A New View of Something Grand

(Editor's note: The Geophysical Corner is a regular column in the EXPLORER and is produced by Ray Thomasson and the AAPG Geophysical Integration Committee. This month's column is part one of a two-part series on "Revisiting the Grand Canyon – Through the Eyes of Seismic Sequence Stratigraphy.")

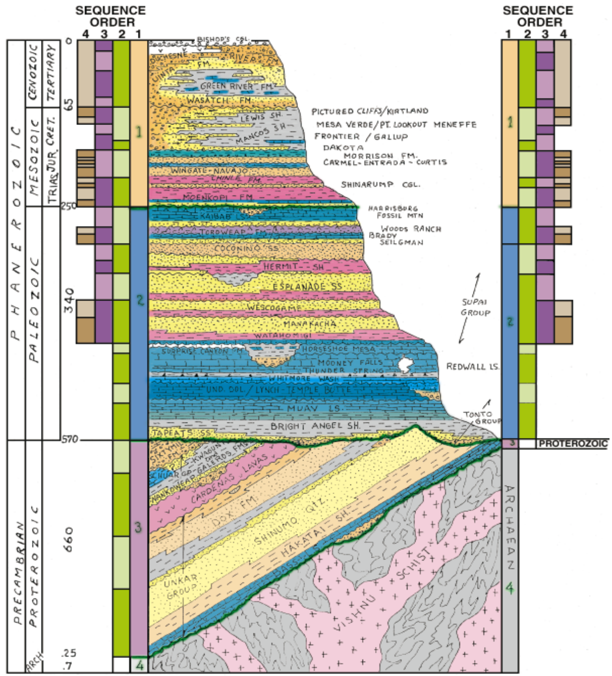
By WARD ABBOTT

The eastern portion of the Grand Canyon in northern Arizona is a geological paradise where previous group and formation designations can be redefined in terms of complete and incomplete unconformity bounded depositional sequences.

Many of these surfaces and their distinguishing characteristics can be recognized seismically.

This portion of the Grand Canyon is one of the most scenically spectacular and geologically instructive areas in North America. Perhaps at no other single locality are so many events, over such a long interval of Earth's history (1.7 billion years) displayed in one view. From Zuni Point on the South Rim, the entire first order sequence of the Paleozoic Era and the first order sequence of the Proterozoic Eon can be observed.

This column is intended to explain the stratigraphy of the eastern Grand Canyon from a sequence analysis viewpoint, in an effort to better describe the geologic history.



Graphics, photos courtesy of Ward Abbott

Figure 1: Hierarchy of depositional sequences — Rocky Mountain area, USA.

It also relates the large-scale geologic phenomenon to seismic scale and shows how they can be recognized on 2-D seismic sections.

The stratigraphy has traditionally been defined from a descriptive point of view and is presently assigned Group, Formation and Member designations. This has led to a lengthy and complicated nomenclature.

The data presented here is based primarily on the work of D.P. Elston, S.S. Beus, E.D. McKee and studies by the author carried out for Shell Oil and Occidental E&P.

The Sequence Model And Grand Canyon Sequence Stratigraphy

As sea, ocean and lake levels rise and fall in response to tectonic, eustatic and climatic events, in both active and passive tectonic settings, a predictable pattern of sedimentary fill for clastic and carbonate rocks can be established.

The grouping together of unconformity-bounded genetic sequences of rocks establishes a complete depositional sequence and its systems tract deposits can be predicated for continental settings, coastal plains, shelf areas, platforms and basins. Therefore, when studying

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Figure 2: Pima Point, looking east. Here, the second order Supai Group can be broken down into two third order sequences, and the lower third order into two fourth order sequences. The second order Mississippian Redwall sequence is seen in the massive cliff, and karsting is evident at the top of the limestone unit. An incised valley fill is present at the top of the Esplanade/base of the Hermit Shale.

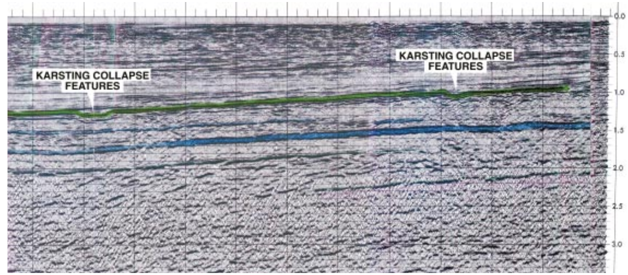

Figure 3: This seismic line shows two examples of collapsed karsting features on a highstand systems tract carbonate shelf. They resemble downcutting, incised valleys on this single seismic line – however, regional mapping indicates that they align parallel to the shelf margin and are sporadic in occurrence. This, along with the collapsed drape, indicates that they are collapsed karsting features.

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and/or correlating outcrop, well and seismic data the observer has the complete, predicted section to compare to his data to define areas where erosion or non-deposition have left only a partial or incomplete sequence.

Unconformity bounded depositional sequence terminology and diagrams have appeared in geologic literature for the last decade. The basic nomenclature and sequence terminology as they pertain to the stratigraphy of the eastern Grand Canyon are shown on Figure 1 (page 20).

From the Grand Canyon display, earth scientists can see that the sequence model has been repeated again and again as depositional base level rises and falls from the Precambrian all the way to the Pleistocene. This same pattern is repeated throughout the earth in different marine and continental settings.

This method of analyzing different genetic sedimentary rocks allows the interpreter to easily visualize the varied phases of geologic history. It offers a "quick look" analysis of the occurrence of hydrocarbon reservoirs, seals and source rocks.

The sediments deposited during the Paleozoic Era are assigned to a first order sequence. Sediments assigned to Group designations are usually classed as second order sequences and generally formation designations represent partial, or in some cases, complete sequences of third and fourth order (see Figure 2).

Each second, third and fourth order sequence typically has a sea level rise, stillstand and fall phase designated as transgressive systems tracts (TST), highstand systems tracts (HST) and lowstand systems tracts (LST).

Fifth order sequences, however, are defined by a base level rise and stillstand with no fall phase and are considered to be eustatic only. Second through fourth order sequence designations are primarily based on time, but thickness and aerial extent also play a part.

Because of their great lateral extent and thickness, incised valleys and basin floor turbidites of second through third order sequences are the only scale to be considered from an exploration point of view, while the fourth and fifth order parasequence categories are mainly used at production scale.

Classic karsting and incised valleys (Figure 2) document the sequence boundaries of the parallel strata of the Grand Canyon.

Parallel stratal patterns are the most common in the stratigraphic record and the hardest to use to

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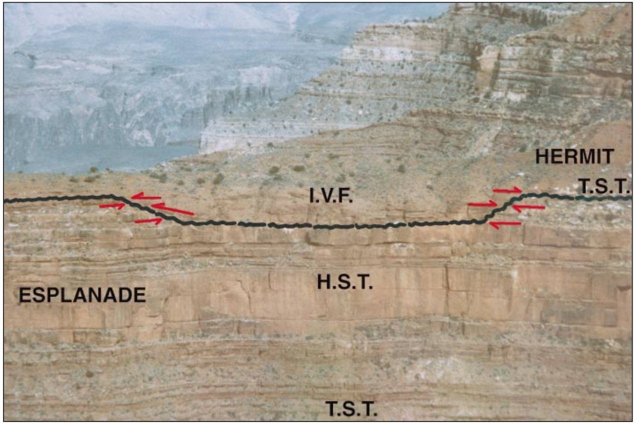

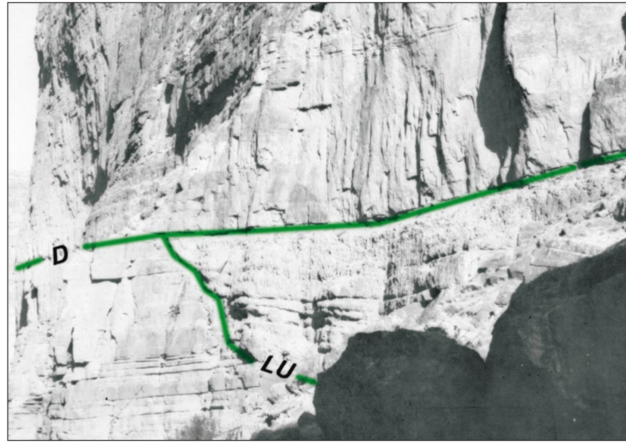

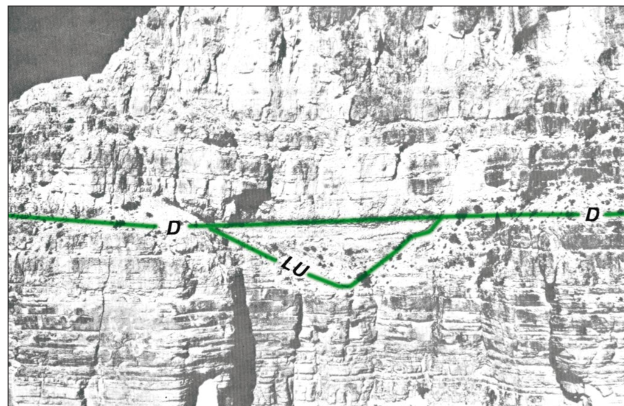

Figure 4 (top left): Pima Point, where downcutting erosional truncation and onlap stratal patterns define the lowstand systems tract incised valley of the Hermit Shale, indicating a surface of erosion and nondeposition. Basinward, LST deposits can be predicted. Figures 5 and 6 (right top and bottom) show Temple Butte incised valley in Marble Canyon and in Eastern Grand Canyon, respectively. Of interest is the truncation of the Mauv (HST) shelf carbonates and the onlap patterns of the Temple Butte fill on the side of the channel wall. (Photos courtesy of W.K. Hamblin)

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define sequence boundaries. Because of this, much of the geologic history contained in them is overlooked.

Generally, there are no clues as to where to define the disconformity surface or sequence boundary.

Therefore, a knowledge of the sequence model can be of great assistance. If one knows the critical criteria to look for in defining the TST, HST and LST, proper placement can be achieved.

Facies criteria, paleo information, sedimentary structures and environmental data all can help in the correct placement of unconformity and sequence boundaries. The

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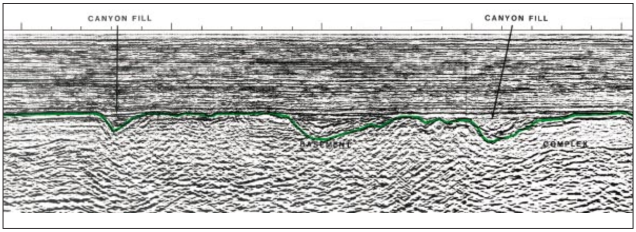

Figure 7: This seismic line illustrates the downcutting erosional truncation and onlap stratal patterns that define a lowstand systems tract incised valley.

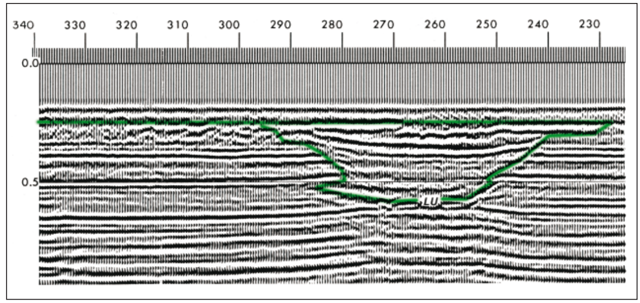

Figure 8: This seismic line illustrates the downcutting and erosional truncation of an incised valley.

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parallel stratal pattern is expressed in disconformity.

The seismic and outcrop expression of these phenomenon are detailed on Figures 3 through 8.

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If you revisit Grand Canyon with the "new eyes" of the seismic sequence stratigrapher you will be convinced of the accuracy of the "sequence model" as you study approximately 15,000 feet of sedimentary rocks exposed at seismic scale continuously for a distance of over 40 miles.

By studying the unconformities in the Grand Canyon one can extrapolate and predict the missing sections for the incomplete sequences and forecast the lowstand systems tracts (shelf margin prograding wedge, slope and basin floor fans) for the deep marine basin setting of eastern California, Nevada and western Utah.

Other sequence boundaries are defined by truncation and onlap. These will be covered next month in this column, with an article on hydrocarbon trap geometries and seals.

(Editor's note: Abbott, a consulting geologist in Washington, Utah, was chief stratigrapher and training coordinator for Occidental International Exploration and Production for 12 years, and had 30 years of experience with Shell Oil in stratigraphic research, teaching and structural/stratigraphic play and prospect development.)

Canyon Offers Grand Seismic View

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By WARD ABBOTT

The Grand Canyon offers a unique opportunity to use the Earth as a textbook (Figure 1) – and sequence stratigraphy not only offers a "quick look" approach to analyzing the hydrocarbon seals, reservoirs and source rocks, it also allows one to visualize and interpret the various trap types.

One can use the Grand Canyon as a model and view angular unconformities, nonconformities, disconformities and local unconformities. First through fifth order depositional sequences are spectacularly displayed. Stratigraphic traps for hydrocarbon plays and prospects are highlighted by facies changes, onlap and truncation stratal patterns. Seals, source rock intervals and maximum flooding surfaces can be clearly defined.

In addition, one of the most exciting facets of studying at the Grand Canyon is that it is one of the world's best laboratories for comparing outcrop data to seismic data. This helps the explorationist avoid some of the pitfalls inherent in correlation.

Hydrocarbon Trap Geometries

By understanding the different stratal patterns and unconformities of this unique geologic setting, an explorationist can use this earth model as a textbook to compare outcrop data to seismic data (even though Ordovician, Silurian and Lower

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Figure 1:

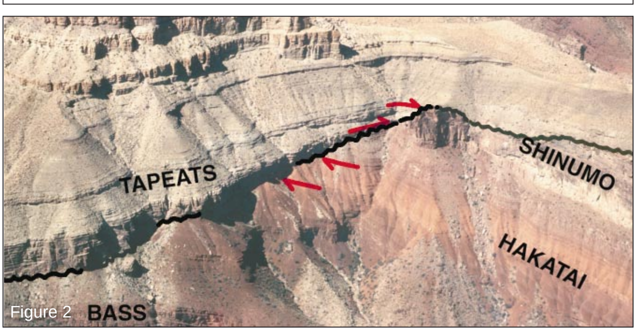


Figure 2

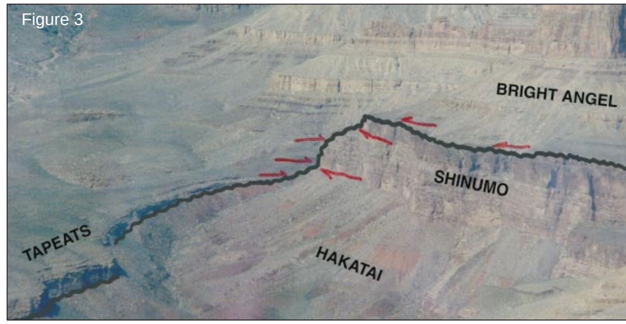
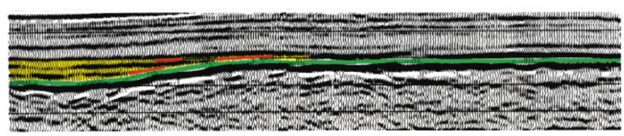


Figure 3

Figure 4


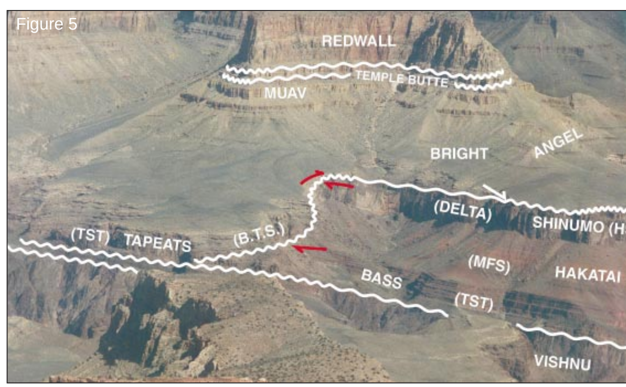
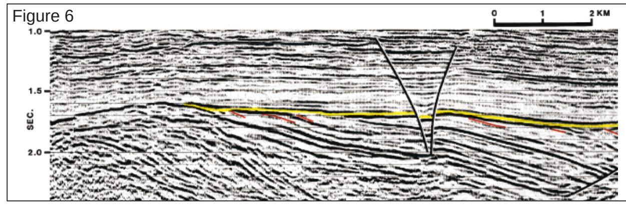


Figure 5

Figure 6


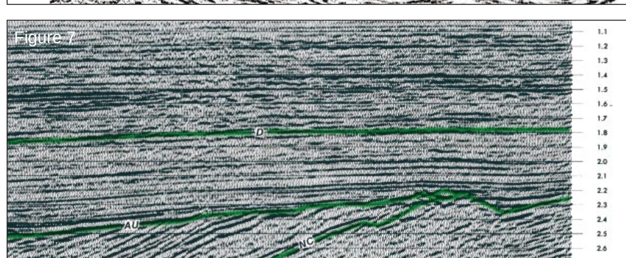


Figure 7

Figure 1: The hierarchy of depositional sequences of the Rocky Mountain area. Figure 2: Looking west from Zuni Point, the uplifted and truncated, basal Proterozoic second order sequence; note the two sandstone units in the Tapeats. Figure 3: A regional, northwest view from Yavapai Point showing the truncated Proterozoic. Figure 4: Partial seismic line illustrates the onlap pattern of a basal transgressive systems tract sand as it onlaps a basement high. Figure 5: This photo, taken at Grandview Point, shows the first, second order sequence of the Proterozoic, and the first second order Paleozoic sequence; the "Great Unconformity" separates these two sequences. Figure 6: Partial seismic line illustrates the truncation, facies pinch-out and the potential hydrocarbon traps illustrated in figures 2, 3 and 5. This comparison of outcrop and seismic data demonstrates the need for the outcrop model to correctly interpret the seismic geometry and predict facies. Figure 7: Seismic line illustrates three regional unconformity surfaces and portrays the basic geometry exposed in the Grand Canyon. Compare figures 2, 3 and 5 for similar geometries to infer facies on this seismic section.

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Devonian rocks are missing).

One can study approximately 15,000 feet of sedimentary rocks exposed at seismic scale (equivalent 1.5-2.0 seconds) continuously for a distance of over 40 miles.

These extensive exposures allow the correlation of outcrop geometries and facies to seismic geometry to infer facies and environment and underscore the importance of having an outcrop model, at seismic scale, to correctly interpret seismic data and define potential hydrocarbon traps.

These trap geometries are illustrated by photos, diagrams, seismic lines and a description of different stratal patterns in Figures 1 through 8.

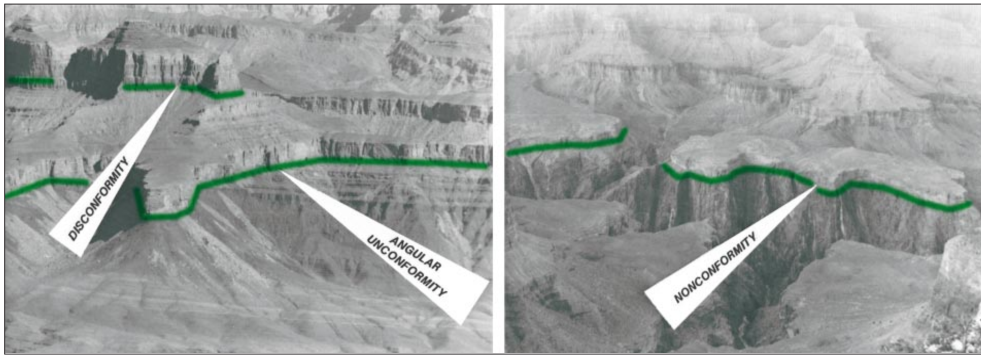

Figure 8: These two photos show three regional unconformity surfaces in the Grand Canyon that are comparable to the seismic line shown on figure 7 (previous page).

Stratal Patterns

Truncation and onlap stratal patterns that define upper and lower boundaries of depositional sequences can be observed in the eastern Grand Canyon area in the Proterozoic and Paleozoic stratigraphic sections.

These stratal patterns are critical to the proper placement of unconformities.

Truncation Patterns

Truncation patterns define the top sequence boundary in second, third and fourth order sequences. There are two types:

❐ Those caused by uplift and erosion (regional scale).

❐ Those due to down cutting erosion (local scale).

In both cases the geologic history of the destroyed or missing section needs to be restored. The time of erosion and the time of fill need to be analyzed to establish proper correlations and geologic history.

The truncation pattern is expressed in angular unconformity. The outcrop expression of these patterns is shown on Figures 2,3, 5 and 8, and they are displayed seismically on Figure 4, 6 and 7.

Onlap Patterns

Onlap patterns define the base sequence boundary in second, third and fourth order sequences. This pattern indicates surfaces of non-deposition.

Onlap patterns can be of local extent, defining the side of incised valleys, or on a more regional scale, defining marine, coastal and non-marine coastal onlaps in transgressive systems tract settings. This pattern is expressed in nonconformity, disconformity and angular unconformity.

The seismic expression of these patterns is shown on Figures 4, 6 and 7, and outcrop comparison is shown on Figures 2, 3, 5 and 8.

I hope you will take the opportunity soon to revisit the Grand Canyon and "see it again for the first time" through the eyes of sequence stratigraphy. It represents one of the most scenically spectacular and geologically instructive areas of North America.

Taking a "seismic scale view" of earth's past is sure to be a rewarding experience.

(Editor's note: Abbott, a consulting geologist in Washington, Utah, was chief stratigrapher and training coordinator for Occidental International Exploration and Production for 12 years, and had 30 years of experience with Shell Oil in stratigraphic research, teaching and structural/stratigraphic play and prospect development.)