largely removed by erosion. The 3D model was constructed for the platform interior.

The platform interior rocks of the Seconda Pala di San Lucano are well bedded and superbly exposed in the glacial "amphitheatre".

The outcrop selected is situated on top of an ancient carbonate platform, the Pale di San Lucano massif, located in the spectacular Dolomites of northern Italy, and which may be more famous for excellent outdoor recreation facilities than for constituting a superb geological laboratory. These carbonates are of local commercial value as hydrocarbon reservoirs in the subsurface of the Po plain of northern Italy. They have also been used as carbonate reservoir analogues by many major oil companies for several decades.

The Pale di San Lucano platform, like many others, is only partially dolomitizied and displays a horizontally bedded platform core consisting of grainstone, now largely removed by erosion, surrounded by steeply dipping (ca. 25-38°) flank deposits of boundstone. The total thickness of the platform is around 1500m and represents about 4-5 million years of deposition. While the lower part of the platform core shows a mainly aggrading development, the uppermost 120m expanded laterally like a mushroom and prograded over the flank deposits.

Tedious work

On the Pale di San Lucano, the progradational part has been preserved in a spectacular outcrop in a glacial "amphitheatre". Access to this outcrop is not easy and requires basic alpinist skills. Thanks to the alpine support and logistics supplied by Ilio De Biasio of Cencenighe (in fact, he helped us in cliffs up to the III grade) we could access this outcrop. This four-week field campaign, which was four hours by foot from the nearest settlement, would have been impossible without his support.

The horizontally bedded, platform interior prograding carbonates consist of limestone and dolomite and were logged

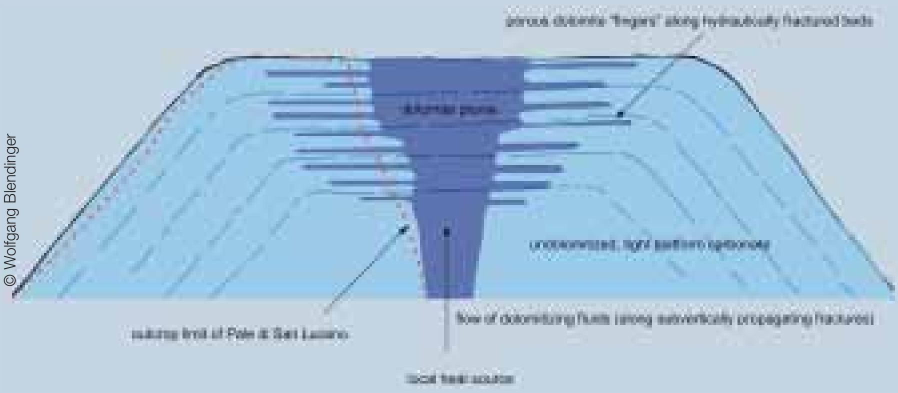
[1] "Boundstones are carbonate rocks which are bound together in the original depositional environment by framework building organisms."
[1] Grainstones are grain-supported carbonate rocks with no lime mud.

The platform interior rocks show distinct colour variations from yellowish (mostly dolomite) to grey (mostly limestone) that follow layering. Calcareous beds in the cliff of Campanile della Besauzega are marked with red numbers corresponding to the bed number. Edwin Meißner is encircled for scale.

in six stratigraphic sections, bed by bed. Control points were accurately mapped using portable GPS equipment. Interbedded are approximately 10 cm thick (acidic) tuff layers and, locally, volcaniclastic breccias, which have not been modelled. A total of 224 beds were identified in the 120 m thick interval covering an area of about 0.4 km^2, and in each section the mineralogy, as assessed from the intensity of the reaction with hydrochloric acid and subsequently coded from 2 (dolomite) to 6 (limestone), was logged as properties for each bed individually. Dolomite beds are often, but not always, yellowish, while calcareous beds are often, but not always, grey. Dolomite beds typically preserve a vuggy porosity estimated at an average 10%. Limestone, not only in this particular outcrop, but in most analgous settings, is always tight and exhibits immeasurably small permeability and correspondingly low (less than 1-2%) porosity.

Dolomite is, accordingly, very often friable and notorious among alpinists for its challenges. Limestone cliffs offer significantly better opportunities for rock climbers because of their compactness due to the absence of microfractures.

The layered distribution of the two end members limestone and dolomite could suggest a very early, syndepositional dolomitization, but small-scale dolomitization fronts show an abrupt change from limestone to dolomite, both upward and downward, within a few millimetres to centimetres. This indicates that individual beds were dolomitized when already covered by calcareous platform carbonate and, probably, by much younger deposits (burial dolomitization).



A model explaining the selective burial dolomitization of platform carbonates, as mapped on the Pale di San Lucano. Hydraulic fracturing parallel to the original bedding, causing a dense microfracture network in the vicinity of the main fracture, may have facilitated flow of dolomitizing fluids rather than the pure matrix flow favoured by most researchers on dolomitization. This type of "natural" hydraulic fracturing requires fluid pressures above lithostatic, and such pressures are normally achieved by a local source of heat in the deep subsurface. For the Dolomites, a Triassic source of heat is readily "available" both during and after platform growth in the Dolomites (widespread volcanic activity), but the regional distribution of dolomite indicates that dolomitization of the Dolomites is a much younger, probably Tertiary, event. Identifying, mapping and dating such sources of heat may, in fact, become more important than classical reservoir predicition based on depositional trends of carbonates.

Result quantification

The lateral change from limestone to dolomite and the abundance of dolomite (the so-called "net to gross") can be rapidly extracted from such a model. In the 224 modelled layers, 54 show a change from dolomite to limestone towards the platform margin (24%). Twenty layers show the opposite trend (9%), exclusively caused by the (partial) section in the northwestern model corner, which is located near a small fault possessing a dolomite "halo". In the remaining layers (67%) no trend is observed (homogeneous mineralogies).

The average property map, created from the "net to gross" model (net dolomite = dolomite cell thicknesses/bulk cell thicknesses), shows a general trend to lower "net-to-gross" from the platform centre to the platform flanks (range of values form 0.57 to 0.77).

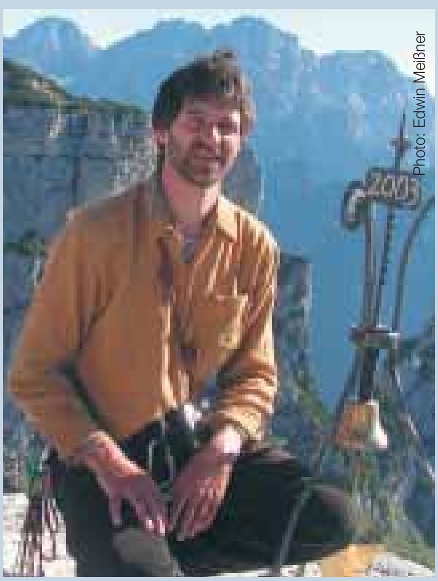
Significance for models

Because dolomite is "porous" and limestone is "tight", the dolomite distribution of the modelled outcrop suggests that the reservoir quality is decreasing form the platform interior towards the platform flank.

This trend could, because following the pattern of platform progradation, easily be misinterpreted as "depositionally controlled", but dolomite geometries like those mapped on the Pale di San Lucano indicate dolomitization under burial conditions. The outward decreasing dolomite abundance indicates a source of dolomitizing fluids overlapping the (now eroded) platform centre of probably hydrothermal origin. A model for hydrothermal dolomitization has previously been developed for another ancient carbonate platform in the Dolomites. Why the dolomitizing fluids selectively percolated laterally along some beds is enigmatic, because the precursor limestone lithologies all indicate completely tight matrix conditions.

Hydrothermal dolomitization is so far one of the few plausible processes that could turn completely tight precursor limestone into reservoir rocks in the deep burial environment. Candidates for this type of reservoir are not only isolated carbonate platforms, but also shelf carbonates (Khuff and Arab reservoirs of the Middle East, for instance, where similar porous dolomites of enigmatic origin are inter-

Wolfgang Blendinger (here sampling limestone near Monte San Lucano) has served 15 years in the petroleum industry with supergiant Shell and the German company Veba Oil. Since 2000 he has been a professor of petroleum geology at Clausthal Technical University, Germany.



Edwin Meißner (here on the Campanile della Besauzega; campanile is italian for "bell tower", hence the bell!) is a diploma student of geology at Clausthal Technical University and has carried out the field work and part of the reservoir modelling described in this article.

bedded with tight limestone). It is in these areas where the proposed hydraulic fracturing and associated dolomitization can be tested, through tedious studies of the geometries and mineral paragenesis associated with dolomites.

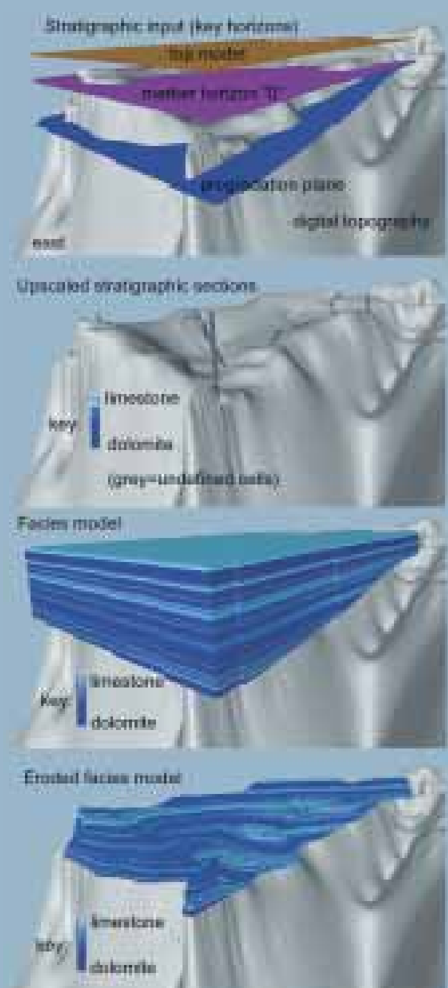
3D model construction from outcrop data

The digital model construction in IRAP-RMS (version 7.4) started with the interpolation of a topography surface from point data, which were digitized manually from topographic maps. The second step was the construction of a reference bed representing the accurate dip direction and angle of the logged interval. The measured beds were interpolated with constant thickness from an artificial well in the centre of the model area and gridded downward and upward, respectively, from the marker horizon "0". In the lower part, the gridded horizons were truncated against the progradation surface.

A 3D grid consisting of grid cells with dimensions of 5x5m (*x. y)* and thicknesses of the individual beds was modelled for the Seconda Pale di San Lucano, covering a total area of about 500x700 m. The path of the logged stratigraphic sections was loaded from accurate (error +/- 0.1 m) GPS data. The grid cells encountered by the actual stratigraphic sections, i.e. the intersections of the path of the logged sections with the 3D grid, were then assigned discrete values for the different mineralogies resulting in so-called "blocked wells" with a discrete number (codes 2 to 6) as property. The properties were interpolated between the stratigraphic sections using the "parameter interpolation" functionality of RMS.

Because the observed dolomitization fronts are stratiform and do not crosscut layering, the interpolation was carried out per layer. The interpolation radius was set to 1000 m (x, y) to avoid undefined cells. The circular interpolation geometry was adopted because of the unknown exact lateral dolomitization trends.

Finally, the 3D model was "eroded" with the topography surface resulting in a 3D model of the present outcrop situation.



The different modelling steps in a 3D view (screenshots from RMS 7.4) from the northeast.

Net-to-gross map for dolomite of the model area (screenshot from RMS 7.4).