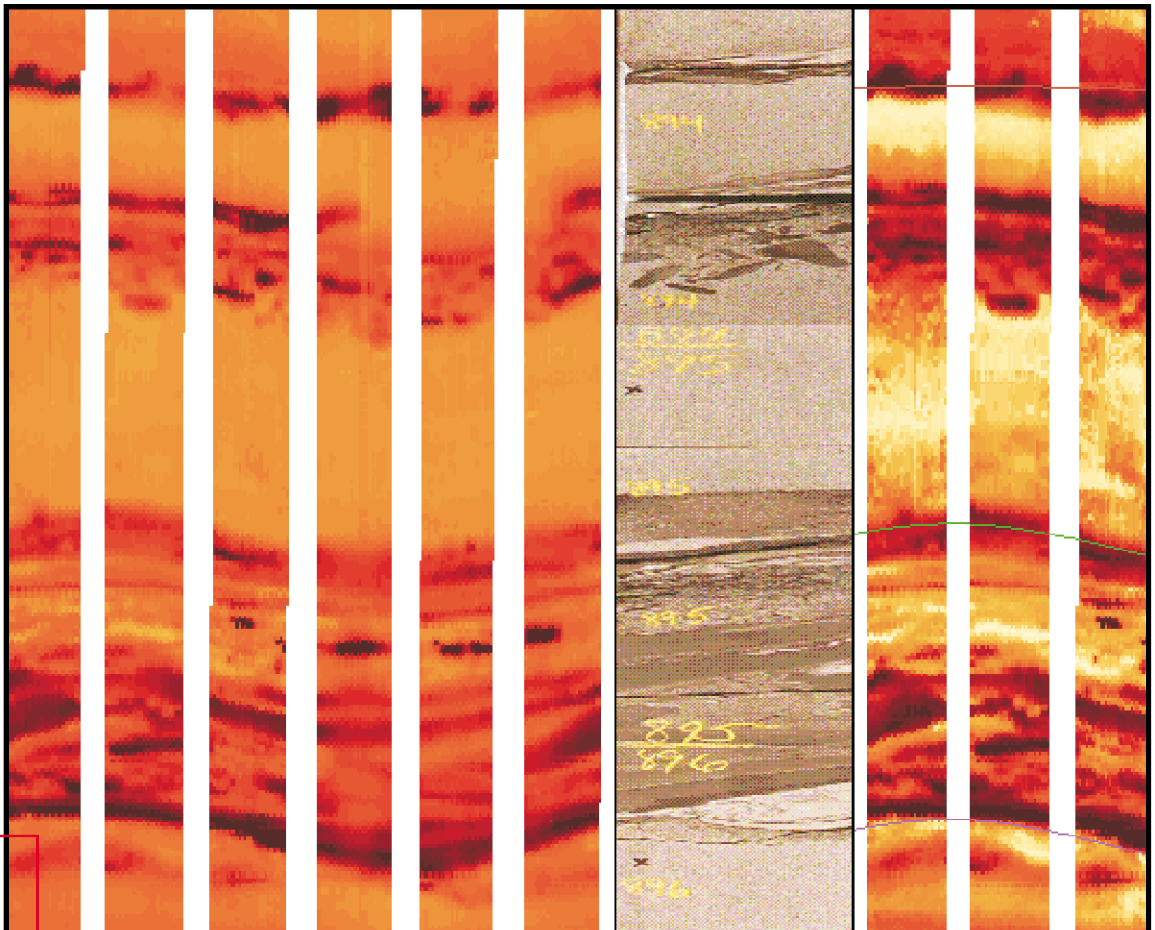
Turbidites Hold Great Potential for Deepwater Exploration

by Gerald Kuecher and John Millington



As shallow-water areas are becoming fully exploited, frontiers of exploration are being pushed further and further into deep water. And the pursuit of hydrocarbons into the deepwater realm is focused on deep-marine sands called turbidites, which contain potentially huge hydrocarbon reserves.

What is so special about turbidites? Why have so many companies de-emphasized all other plays to be involved heavily, and in some cases, solely with turbidites? The answer is tied to oil company strategy for long-term hydrocarbon development and production. Evidence from the Gulf of Mexico shelf suggests a steeply declining rate of new field replacement reserves for shelf plays and a steady rate of new field replacement in the deepwater plays (Pettingill, 1998).

Consequently, the larger oil companies have elected to move into deep water as rapidly as technology allows. Operators are exploring for and producing hydrocarbons in water depths where drilling was considered impossible only a few years ago. Drilling technologies presently allow exploratory drilling in depths greater than 8,000 feet (2440 m) and production in water depths greater that 6,000 feet (1830 m).

While exploration for oil-producing deepwater turbidite deposits is global, a recent study indicates that the majority of deepwater reserves will come from only a few petroleum regions (see Figure 1).

In West Africa, the developing countries Nigeria, Angola, and Equatorial Guinea will experience most of the new activity. Norway is expected to hold the majority of deepwater reserves in the North Sea, Brazil will dominate in South American activity, and the Gulf of Mexico will remain a significant deepwater producing region.

Billions of dollars will be invested in these regions by a few very large companies. The service industry must be responsive to these new initiatives. The Baker Atlas division of Baker Hughes is strategically positioned to participate in these dominant areas with its ongoing programs to develop geoscience tools and technologies targeted at evaluating deepwater turbidite formations.

The Nature of Turbidite Channels

One submarine landform that deserves special mention is the turbidite channel. Submarine channels transport sediment-gravity (turbidity) flows from the shelf and shelf-edge to the continental slope and abyssal floor of the world's oceans, both past and present. Submarine channels often originate as small feeder channels on the shelf, and gather at the apex of large incised canyon systems. Turbidity flows moving through these canyons may initiate as large shelf edge collapses that move down the continental slope and deposit their sediment load on the abyssal floor as fan-shaped lobes. These deposits form the economically important turbidite reservoirs found in deepwater exploration areas today.

Modern submarine channels commonly occur at water depths of several thousand feet. Surface methods of observation, therefore, are out of the question. Data must be acquired remotely, and the most effective geophysical methods involve acoustic technologies.

High frequency marine seismic data collected from the ocean surface in deep water is useful for mapping the distribution of large submarine channel distributary systems. One map of submarine channels on the Mississippi Fan, produced from seismic data acquired at the ocean surface, is shown in Figure 2.

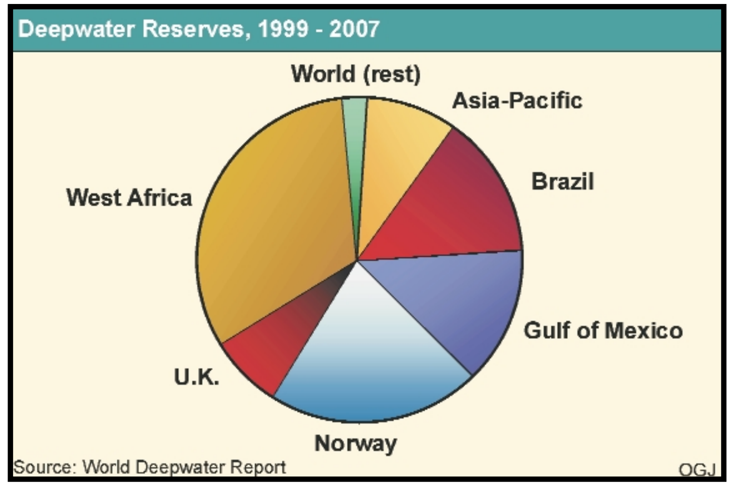


Fig. 1. Future deepwater reserve estimate 1999-2007 (Knight et al., 1999)

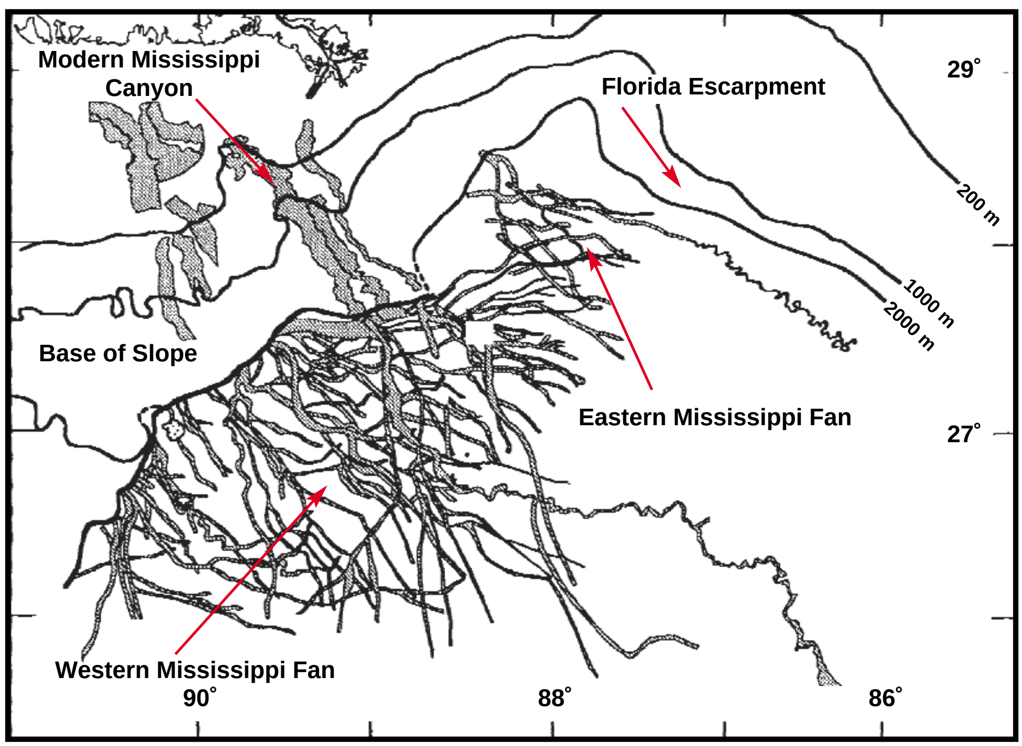


Fig. 2. Major submarine channel systems mapped at or near the surface of the Mississippi Fan (Weimer et al., 1988).

The most surprising discovery from this study of the Mississippi Fan was the pervasive nature and longitudinal extent of submarine channels. They appear to travel for great distances beyond the break-in-slope from continental slope to abyssal plain. High-resolution acoustic methods (Twichell,

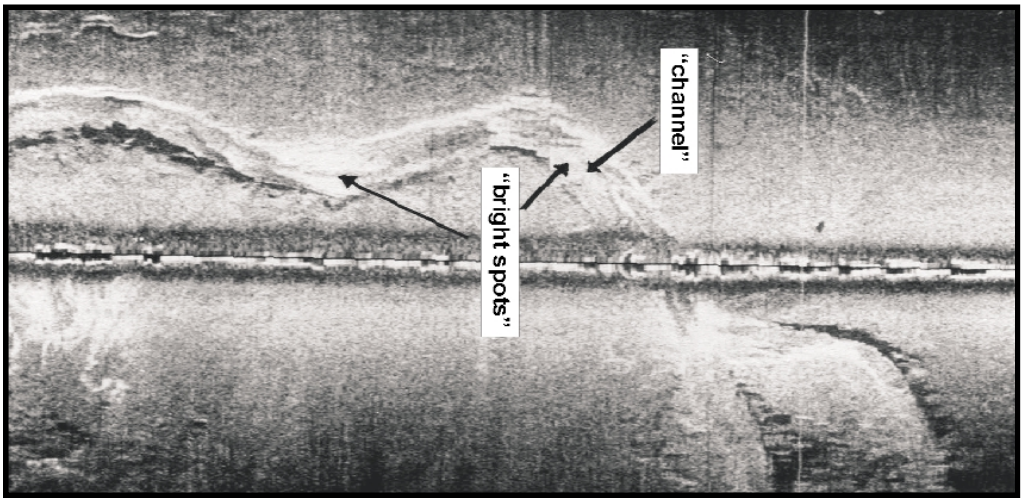


Fig. 3. Side-scan sonar image of the Umnak submarine channel, Bering Sea, Alaska (Kenyon and Millington, 1995). Light shades refer to high acoustic backscatter.

1996) indicate individual channels can persist to the very limit of the fans. In addition, channels near the inner fan break-in-slope commonly are leveed, while those in the distal outer fan areas do not appear to build levees. Flow velocity and attendant sediment size are important factors governing this physical response.

Side-scan sonar also has been successfully employed for mapping submarine channel morphology and surface character. In side-scan sonar, high-frequency acoustic signals are generated and received by a "fish" towed behind a survey vessel below the water surface.

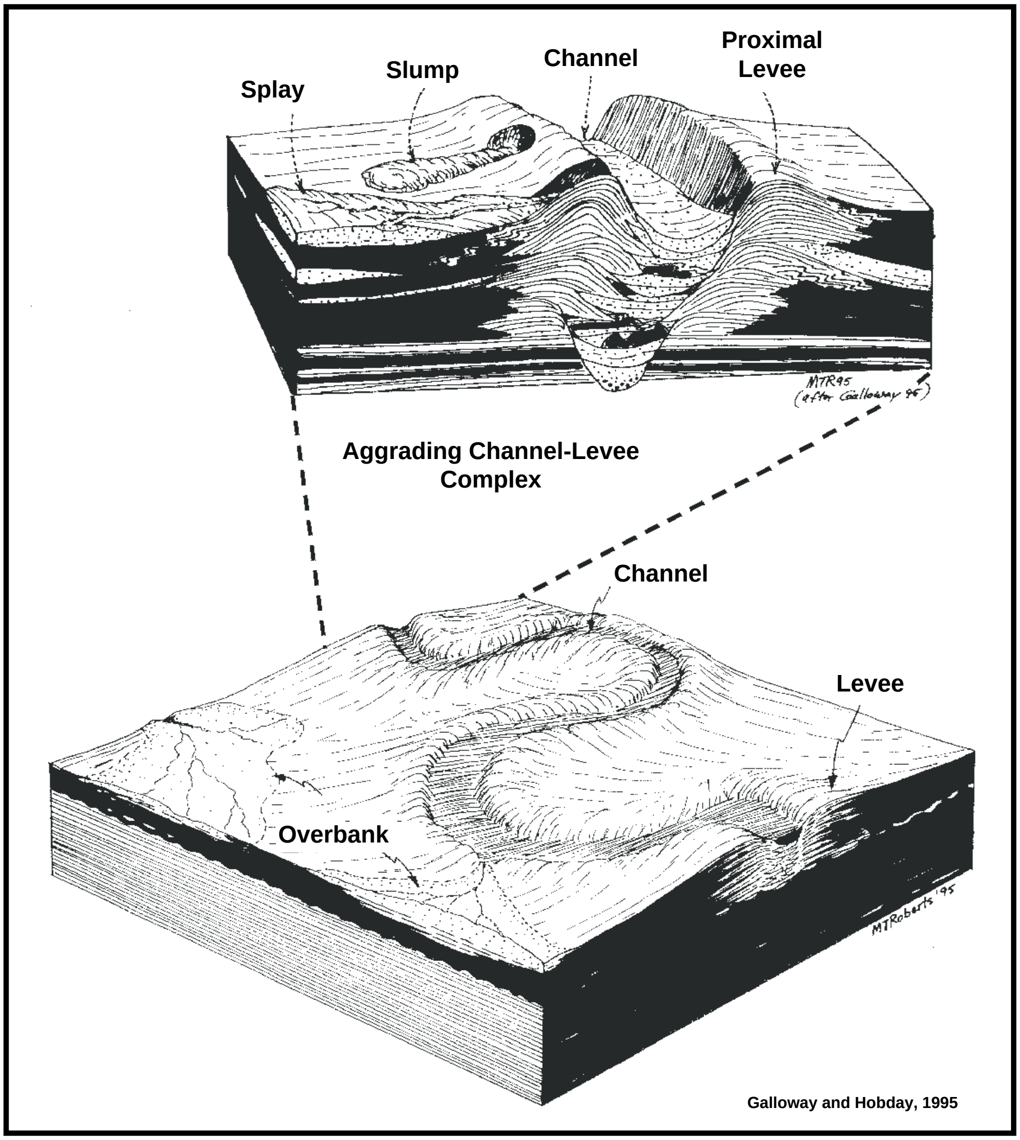


Fig. 4. Block diagrams illustrating possible 3-D architecture of a leveed submarine channel (after Galloway et al., 1996).

An example of a side-scan generated image appears in Figure 3.

The channel shown in Figure 3 exhibits sinuosity similar to that seen in rivers on land. Channel sinuosity appears to be a fundamental characteristic of submarine channels. Sinuosity developed in submarine channels is apparently controlled by two main factors: slope gradient and sediment grain size. Steep slopes (>1%) and coarse-grained sediments commonly develop straight channels while gentle gradients and fine-grained sediment commonly produce a sinuous channel morphology (Clark et al., 1992). Tight meander loops, cutoffs, and abandoned meander loops are common elements of sinuous submarine channels (Clark et al., 1996), much as they are characteristic of the modern Mississippi River.

The 3-D architecture of submarine channels appears to be similar to channels observed on land. Submarine channel architecture is summarized in Figure 4.

Despite the advances of imaging in-place modern submarine channels, the most definitive picture regarding internal sedimentary architecture emerges when geologists examine ancient submarine channels preserved on land. Ancient outcrops provide us with information that is complementary to the interpretation of both modern and subsurface environments.

Two localities in the United States provide valuable insight into the character of submarine channel successions and their internal heterogeneities.

The first locality is just north of Little Rock, Arkansas at Jeffrey Quarry. A single, turbidite-filled submarine-channel in the deepwater Jackfork Formation (Pennsylvanian age) is exposed here in cross section.

This channel is 530 ft (161.6 m) wide and 16.3 ft (5.0 m) thick. Close examination of this channel reveals that the base of the channel is mud-filled and the sand-filled portion consists of seven individual sand members (Kuecher, 1992). Repeated occupation of this same channel over time is suggested. Levees are present, although very low in relief. It is proposed this was a feeder channel on the lower shelf to upper slope.

Fig. 5. An ancient turbidite-filled channel exposed at the Jeffrey Quarry, Arkansas.

The second locality, which is of great interest to petroleum geoscientists, is the Lewis Shale. This is a deepwater deposit of Upper Cretaceous age that outcrops in a remote area near Baggs, Wyoming. The Colorado School of Mines (CSM) has an active research program focused on the Lewis Shale. Baker Atlas was the principal financial sponsor for a test well penetrating the Lewis Shale.

Submarine channels exposed near the drill site were contained within four major sand intervals in the Lewis Shale. The proposed paleogeographic setting for these channels is mid-fan to outer-fan, abyssal floor. A photograph of one of these exhumed submarine channels is shown Figure 6.

The channels vary between 4 and 20 feet (1.2-6.1 m) in thickness and between 10 and 50 feet (3.0-15.2 m) in width. Additionally, they are straight

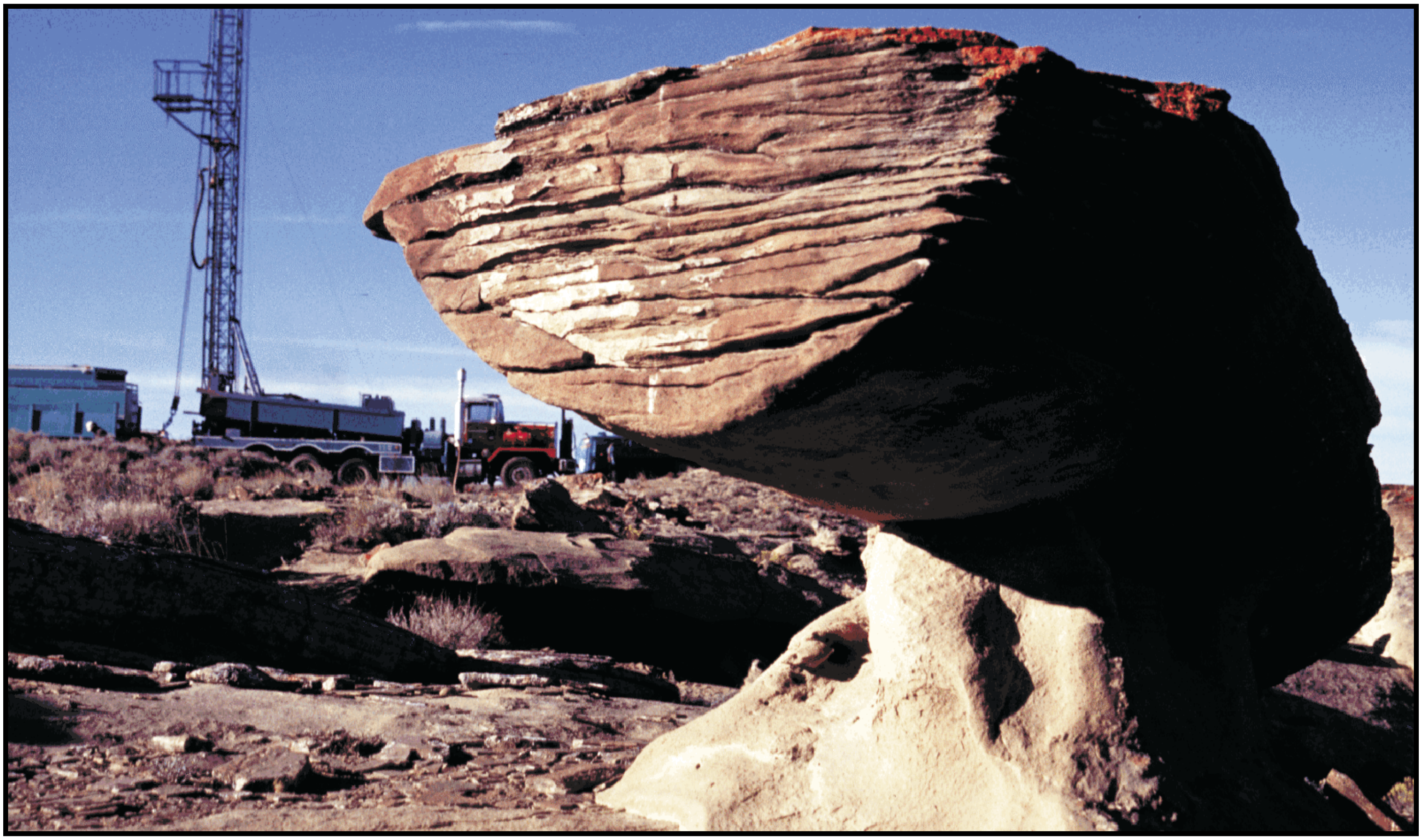


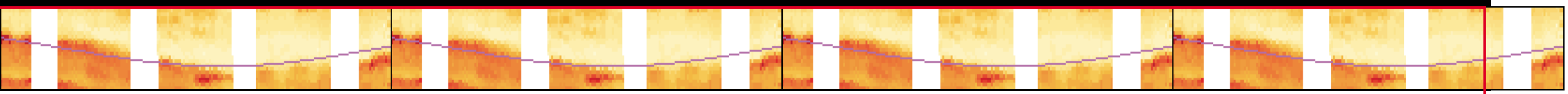
Fig. 6. Submarine distributary channel exposed near the Lewis Shale test well, Baggs, Wyoming. The rig drilling the test hole is in the background.

in plan and parallel with respect to one another. Consolidated, channel fill sands are nested largely within unconsolidated sand intervals in the Lewis Shale called the Dad Sandstones. Internally, these channel fills consist of cross-bedded sands near the base, becoming parallel bedded near the tops.

Conventional core was taken over two intervals straddling the Dad Sandstones and the underlying Lower Shale. These cores were calibrated to Simultaneous Acoustic Resistivity Imager (STAR™) image logs run in this hole. A few examples of the remarkable correlation of core to log is provided in Figures 7-9.

These remarkable images support a number of field observations made over the years in studying submarine channels, namely the existence of channel slumps as in Figure 7, mud-filled channels and oriented mud clasts as in Figure 8, and scour surfaces with amalgamated sands and flame structures as in Figure 9.

So what have we learned from these submarine channels that will improve our effectiveness in dealing with such rocks in the subsurface? Clearly, there are architectural elements common to all submarine channels and there are elements that may be unique to any given submarine channel. Baker Atlas geoscientists are trained in the interpretation of submarine channels and possess considerable expertise in the interpretation of deepwater sediments. STAR imagery is but one of our high resolution logging technologies.



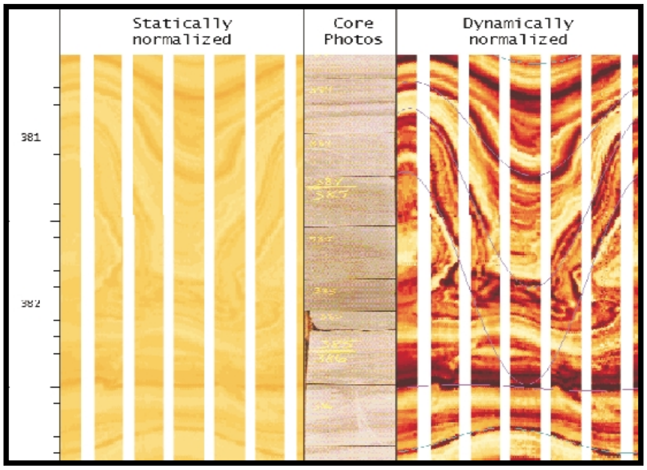


Fig. 7. Baggs site core (center) calibrated with statically normalized (left) and dynamically normalized (right) STAR images. Depth of investigation 380.5 - 383.0 feet below surface elevation.

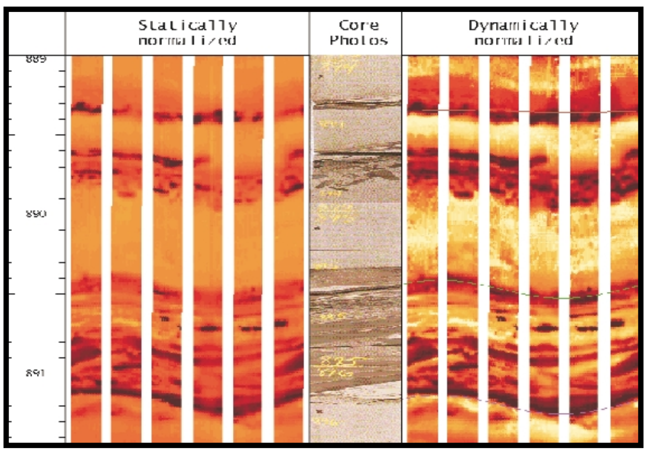


Fig. 8. Baggs site core (center) calibrated with statically normalized (left) and dynamically normalized (right) STAR images. Depth of investigation 889 - 891.5 feet below surface elevation.

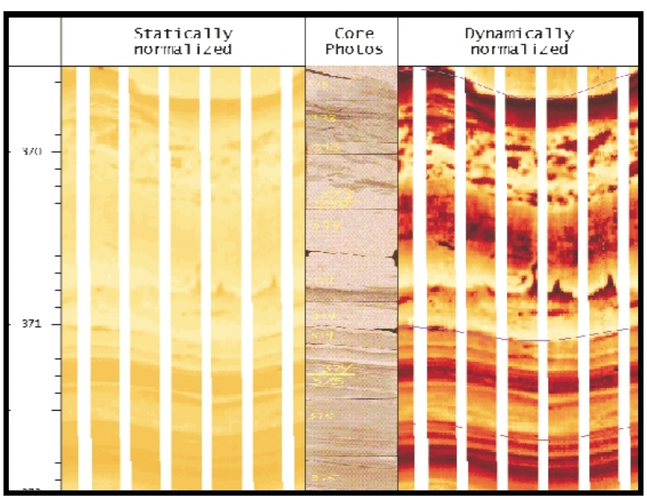


Fig. 9. Baggs site core (center) calibrated to statically normalized (left) and dynamically normalized (right) STAR images. Depth of investigation 904 - 906.5 feet below surface elevation.

About the Authors:

Gerald J. Kuecher holds a Ph.D. in Sedimentology from Louisiana State University. Dr. Kuecher has 11 years experience as a petroleum geologist working with international exploration and production companies and 3 years experience as a professor at Northwestern University in Evanston, Illinois. He joined Baker Atlas in 1998 and works as a sedimentologist and image log analyst.

John J. Millington holds a Ph.D. in Sedimentology from the University of Leicester. Dr. Millington joined Z and S in 1996 and has worked largely with deepwater projects in Europe. By merger, he joined Baker Atlas in 1998 and works as a sedimentologist and image log analyst.

References:

CLARK, J.D., and PICKERING, K.T., 1996. Architectural elements and growth patterns of submarine channels: applications to hydrocarbon exploration, Bulletin of the AAPG, v. 80, no. 2, P. 194-221.

CLARK, J.D., KENYON, N.H. and PICKERING, K.T. 1992. Quantitative analysis of the geometry of submarine channels: implications for the classification of submarine fans. Geology, 20, 633-636.

GALLOWAY, W.E., and HOBDAY, D.K., 1996. Terrigenous Clastic Depositional Systems, Second Edition, Springer-Verlag Publisher, Berlin, p. 195.

KENYON, N.H., and MILLINGTON, J.J., 1995, Contrasting deep-sea depositional systems in the Bering Sea. In: PICKERING, K.T., RICCI LUCCHI, F., SMITH, R., HISCOTT, R.N., AND KENYON, N.H., eds. Atlas of Deep-Water Systems. London, Chapman & Hall, 196-202.

KNIGHT, R., and WESTWOOD J., 1999. Long term prospects very bright for deep waters off West Africa, Oil & Gas Journal, January 18, p. 33-37.

KUECHER, G.J., 1992. Seismic mapping of turbidite channels and channel complexes based on predictable scale. Bulletin of the Basin Research Institute, Louisiana State University, Baton Rouge, March issue. 46-52.

PETTINGILL, H.S., 1998. World Turbidites-2, Oil & Gas Journal, October 12 issue, p. 93-95.

PICKERING, K.T., HINSCOTT, R.N., and HEIN, F.J., 1989. Deep Marine Environments, Unwin-Hyman Publishers, London, 178 pp.

TWICHELL, D.C., ed., 1996. Geology of the United States seafloor: a view from GLORIA, Cambridge University Press, Cambridge, United Kingdom. 181-192, 85-96.

WEIMER, P., and BUFFER, R.T., 1988. Distribution and seismic facies of Mississippi Fan channels. Geology 16, 900-903.