An introduction to this special section—carbonates

Though carbonate rocks make up only 20% of the sedimentary rock record, carbonate reservoirs hold 60% of the world's petroleum reserves and presently account for 40% of the world's total hydrocarbon production. Because of this obvious mismatch between potential and current production, our industry has recognized the need to understand carbonate reservoirs better and be able to produce them more efficiently. The emphasis is likely to continue and grow in the future.

Carbonate sedimentary rocks significantly differ from siliciclastic rocks in several ways. Table 1 lists some salient differences.

Table 1.

	Carbonate rocks	Siliciclastic rocks
1.	Carbonate rocks consist mainly of two minerals: calcite and dolomite. They usually remain near their point of origin.	Siliciclastic rocks (predominantly sandstones and shales) are composed of a variety of silica-based grains. They generally have traveled hundreds of kilometers from their source.
2.	Carbonates form in special environments in shallow and deep marine settings.	Siliciclastic rocks do not require any special environment.
3.	Once formed, carbonates undergo diagenetic changes—mineral dissolution (grains dissolved to form new pore space; dissolution along fractures and bedding planes produce vugs and caves) and dolomitization (improves hydrocarbon-producing characteristics).	Siliciclastic rocks undergo minor diagenesis as specific temperature and pressure are required.
4.	Carbonate rocks are distinguished on the basis of depositional texture, grain or pore types, rock fabric and diagenesis.	Clastic rocks are distinguished on the basis of their grain composition and size.
5.	Carbonate rocks have a wide range of grains, pore types and sizes. Consequently, several types of porosities are considered.	Intergranular pores are uniformly distributed throughout the rock matrix; only intergranular porosity is generally considered.

A detailed description of carbonate reservoirs requires that all available petrophysical and geophysical data be used to understand the measured elastic quantities and relate them to rock properties. Seismic methods, therefore, need to be applied as quantitative diagnostic tools. Depending on the interpretation goals and the reservoir type, some seismic indicators are more reliable than others. Most often a combination of different seismic data types is used—borehole, VSP, surface seismic, OBS, and sometimes data from lab experiments. The need for detailed reservoir description has also led to multicomponent recording in areas where S-wave data may provide additional information on rock properties beyond the conventional analysis of P-wave and PS converted data. Similarly, time-lapse surveys are carried out more and more to monitor the life cycle of these reservoirs and evaluate the effectiveness of enhanced oil recovery schemes.

The papers in this special section provide a flavor of the typical areas of interest in carbonate characterization, how different tools are applied, and how the new challenges are being addressed.

The special section begins with two papers on rock physics and well log analysis on marly chalk reservoirs from Valdemar Field in the Danish North Sea. The paper by Prasad et al. discusses a rock physics and a statistical well log analysis on the field. A principal component analysis on different log curves from six wells was performed to examine the difference between oil-bearing and water-bearing carbonate formations. The study indicated different correlation coefficient sequences for the water-bearing and oil-bearing wells. Due to the dominance of capillary forces in low-permeable chalk reservoirs, interpretation of fluid distribution is a challenge. This issue was addressed in the paper by Fabricius et al. which discusses a log interpretation strategy to analyze the stiffness of reservoir rocks as well as the free water level. By using the iso-frame concept based on effective medium theory, the solid phase is split into load-bearing material in the frame and material in suspension. They demonstrate how this can be indicative of the potentially weak and stiff intervals, and thereby draw inferences on their tendency to compact. The application of the proposed analysis is discussed for three formations: Åsgaard (water-bearing), Tuxen (oil-bearing, porosity~30%, and permeability between 0.1 to 1 mD), and Sola (oil bearing, porosity > 40%, and permeability > 1 mD).

The effect of saturation on velocity in carbonate rocks has been investigated by different researchers with different inferences—one that supports and another that questions the constant shear modulus assumption in Gassman's theory. By performing measurements on 30 limestone samples from Cretaceous and Miocene reservoirs with porosities between 5% and 30% and varying texture and pore types, Baechle et al. observed shear weakening as well as shear strengthening in the rock samples. The observed change in the shear modulus leads to a difference between the measured velocities and the Gassman predicted velocity. Their results question the application of Gassman's theory for velocity prediction in carbonates.

The paper by D'Agosto et al. discusses the application of coherence attributes on PS converted waves from a land 3D survey over a carbonate reservoir in southwest Venezuela. They find that, in spite of the coarser bin size, PS reflections provide better lateral resolution than PP reflections. The subtle faults tend to stand out better in the gradient of eigenvector attribute displays for PS data; the east gradient of the eigenvectors enhances the NS features and the north gradient of the eigenvector enhances the EW features.

The next paper discusses the application of rock physics to a carbonate play from Brazeau River in Alberta foothills.

Pelletier and Gunderson demonstrate the importance of petrophysical and rock property analysis for guiding the interpretation of seismically-driven attributes and calibrating them with geology. The porous dolomite in Nisku Formation and the shales exhibit similar stacked responses. By examining rock physics relationships from log data it was found that Lambda-Rho and Mu-Rho crossplots provided the needed discrimination. The workflow was then applied to the prestack seismic data for identification of Nisku lithology.

Time-lapse analysis is not common in carbonate reservoirs, so the case studies in next two papers are of particular interest. The paper by Raef et al. discusses the application of time lapse seismic to image a thin carbonate reservoir by monitoring the movement of miscible CO_2 flood, in Hall-Gurney Field in Kansas. They apply an approach they call parallel progressive blanking (PPB) that uses a nonlinear color scale and assigns a single color to all values above and below a progressively decreasing range of values while searching for spatial textural differences between the baseline and monitor datasets. The advantage of using such approach is its sensitivity to weak amplitude signatures associated with change in fluid concentration. Those amplitude anomalies could otherwise be concealed by noise and balancing/cross-equalization techniques. The paper by Ng et al. discusses the application of time-lapse analysis on the Rainbow B pool which is undergoing solvent and gas injection for extracting the bypassed oil. The study indicates that (1) the presence of gas and solvent were best interpreted using time-delay results as opposed to amplitude changes and (2) fluid related changes were detected in vuggy or low pore aspect ratio porosity zones but not in zones with intergranular porosity. An interesting observation of this study is that the application of Gassman's equation underpredicts velocity changes in the reservoir, confirming a result of the paper by Baechle et al.

The last paper describes a recent geophysical survey carried out to locate a solution cavity, a 570 000 year old bone cave, beneath Valley Forge National Historical Park, in the carbonate belt of southeastern Pennsylvania. A magnetic, a microgravity, and a 3D electrical survey were conducted. A distinct low gravity expected of a solution cave was observed. Roughly consistent with the gravity anomaly, a resistivity anomaly that extends to depths greater than expected, was also observed. This paper will interest movie fans in addition to geophysicists, but you'll have to read it to learn why.

The set of papers in this special section touches upon some of the trends under way in exploring and exploiting carbonate reservoirs. The complexity and heterogeneity alluded to in these papers emphasizes the interpretation challenges that geoscientists face. Some areas not covered in these articles but the subject of active research are: fracture detection and characterization, seismic imaging tools and AVO studies, seismic attribute analysis techniques, and prediction of porosity and permeability in carbonate rocks. As the papers in this section and the other research areas indicate, integration of all available data and a careful choice of evaluation tools are essential requirements for detailed description of carbonate reservoirs. TLE

—*Satinder Chopra, Calgary, Canada*
—*Nizar Chemingui, Houston, USA*
Richard D. Miller, Lawrence, Kansas, USA