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STATE OF ARKANSAS

ARKANSAS GEOLOGICAL COMMISSION

Norman F. Williams, State Geologist

THE JACKFORK FORMATION OF ARKANSAS

A TEST OF THE WALKER-MUTTI-VAIL MODELS

FOR DEEP-SEA FAN DEPOSITION

by

James L. Coleman, Jr., Amoco Production Company
Gordon Van Swearingen, Mortimer Exploration Company
and
Curtis E. Breckon, University of Tulsa

Prepared for the South-Central Section
Geological Society of America
Little Rock, Arkansas
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ABSTRACT

The Jackfork Formation of the Arkansas and Oklahoma Ouachita Mountains is part of one of the most completely studied, large submarine fan complexes in the world. As such, geologists in the U.S.A. probably know more about it than many other deep water sedimentary complexes. By taking a detailed look at a single, complete transect of the Jackfork Fan, well out into the depositional basin, one should be able to measure the effectiveness of the most popular deep sea fan models and judge whether the recommended abandonment of these models, in two instances by the authors themselves, is warranted.

The mood of most veteran submarine fan workers is to abandon the generalized depositional facies models of the past, because no one model accurately predicts observations of all submarine fan complexes. Yet, the managements of today's mineral and hydrocarbon exploration and production companies frequently request that investment recommendations be explained in terms most commonly associated with these models. Additionally, geoscientists have demonstrated the need for viable, spatially-oriented models as frameworks in which to bring observations, ideas, theories, and communication.

The Jackfork Formation in the vicinity of DeGray Dam and Lake is almost continuously exposed for 7000 feet (2133 meters) between its stratigraphic top and bottom, without significant fault offset or interruption. The exposures in this area are approximately 150 miles (241 km) from the northern, eastern, and southern paleo-shelf edges.

Jackfork deposition was initiated through a combination of increased precipitation, weathering, and runoff immediately prior to a large, relative sea-level fall. The section at DeGray begins with a complex of debris flows and channel-fill sandstones and intrachannel(?) shales and siltstones, and progresses upwards through a thick channel-levee overbank section, with channel complexes increasing in thickness. The section is capped by thick channel-fill sandstones and slump deposits, and is unconformably overlain by the Johns Valley Shale.

Regional and detailed interpretation of outcrop and subsurface data in the Ouachita Basin makes understanding the depositional location of the DeGray area outcrops relatively

straightforward. As such, these outcrops enable an objective evaluation of today's popular deep-sea fan depositional models.

INTRODUCTION

The purpose of this trip is to examine the functionality of widely used, deep-sea fan models to adequately predict facies succession of a deep-sea fan complex. In doing so, we will also examine the Jackfork Formation as a type example for large, deep-sea fans.

To some, it may seem pointless to test the functionality of concepts generated by some of the masters at sedimentary complex interpretation. To others, who have cast aside all belief in the utility of models beyond the "type locality" for that model, this exercise may seem utterly stupid, or at least without any scientific or economic merit whatsoever. However, to some (or possibly to many), establishing the viability of a depositional model as a useful interpretation framework is comforting during one's struggle to understand and extremely helpful during one's attempt to explain.

The collective stops on this trip are meant to mimic a single point of control, almost like a well with an unbelievably large core. Visiting the DeGray area is similar to falling out of the sky (or, perhaps, a boat) and landing somewhere on the surface of a large submarine fan. Many times we know very little about the fan before we land. Thus, some type of model is needed to put our one point into a regional perspective to understand better the economic potential of our location, as well as any regional significance this location has.

DEVELOPING THE MODEL

Before we develop our model(s) and our testing process, a brief review of deep-sea sedimentology and the historical background of this study is appropriate. Perhaps this will also help us to understand the viewpoint as well as the scale of thought of the modeler. This scale of thought translates subconsciously, if not consciously, to the effective scale of the model.

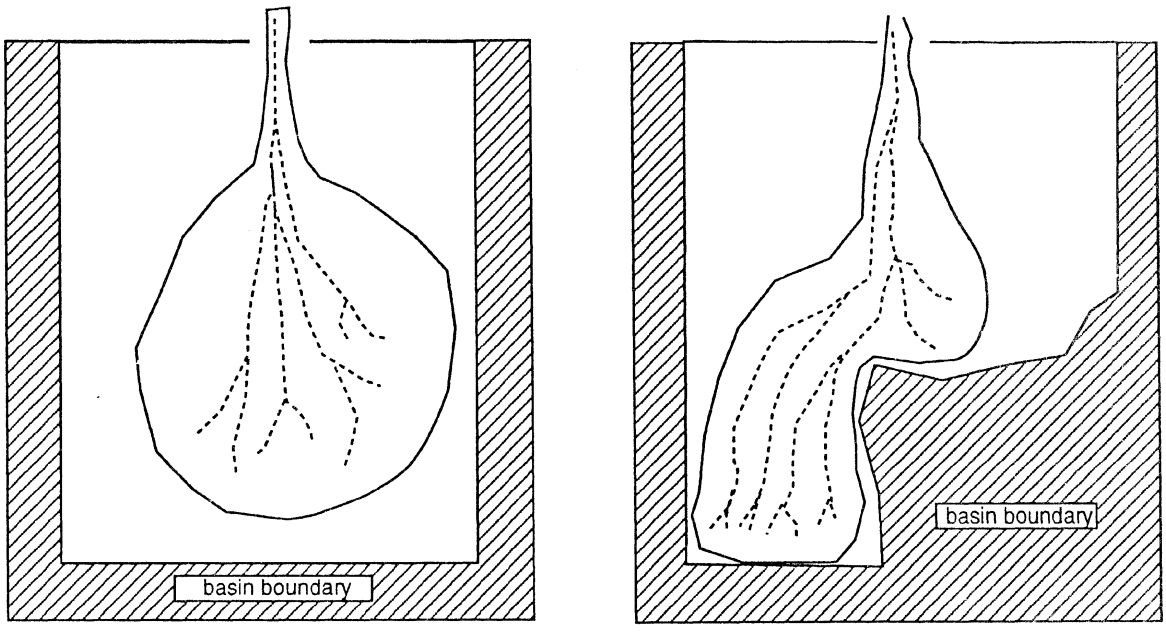
Large, laboratory basin-modelling studies of turbidites (i.e., Ravenne et al., 1990; Simpson, 1987) show that density currents emanating from a point source repetitively produce fan-shaped deposits as long as the flow is not affected by the boundaries of the study basin (Figure 1a). If the volume of the suspended load is sufficiently large, the deposit will always take the shape of the settling basin (Figure 1b). Subaqueous debris flows behave like turbidite flows and also spread out across the basin. Likewise, if they are constrained by the basin, they will take its shape (Middleton and Hampton, 1976; Hampton, 1972).

Laboratory, outcrop, and reflection-seismic profile studies have shown that a sedimentary succession in basinal deposits proceeds generally in this manner:

slides and slumps >>> debris flows >>> turbidites

(Dott, 1963; Walker, 1978; Einsele, 1991; Mutti, 1992)

The density of each of these flow types may vary and will generally decrease in the down-current direction.



1a. UNBOUNDED DENSITY-FLOW DEPOSIT

1b. BOUNDED DENSITY FLOW

Figure 1. Schematic diagrams of the shapes of bounded and unbounded density-flow deposits.

Examination of these laboratory models shows a continuum through time and space of submarine depositional processes. These processes do not continually segregate into discrete sedimentary process areas, rather, they tend to move laterally into a nearby depositional site. Analyses of Holocene and late Pleistocene fan complexes indicate that different sedimentary processes may be active at the same time across the whole fan complex. Yet, during any one interval of time, under nearly uniform basinal conditions, these processes tend to occur in reasonably repetitive, subregional areas.

The Bouma (1962) sequence describes an ideal turbidity-current deposit. However, variations in provenance areas may lead to variations in flow, grain content, size, and availability. High-density turbidite flows usually do not produce the typical Bouma, fining-upward sequence that low-density turbidity currents do (c.f. Lowe, 1982, for a detailed discussion). Grain-size variations and compositions, in conjunction with transport distance, may cause a significant variation in Bouma sequences down current, such that some members of the idealized sequence may be missing (Lowe, 1982; Mutti, 1992). Recognizing and identifying what is missing from the idealized sequence, as well as what is present, can be highly significant in reconstructing the size and distribution of a turbidite system (Mutti, 1992).

Walker (1973, 1980) and Shanmugam and Moiola (1988) have reviewed in some detail the history of fan-model development. The modern study of turbidites and deep-sea fans has its origin in early work by Kuenen and Migliorini (1950). By 1959, sedimentologists were developing models to explain some shallow-water phenomena. With the initial success of this type of scientific logic and application, a flood of sedimentary models were published in the 1960's. Walker's (1965) paper was one of these and discussed early concepts of submarine sedimentation. Most of the early models were developed from one or a few submarine fan complexes and were used to interpret later studies in model-driven logic paths. Unfortunately (perhaps?), the data collected on turbidite sedimentation, which were used to formulate early, as well as recent models, come mostly from the past forty years of outcrop examination in thrust--fold belts (Mutti, 1992).

For the purpose of this exercise, we have chosen three of the more widely used (and therefore, by implication only, popular) models -- not that there are not many more equally useful (or disuseful) models, just these three accurately represent the spectrum of potential for the set of available models. The models we have chosen are those commonly associated with Roger Walker, Emiliano Mutti, and Peter Vail. They are reviewed in chronological order of their development.

THE WALKER MODEL

The Walker Model, as presented in Walker (1978, and earlier with E. Mutti, 1973) stands as an example of a model developed from sedimentological observations and associated sedimentary process regimes or areas. It was born out of Walker's (1964) Ph.D. dissertation (published, in part, as Walker, 1966) and drew extensively from Normark's (1970) study of modern California fans and Mutti's ideas from ancient fans in Spain and Italy. As such, it is similar to, yet more inclusive in depositional concepts than Normark's (1970) and Mutti and Ricci-Luchi's (1972) models. These models put the Bouma model (1962) for turbidite depositional dynamics into two- and three-dimensional space.

The Walker Model looks at fans from the viewpoint of a detailed sedimentologist with a need to relate spatial and temporal sedimentary events and facies to each other. It works well within one outcrop or a set of related outcrops. The model works best when limited to application within the fan complex.

The Walker-Model fan complex is divided into eight depositional processes areas, each of which is transitional with its bounding neighbor. These process areas can be divided into:

Slope -- canyon cuts and fills, slope slumps, debris flows

Upper Fan -- sinuous, meandering channels with flanking terraces

Middle Fan -- shifting lobes composed of non-leveed, braided channels; grades imperceptibly with the lower fan

Lower Fan -- smooth, low-gradient area, with periodic deposition of very regular and parallel-bedded "classic turbidites"

Basin Plain -- slow hemipelagic sedimentation

A smooth continuum exists between the fan areas. Channelized areas (upper fan and the upper reaches of the middle fan) are recognized by a fining- (or thinning-) upward pattern, whereas the non-channelized (or lobe) areas (lower middle fan to outer lower fan) are characterized by a coarsening- (or thickening-) upward sequence.

In the Walker Model, no spatial or temporal scale is implied; nor is a driving mechanism. It is a dynamic, prograding model (*a la* riverine deltas). Within this model, the fan does not undergo any (or at least any significant) modification after deposition. It is primarily an areal distribution map of sedimentary process cells.

Walker sustained and simplified his model through the 1980's (Walker, 1984b), but following the publication of numerous, seismically-based interpretations of modern fans, he had abandoned his model by 1989. In unpublished short-course notes Walker (1989), presented the elements of a new fan model which incorporated the effects of sea-level change and was heavily based

on seismic facies characteristics of modern, passive-margin fans. The essence of these notes was published in Walker (1992b). This new model embraces the sedimentary process areas of upper, middle, and lower fan for channel-levee and non-channelized deposition. It also incorporates debris flows as a significant fan-building agent.

> Inner Fan -- 1 main, active channel at any one time, in a stacked set of channel-levee complexes; some lateral channel migration
>
> Middle Fan -- 1 main channel, successive in nature, producing through time and avulsion, a set of shingled, channel-levee complexes
>
> Lower Fan -- numerous wide and shallow, non-leveed channels producing extensive turbidite sheets; sand depocenter
>
> Debris flows -- present across all elements of fan
>
> (Modified from Walker, 1990b, unpublished.)

Much of Walker's new model is based on the seismic-sequence analysis of the Mississippi Fan by Weimer (1989, 1990). Weimer recognized seventeen seismic sequences, each of which is characterized by the following succession:

> ^ channel-levee and overbank systems
>
> ^ mass transport deposits

Mass-transport deposits are distinguished by hummocky and mounded reflectors of poor to fair continuity and variable amplitude. They occur at the base of sequences and are overlain and/or overlapped by channel and levee sediments. Mass-transport deposits are interpreted to have formed as disorganized slides, debris flows, and turbidites.

Overlying the mass-transport deposits are channel-levee systems which represent 80 - 90% of the fan's sediments. Channels have high amplitude, subparallel reflections; levees have subparallel reflections that have high amplitudes at the base changing upward to low amplitudes. Overbank sediments have interbedded subparallel to hummocky and mounded reflections, suggesting both channel-derived turbidites as well as slope- and locally-derived slides and debris flows.

Weimer's work suggests that the following sequences of events have happened repeatedly on the Mississippi Fan:

> (final)↑ Fan "abandoned"/condensed section deposited
>
> ↑ Major channel-levee systems form
>
> ↑ Initial channels form
>
> ↑ Debris flow deposition >> mass transport complexes
>
> (initial)↑Renewed slope slumping and canyon forming/enlarging

This sequence interpretation may prove useful in understanding the Mississippi Fan, but may not be transferrable to other large, open-ocean or foreland-basin fans.

THE MUTTI MODEL

The Mutti Model for fan complexes, as most commonly used today, is his 1985 version, which we subtitle the "sediment-availability" model. This model divides basinal deposition into three phases of fan construction: Type I, II, and III. As originally published, this model did not incorporate sedimentological processes *per se*, but rather a stratigraphic stacking/ordering of turbidite sequences.

The Mutti Model is the viewpoint of an experienced field geologist who needs to correlate from one sedimentary area or structural panel to another within the same stratigraphic age. It functions best at the basin scale.

Type I turbidite systems contain the bulk of sandstone deposition in non-channelized and elongate bodies or lobes in the outer reaches of the system. These sandstone bodies have a high degree of lateral continuity and a general tabular geometry across tens of kilometers. These deposits commonly grade from thick-bedded, coarse-grained strata to thin-bedded, fine-grained lobe-fringe deposits down current. Up current these deposits are apparently transitional with chaotic, debris-flow sediments filling erosional channels. Type II systems include all sandstone facies deposited in the lower reaches of channels and in lobes beyond the channel margins. Type III systems have small sandstone-filled channels surrounded by muddy sequences. The sandstone facies do not extend very far basinward and are restricted to inner reaches of the fan complex. Composites of all three types are apparently common as sea-level variations control various styles of growth.

Type I systems are extremely large, measuring 10's of miles (kilometers) parallel to the current, with each lobe ranging between 11.5 and 57 ft (4 and 17 m) in thickness. Type II deposits are highly variable in their dimensions, ranging between 2.5 and 12.5 mi (4 and 20 km) across and 33 to 330 ft (10 to 100 m) thick. Type III systems may be as thick as 33 ft (10 m) and as wide as 330 ft (100 m). A composite thickness and areal extent of all three systems may constititute a volume in excess of 4800 cu. mi. (20,000 cu. km).

Sediment availability drives the system, although sea level falls may accentuate basinal sedimentation. Large-scale, catastrophic slope failure typically produces the largest Type I system. Type I and II systems are characteristic of lowstands; however, some Type II systems probably could form during highstands, if high rates of deltaic sedimentation caused the delta to prograde beyond the shelf edge. Type III systems are commonly deposited during highstands. The duration of sedimentation will vary based on sediment availability; however, the initial megaslumping which sets off Type I deposition probably takes places in a very short period of geologic time. Hence, Type I deposition must also be very rapid.

The Mutti Model has been discussed numerous times, and usually by people trying to invalidate some points of the model (c.f., Shanmugam and Moiola, 1988) It may have been this constant dissention which led Mutti to drop his spatial model in favor of a sedimentological processes model without any specific spatial bounds (i.e., a graphic depiction of his model does not necessarily look like a map, cross section, or stratigraphic column).

Mutti (1992) developed his newest model using the sedimentary process element by dividing the parent turbidite flow into a series of attached or detached facies tracts F1 (coarse-grained debris flows) through F9b (fine-grained, traction-current deposits). Recognition of these facies tracts enables the observer to interpret where within the parent flow a particular outcrop (or core) rests. This new model is not three- (or four-) dimensional and is very detail-dependent to resolve the "where am I" problem. Mutti also upgrades the importance of post-depositional, bottom-current re-working in molding the final sedimentary product.

THE VAIL MODEL

The Vail Model is attributed to Peter Vail in the sense that he is considered the founding father of modern sequence stratigraphy. Pure credit probably should be extended to him as well as all of his Exxon colleagues who helped discover and modify the concepts. The Vail model, as discussed here, is a synthesis of Mitchum (1985), Vail (1987), Posamentier et al. (1988), and Vail et al. (1991). It is a genetic model driven by eustatic changes in global sea level. It is independent of sedimentary processes to a certain extent (and sediment type to a much greater extent). While specific lithofacies are inferred to dominate a certain systems tract, they are by no means a guaranteed phenomena.

It is primarily a geometric model, driven by a spatial association of geophysical phenomena. The Vail Model is the most far-ranging of "our" three models. It has a sequence stratigraphic viewpoint developed from years of seismic and well-log-profile stratigraphic analysis. Its application allows the user to work from the bordering shelf areas into the deep basin.

The initial modern concepts of sequence stratigraphy (Payton, 1977) called for increased basinal sedimentation during sea-level falls (Vail et al., 1977). Mitchum (1985) depicted the seismic-facies characteristics of fans in terms of leveed channels (concave up) facies of the upper fan and lobes (convex up) of the lower fan. The adjacent canyon-fill facies was marked by erosional truncation and shale infill. Vail (1987) introduced the terms "basin-floor fan", "slope fan", and "lowstand wedge-prograding complex" to basinal sedimentation. These deposits overlie a regional sequence boundary. Basin-floor fans are composed primarily of massive sands or carbonate debris deposits in channels or lobes. They are widespread and 100 to 300 ft (30 to 91 m) thick and were deposited during a relative fall in sea level. Slope fans are composed of debris flows and turbidite channel-levee-overbank deposits. They may occur in a variety of sizes, but are generally associated with the last portion of the sea-level fall and the beginning of the relative lowstand stillstand. Lowstand wedges are built up by prograding, lowstand deltas. These also have a variety of shapes and sizes and are deposited during the late lowstand stillstand and the beginning of the following rise. Modification by basin bathymetry (i.e., ramp, shelf margin, growth faulted) are to be anticipated. Posamentier et al., (1988) introduced three-dimensionality to the sequence stratigraphic, time-sea level change model. More lithologic details were added by Vail et al., (1991). Vail (with his colleagues) remains alone in our trio in retaining his model as an effective predictor of basinal sediments.

PROBLEMS WITH FAN MODELS

Dislike (or distrust) of sedimentary models probably began the day after the first model was formulated. In recent years, Bouma et al. (1985) were instrumental in pointing out major problems in creating generalized fan models.

Mutti and Normark (1987) acknowledged this predicament, offered a systematic approach to comparing submarine-fan complexes, and supported a moratorium on model building until adequate field work resolved many of the questions posed. Then they proposed a matrix of comparison to facilitate the understanding of submarine fans:

Type of Basin:

A (oceanic crust -- no tectonic activity)

B (oceanic crust -- tectonic activity)

C (continental crust -- continuous, tectonic activity

D (continental crust -- high amplitude, short-cycle tectonic activity)

Scale Factors: 1st (basin scale)
2nd (depositional sequence)
3rd (including turbidite systems)
4th (depositional environment area)
5th (specific depositional features)

Sedimentary process areas:
channel deposits
scours (scour fills)
overbank deposits
lobes (lobe deposition)
channel to lobe transition

Bouma (1992) advocates the sedimentary process analysis and interpretation approach, reminding workers that frequently investigators refer back to models so as to locate their outcrops or wells. This method of somewhat circular reasoning is then reinforced, because the models can be used to successfully predict individual locations on an ancient fan complex. Bouma (1992) concludes that we will be unable to satisfactorily interpret a submarine-fan complex as long as we fail to map out the entire complex in three dimensions.

Shanmugam and Moiola (1988) recognized that "a clear understanding of [submarine-fan] geometry, facies relationships, and reservoir quality is critical for exploring and exploiting these deposits effectively" (p. 383). The emphasis of this statement, which is generally adhered to by most, if not all, submarine-fan workers, is that a three- (and four-) dimensional understanding is needed -- a format, a map, a model of some type -- for communication, interpretation, and interpolation and extrapolation of data and ideas.

REQUIREMENTS FOR EFFECTIVE MODELS

Walker (1979, p. 3; 1984a, p. 5; 1992a, p. 6) defined a facies model as "a general summary, of a specific sedimentary environment, written in terms that make the summary usable in at least four different ways."

The essential ingredients of any model (Walker, 1979, 1984a, 1992a) which will serve us well in testing "our" three (and any other) depositional facies models are:

1. It must act as a norm.
2. It must act as a framework and guide for future observation.
3. It must act as a predictor in new situations.
4. It must act as an integrated basis for interpretation.

As a norm, it must be comparable with new examples to determine if a new example contains any unusual features. Conformity strengthens the model, and disconformity prompts

significant questions targeted at understanding the causes for the differences. As a guide for future observations, workers need to look for the key elements of a model when looking at a new example. Walker (1992a) warns against not looking for new information that may not be specifically indicated by the model in its present condition. As a predictor, the model acts in its most important role. It enables us to make interpretations of partial information (a seismic line, an outcrop, a well log) and hopefully avoid potentially large amounts of guesswork, as well as time and money expenditures. With the final factor, to act as an integrated basis for interpretation, the model combines features of numerous examples (not one or two local ones) for what becomes a common body of knowledge.

A model becomes more precise with the degree of homogeneity of sedimentary processes and less effective as the homogeneity degrades (decreases). A model which includes examples from diverse basin types and diverse morphologies will result in a high degree of inhomogeneity and low predictability. Models which subdivide the examples into sufficient cells of commonality (i.e., basin type, relative sea level, etc.), and which show a higher degree of homogeneity, are therefore much more valuable.

Walker (1992a) concludes that because all depositional systems are controlled by internal as well as external controls, any model must take into account these factors, especially the external controls of relative sea-level changes and tectonics. "This is best done in the flexible context of allostratigraphy*, instead of the rather theoretical and more interpretive framework of sequence stratigraphy " (Walker, 1992a, p. 13).

Walker (1990a, p. 779) emphasized that "a model can only predict within the framework of the model." He concluded, "I strongly retain the idea that facies models are absolutely necessary in stratigraphy and sedimentology, and hence that efforts to improve existing models and construct new ones are worthwhile. Models alone give us a *norm*, without which we are unable to assess the significance of a new example. Models alone embody the *predictive* capability of *sedimentology*. . . ." (Walker's italics).

A model can be simply visualized as a net. A net is a lattice of strings or ropes with tie points. Yet, most of a net is empty space. The tie points in a geologic model are the data control points. The closer the tie points are to each other, the smaller the intervening holes. In geological applications, the net, or model, with the biggest holes fits the data best. However, desired detail may be absent. In nets with smaller holes, the fit to the data is poorest on the first pass, but after several episodes of refinement, a better or even best fit may be found. In two fishing nets of the same outer diameter, one catches more fish with smaller holes than with larger holes, yet both will catch large fish. In making a net with smaller holes, the fisherman must spend much longer, because there is more twine. In hauling in fish with a net with smaller holes, the fisherman must also expend more energy, because he will have a larger (by number) catch, which obviously produces more frictional drag. So, a model with few control points, and large holes, will be quicker to build, easier to use, and capable of catching a few "fish", but only if they are large. A model with many control points, and small holes, will take longer to build, and be more difficult to use, mainly because it will catch more "fish" of many different sizes, shapes, and economic return.

A geologic model based on a few control points may be effective, but the potential for failure is great. A geologic model based on many control points may be just as effective, but it has a much higher potential for some degree of success.

**Allostratigraphy - the "subdivision of the stratigraphic record into mappable rock bodies 'defined and identified on the basis of their bounding discontinuities' (NACSN, 1983, p. 865)" (Walker, 1992a, p. 2)*

FUTILITY OF THE GENERAL APPLICATION OF MODELS: A POINT OF VIEW

Anderton (1985, p. 31), in rebuttal to Walker i.e. (1984a), states, "a familiarity with published facies models is clearly essential for any practising sedimentologist." But this understanding is not nearly as important as an understanding of how the model was constructed.

Anderton (1985) explains the dark side of using facies models without thinking. He believes that nature is not ordered and therefore, not readily susceptible to stereotyping or modelling. "Every descriptive sedimentary facies is . . . unique and has a unique interpretation in terms of a facies model" (Anderton, 1985, p. 33). Carr (1982, p. 905) suggests that "science places a premium upon the investigator's ability to perceive order in what appears disordered". He further states, "Scant attention is paid to studies warning that what we perceive as order in nature may be only a reflection of our desire for order". Yet, Anderton (1985) concludes that models have proven "extremely valuable" in regional hydrocarbon-exploration projects by directing activity to specific areas or stratigraphic intervals. These models begin to fail in the more detailed development phase, when the difficulty of accurately predicting three-dimensional reservoir properties from minimal data become almost insurmountable.

While it is apparent that facies models are only as good as the data upon which they are developed and the interpretation of that data, they are also limited by the scalar resolution of the investigative tools. Detailed models are needed to make detailed predictions. Detailed models cannot be constructed without detailed data. Detailed predictions are not needed if one already has the detailed data necessary to create the detailed model to make a detailed prediction.

Since this is an undesirable situation, one might wish to revert to the Mutti - Normark (1987) and Mutti (1992) system of sedimentary process areas (i.e., channels, levee-overbank, etc.). Tools which cannot be used to successfully interpret sedimentary process areas should not be used as key elements in model creation.

Anderton (1985, p. 36) wraps up his philosophical discussion by saying that "facies models are ephemeral. Any model is just a particular way of looking at a particular phenomenon at a particular time." More recently, Vail commented similarly: "we see what we are trained to see" (Vail, 1992, p. 85).

"One must have the courage and honesty to repeatedly change and update facies models as our understanding advances." (Anderton, 1985, p. 45).

Even though "no single facies model can adequately explain all submarine fans" (Shanmugam, 1991, p. 671), and "no single submarine-fan model suffices to describe reservoir characteristics" (Nelson, 1990), "there is [still] a pressing need for a schema in which we can arrange the variety of fan facies, both modern and ancient" (Gorsline, 1987, p. 560).

Mutti (1992): "Neither the 'sedimentological' fan model [i.e., Walker model of this discussion] nor the 'eustatic' sequence-stratigraphic model [i.e., Vail model of this discussion] can adequately describe the great variety of deep-water siliciclastic systems found in both modern and ancient basins". "No general model can be used to describe inherently different systems" as those created in different basin types, with different local sedimentary provenances, and source type, or relative sea level. Each of the factors will produce a set of unique conditions that will determine the final type of deposit.

"Turbidite facies have to be revisited and redescribed from a new perspective, without preconceived ideas or existing models in mind". (Mutti, 1992, p. 105).

Thus, we have a conundrum -- a need for models, yet a warning that models do not work. What will we do? What will we do?

REGIONAL BASIN SETTING OF THE JACKFORK FORMATION

The Jackfork Formation of the Ouachita Mountains of Arkansas and Oklahoma is part of an estimated 30,000- to 45,000- foot (9,100 to 13,700 m) sequence of Carboniferous strata, mostly of deep-water basinal deposition (Figure 2). The Ouachita Basin is a deep-water siliciclastic and siliceous depositional basin which formed in Late (?) Cambrian time in response to rifting along the (present-day) southern margin of North America. Approximately 10,500 feet (3200 m) of Late Cambrian to Early Mississippian rocks form the base of the sedimentary sequence. Overlying the late Devonian to earliest Mississippian Arkansas Novaculite is approximately 12,000 feet (3660 m) of Mississippian Stanley Shale (with interbedded sandstones and tuffs). Succeeding the Stanley is the Jackfork Formation of latest Mississippian to earliest Pennsylvanian age. Regionally the Jackfork is 6,000 to 7,000 feet (1830 to 2130 m) thick.

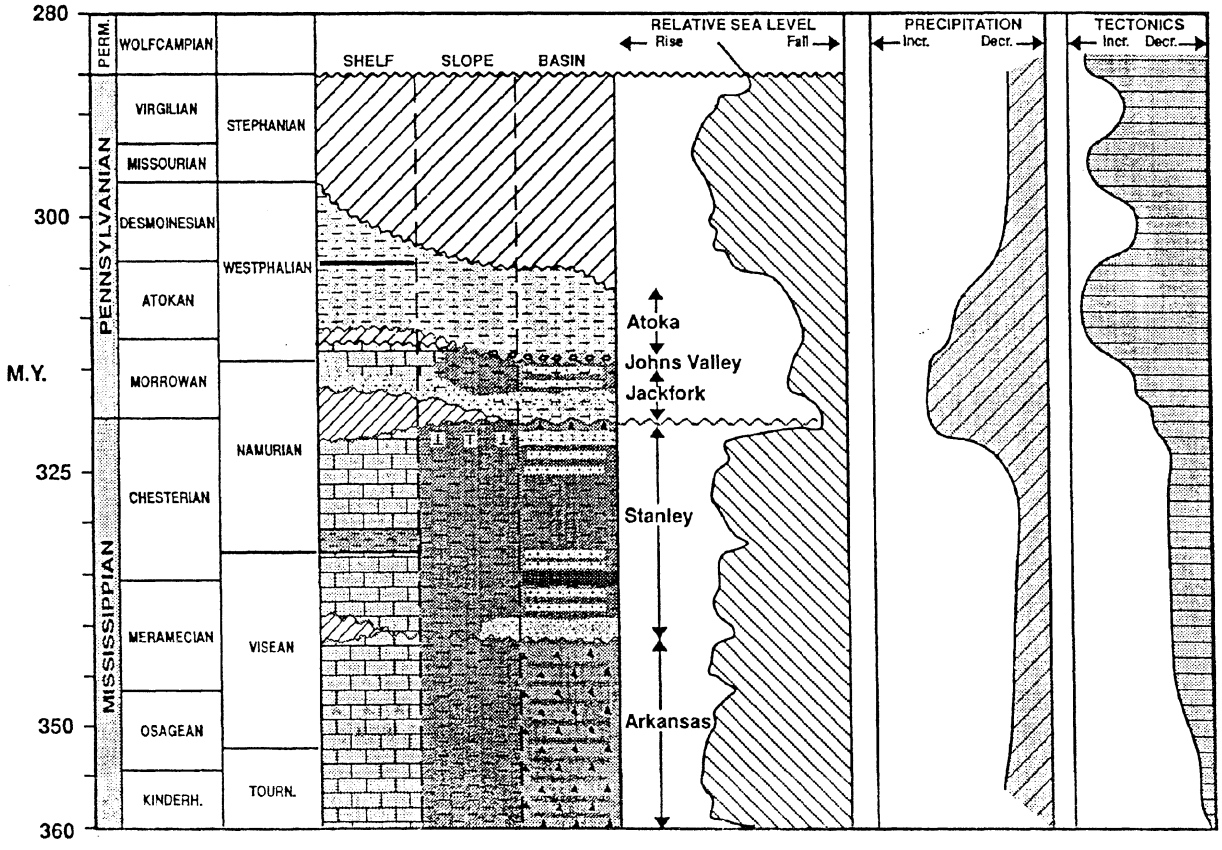


Figure 2. Generalized stratigraphic column for the Ouachita Basin, with relative sea-level, precipitation, and tectonics curves. Modified from Ross and Ross (1987); Cecil and Eble (1989); Arbenz (1989); Sutherland and Manger (1979).

Following the Jackfork is the lower Pennsylvanian Johns Valley Formation, a problematic unit of shale, thin turbidites, and boulder beds containing clasts of Cambrian to Pennsylvanian age shelf, slope, and basinal(?) strata. If the Johns Valley were not such an unusual, and therefore important marker bed, its thickness of 500 to 900 feet (150 to 275 m) would make it rather insignificant in the overall scheme of Carboniferous deposition in the Ouachitas. Succeeding the Johns Valley is the Atoka Formation, a thick section of Lower and Middle Pennsylvanian sandstone and shale which may have originally exceeded 30,000 feet (9140 m) in depositional thickness. The Atoka shallows upward from deep-water turbidites, etc., to fluvial deltaic strata before being capped by the shallow-water Desmoinesian Hartshorne Formation (Figure 3).

In the deep basin, thick, rapid deposition during the Carboniferous produced a severe dilution of significant biostratigraphic indicator fossils, resulting in a very poor biostratigraphy within the submarine-fan complex. Sequence-stratigraphic concepts have been used to infer chronostratigraphic ages where biostratigraphic zones are not definitive (Coleman, 1990) (Figure 2).

AGE OF THE JACKFORK FORMATION

The Jackfork Formation (of Arkansas; equivalent to the Jackfork Group of Oklahoma) was first described by Taff (1902) from Jackfork Mountain in eastern Oklahoma. He assigned a Chesterian Mississippian age to it at that time. White (1937) determined the Jackfork was early Pennsylvanian Morrowan in age based on a meager fossil flora of *Lepidodendron, Calamites*, and reeds. Cline (1960), Morris (1971), Gordon (1973), and Gordon and Stone (1969, 1977) established a correlation of the Jackfork to the Lower Pennsylvanian Hale, lower Boyd, and Sausbee Formations (of Arkansas and Oklahoma).

Detrital fossils from the Jackfork are Morrowan in age (Gordon and Stone, 1969; Jordan et al., 1991a) and the adjacent, northern shelf is firmly established as Morrowan. Jennings (1986) concluded from floral assemblages that the Jackfork is younger than the youngest Mississippian and older than the oldest Pennsylvanian preserved on the northern shelf (i.e., younger than the type Mississippian in Illinois, and older than the type Pennsylvanian). This is consistent with previous determinations by Girty in Miser and Purdue (1929), White (1937), and Harlton (1938), among others. This places the Jackfork at the Mississippian - Pennsylvanian boundary and explains the relatively poor lithologic correlations with the shelf units in Arkansas and Oklahoma, as well as in the Black Warrior Basin to the east in Mississippi. Based on biostratigraphic work by Jennings and Thomas (1987), the best stratigraphic correlation appears to be with the Parkwood Formation of the Black Warrior Basin of Alabama and Mississippi.

Sequence-stratigraphic concepts would predict that under low tectonic conditions, basinal deposition should not have a time-equivalent or genetically associated shelf section. Thus it is consistent with observations and theory to place the Jackfork at the Mississippi - Pennsylvanian boundary, approximately 320 - 318 m.y. (middle Namurian Carboniferous) (Coleman, 1990) (Figure 2).

PALEOENVIRONMENTAL INTERPRETATIONS

Early workers on the Jackfork interpreted it as a shallow-water deltaic complex, prograding northward from the southern Llanoria landmass (Taff, 1902). White (1937) suggested that a substantial portion of the Jackfork was the result of slides or slumping from shallow water into

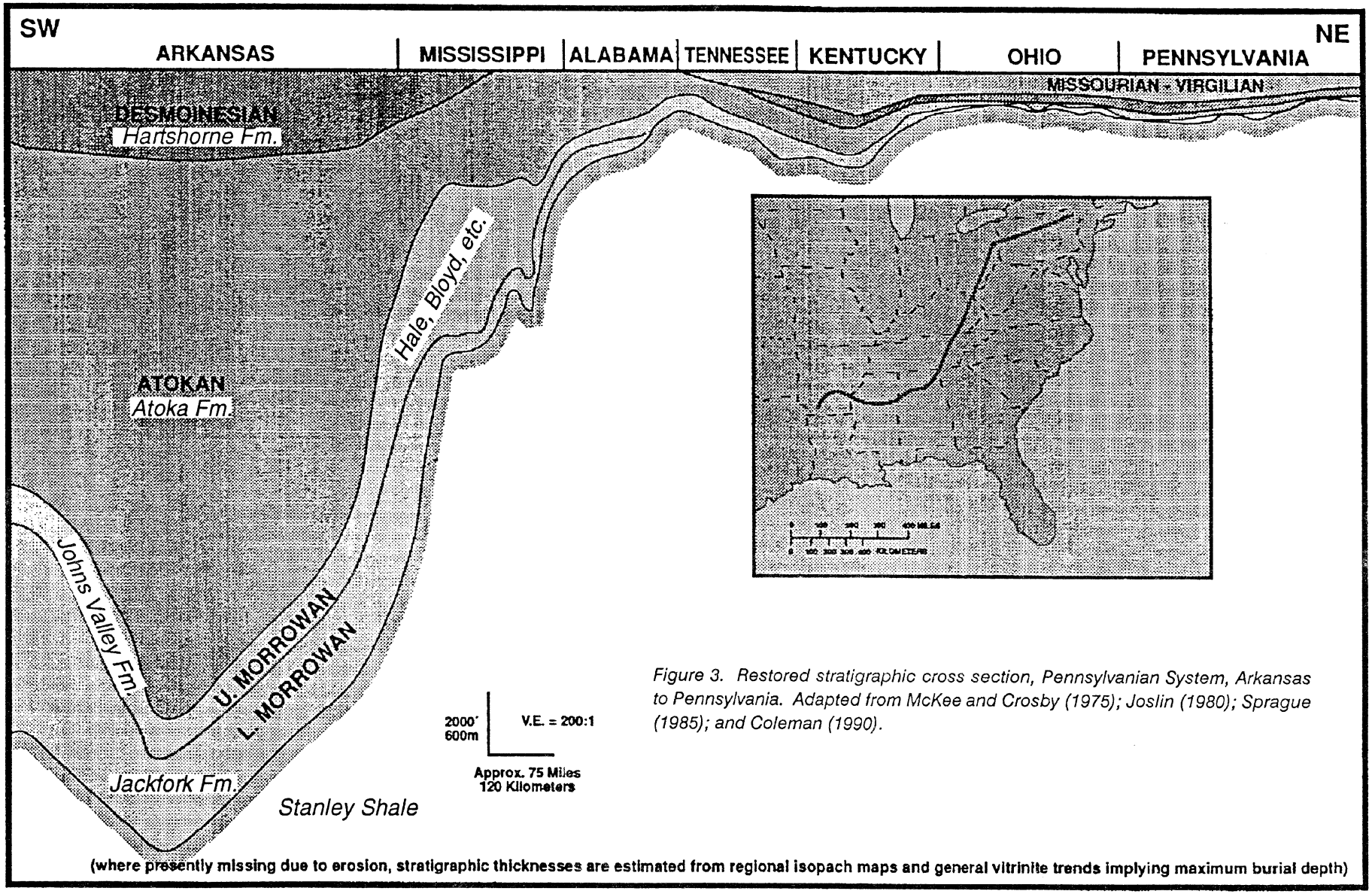


Figure 3. Restored stratigraphic cross section, Pennsylvanian System, Arkansas to Pennsylvania. Adapted from McKee and Crosby (1975); Joslin (1980); Sprague (1985); and Coleman (1990).

deep water. Van der Gracht (1931) may have been the first to assign the Jackfork to deep-water deposition. Morris (1964, 1973) placed the Jackfork as part of a thick Carboniferous flysch sequence based on sedimentary structures and bedding characteristics. Chamberlain (1978) interpreted the trace-fossils assemblage to indicate a middle to lower bathyal water depth (6500 ft/2000 m) for Jackfork deposition. Recent work on ichnofossil assemblages indicate they are not necessarily accurate paleobathymetric water-depth indicators, but more appropriately good indicators of oxygen and food content at or near the sediment -- water interface (Ekdale and Mason, 1988).

Sedimentary-structure analyses have determined that the overwhelming majority of features in the Jackfork is consistent with turbidite and/or debris-flow deposition (LoPiccolo, 1977). While this does not indicate a specific water depth, the preserved presence of these features throughout the section indicates deposition was consistently below major storm wave base. Preliminary sequence stratigraphic analysis suggests that water depths of 5000 to 6500 ft (1500 to 2000 m) are consistent with overall depositional patterns (Coleman, 1990) (Figure 4).

JACKFORK DEPOSITIONAL BASIN

At the Mississippian - Pennsylvanian boundary, the Ouachita Basin of Oklahoma - Arkansas - Mississippi was just beginning to experience the sedimentary effects of the orogenic uplift and northward movement from what were probably microcontinental blocks being pushed ahead of the main plate body of South America (Figure 5). Orogenically induced sedimentation had been well underway in the Black Warrior Basin of Mississippi and Alabama since Mississippian time (~ 325 m.y.)(Thomas, 1988). Siliciclastic, as well as volcaniclastic, detritus flowed from the south and east into the Ouachita Basin in Chesterian Stanley time. Little evidence exists which indicates that the Jackfork depositional basin floor had been compartmentalized by the uplift of major thrusted anticlines during Stanley or early Jackfork times. These anticlines would have formed bathymetric barriers to basinal sediment transport, resulting in localized sedimentary thickening and thinning. Additionally, no clearly recognizable regional erosional truncations of Stanley-age structures has been demonstrated. These observations, when coupled with the fairly uniform, subregional thickness values for the Jackfork, indicate that the Jackfork was probably deposited on the extremely flat, featureless basinal plain of the Ouachita Basin in 4900 to 6500 ft (1500 to 2000 m) of water (Figure 6).

The true dimensions of the basin will probably be impossible to accurately determine, since the southern boundary is (probably) very deeply buried by Mesozoic-Cenozoic, Gulf of Mexico rift-drift sediments. However, gravity and magnetic geophysical data suggest that the present-day location of the southern paleo-shelf margin may be in the vicinity of the Arkansas - Louisiana state border. Palinspastic restoration work by Blythe et al., (1988) and examination of Amoco and speculative seismic profiles (e.g., Bertagne and Vuillermoz, 1991) indicate that regional, northerly-directed compressional shortening may be on the order of 50%. Restoration of this basin based on this factor of compression suggests that the pre-deformation, Carboniferous Ouachita Basin was approximately 280 mi. (450 km) north-south by 340 mi. (550 km) east-west , yielding an areal extent of some 95,500 sq. mi. (250,000 sq. km). It was open on the west and southwest end until thrust closure in Late Pennsylvanian (Morris, 1974a, b; Houseknecht and Kacena, 1983; Coleman, 1990; Hale-Erlich and Coleman, 1993) (Figure 7).

1. SW Lynn Mountain
2. Albion
3. Honobia
4. Kiamichi Mountain
5. E. Rich Mountain
6. Brush Knob
7. Forked Mountain
8. Exxon #1 City of Searcy
9. Lion #1 Nalley
10. Texaco - Exxon #1 Ivey
11. Exxon #1 Fulgham

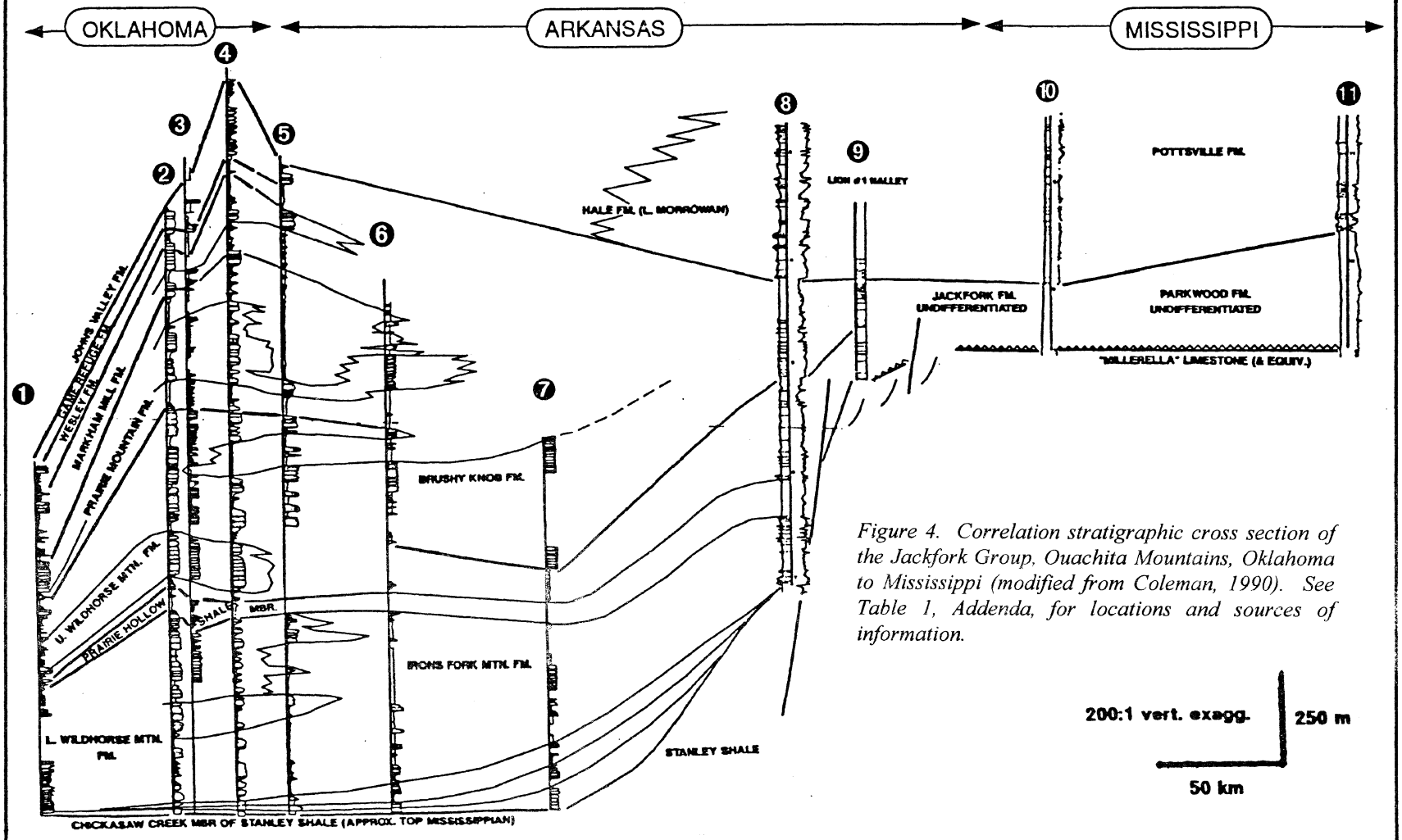


Figure 4. Correlation stratigraphic cross section of the Jackfork Group, Ouachita Mountains, Oklahoma to Mississippi (modified from Coleman, 1990). See Table 1, Addenda, for locations and sources of information.

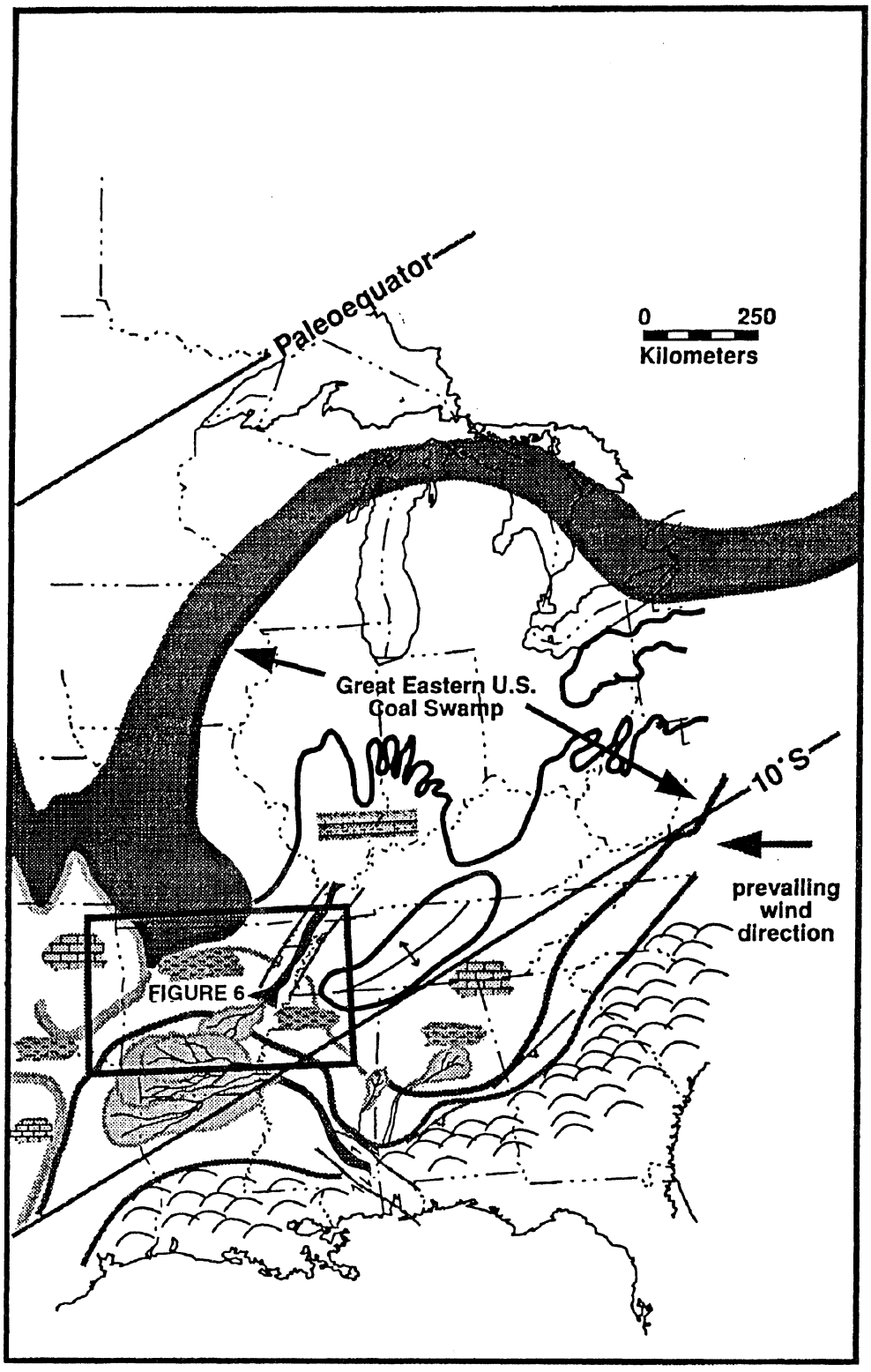


Figure 5. Early Carboniferous (Namurian) paleogeographic setting, eastern United States. Modified in part from Scotese and McKerrow (1990); Witzke (1990); Johnson et al. (1988); Thomas (1988); McKee and Crosby (1975); Houseknecht and Kacena (1983).

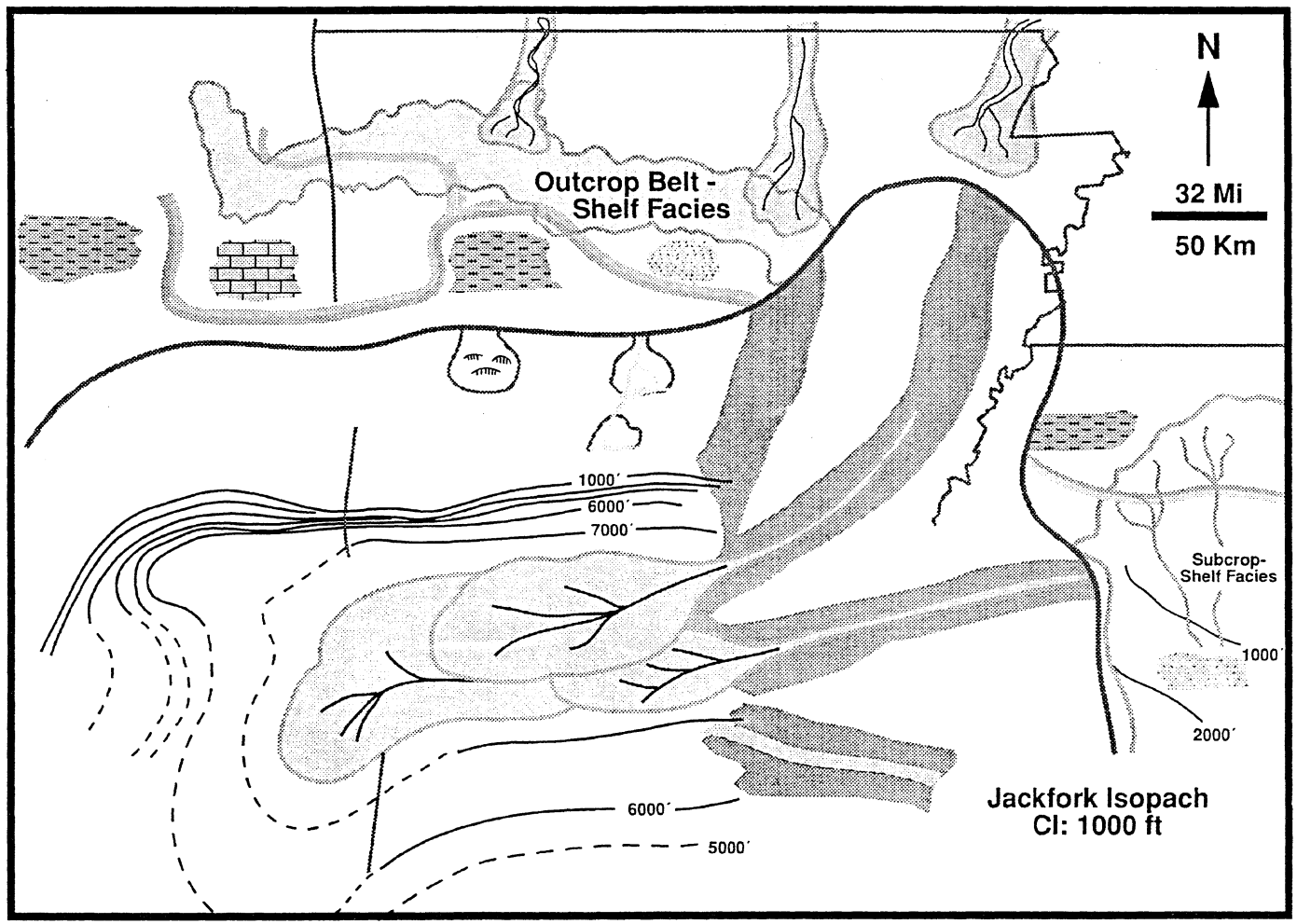
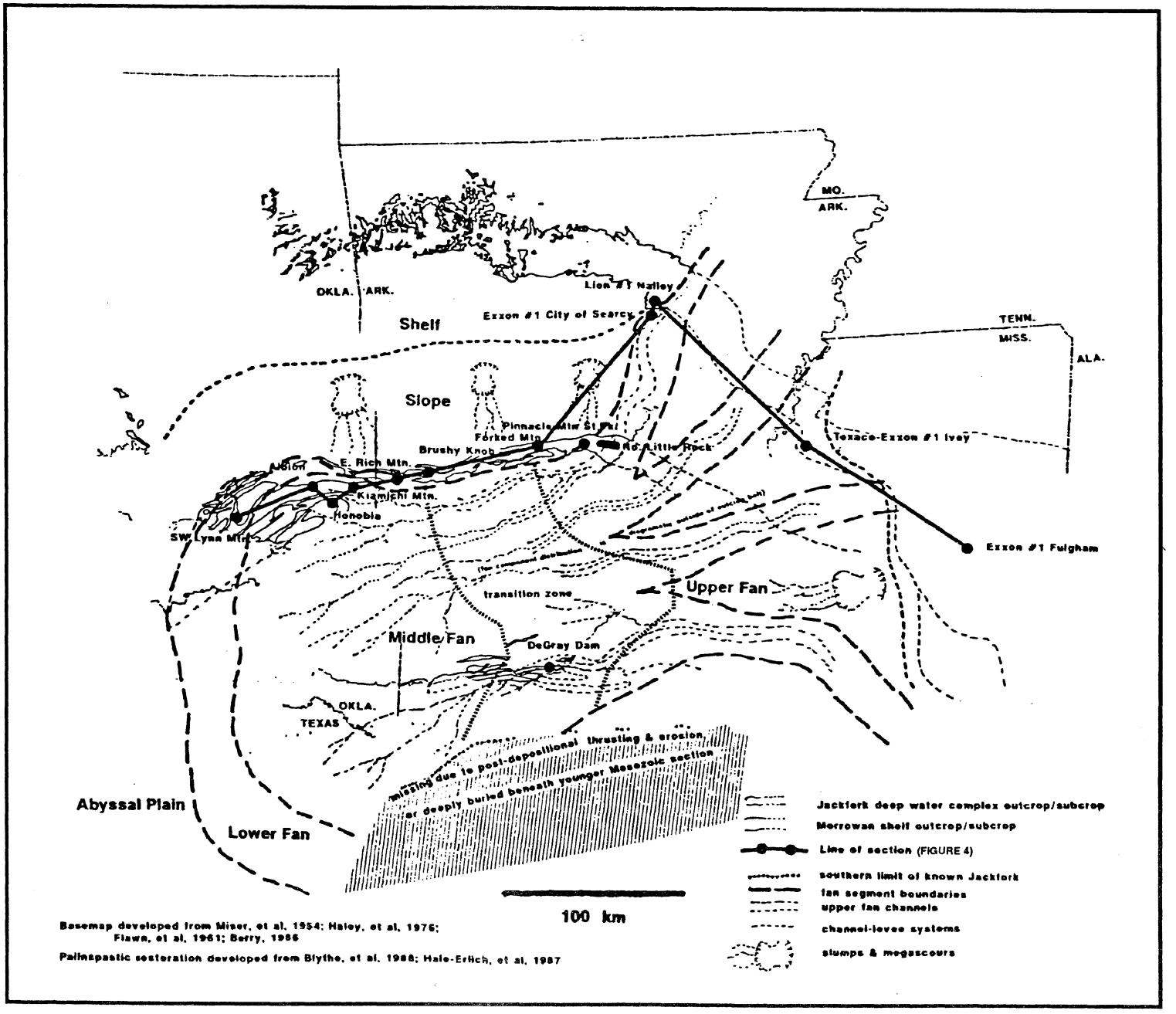


Figure 6. Morrow paleogeographic map, Ouachita Basin. Modified from Coleman (1990); Johnson et al. (1988); Houseknecht and Kacena (1983); Morris et al. (1979); Roberts (1985); McKee and Crosby (1975).


MO.
ARK.
OKLA.
ARK.
Lion #1 Malley
Exxon #1 City of Searcy
Shelf
TENN.
MISS.
ALA.
Slope
Pinnacle Mtn
Forked Mtn
Brushy Knob
Mt. Little Rock
Texaco-Exxon #1 Ivey
Arbor
E. Rich Mtn.
Kiamichi Mtn.
Honobia
SW Lynn Mtn.
Exxon #1 Fulgham
transition zone
Upper Fan
Middle Fan
DeGray Dam
OKLA.
TEXAS
Abyssal Plain
Lower Fan
missing due to post-depositional thrusting & erosion
or deeply buried beneath younger Mesozoic section
100 km
Jackfork deep water complex outcrop/subcrop
Morrowan shelf outcrop/subcrop
Line of section (FIGURE 4)
southern limit of known Jackfork
fan segment boundaries
upper fan channels
channel-levee systems
slumps & megascours
Basemap developed from Miser, et al, 1954; Haley, et al, 1976;
Fiawn, et al, 1961; Berry, 1986
Palinspastic restoration developed from Blythe, et al, 1988; Hale-Erlich, et al, 1987

FACTORS CONTROLLING JACKFORK DEPOSITION

The primary factors controlling deposition of basinal sediments are tectonics, eustasy, and climate. Coleman (1993) compared the various Carboniferous deep-water sediment complexes and found that each of these factors varied in their degree of significance in controlling deposition. (See Table 2, Addenda.)

The Jackfork was deposited following a rather short period of high precipitation during a relative eustatic high stand. This was followed by a major eustatic lowstand which shifted the accommodation space basinward off the Black Warrior and Ozark shelves into the Ouachita Basin (Figure 3). Perhaps, several third-order cycles of sea-level fluctuations produced four "sequences" cycles of deep-water clastics within the Jackfork. These sediments are separated by siliceous shales deposited as highstand and condensed-section intervals. These shales are best developed in Oklahoma where seven Jackfork units are mappable as formations, thus elevating the overall Jackfork to group status. Because of the poor development of the siliceous shales towards the east, the Jackfork is not easily divisible in Arkansas. A potential correlation between Arkansas and Oklahoma, based on sequence stratigraphic principles, is presented in Figure 4. Through this solution we see that the Jackfork is a multifaceted, basin-complex system.

DEVELOPMENT OF TEST FORMAT FOR THE FIELD TRIP

In order to create a test that is basically an "apple-to-apple" comparison, it is important to bring each of the three test cases to common perspectives for comparison. These perspectives were generated to fill the needs of most geoscientists to have a map, cross section, and columnar section to communicate their ideas. (See Table 3, Addenda.)

Six diagrams, formulated from key illustrations and written descriptions by the three primary authors, are presented as Figures 8 through 16.

No time or spatial scale is implied.

In creating these perspectives, new views of these models were created to supplement existing visual arguments by "our" three authors. What was originally created for these models gives an insight into how the authors viewed potential use of these models. Walker viewed his work in a detailed, sedimentary-process interpretation based on the vertical succession of facies in a "Waltherian world*". Mutti sought to generalize detailed field observations into map and profile views, both of which captured the essential concepts of basinal sedimentation. Vail looked to generalize details gleaned from seismic-scale, profile-oriented observations and their inferred map distribution. This generalization was codified into a set of global process concepts.

In an effort to remove any bias by creating "apple-to-apple" comparisons, we may have inadvertently biased our test by bringing you to a single outcrop, rather than giving you a box of seismic lines and well logs, or a visit to a whole series of genetically related outcrops.

* *See definition of Walther's Law, page 39.*

Figure 7. Depositional facies map, Jackfork fan complex, Ouachita basin. Modified from Coleman (1990).

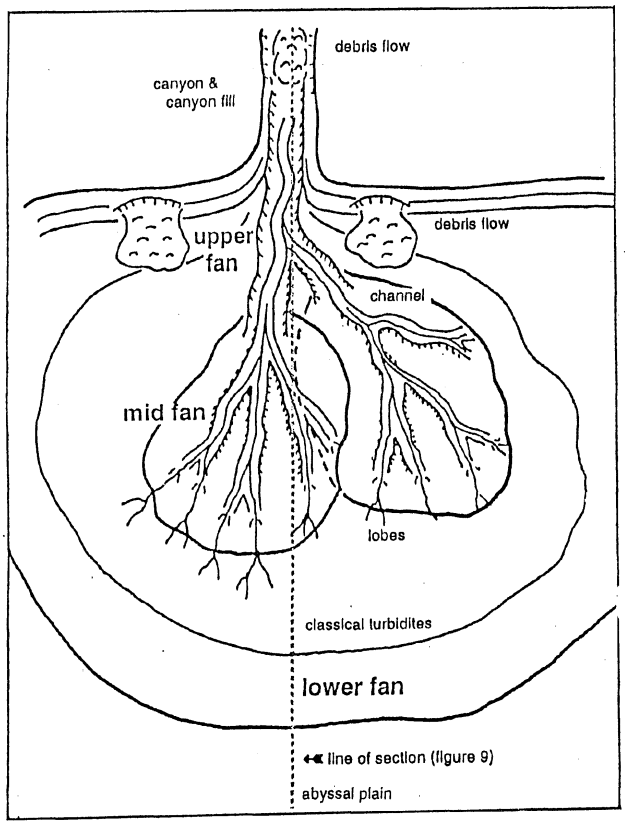


Figure 8. Walker model -- hypothetical planar view. Developed from Walker (1966, 1978).

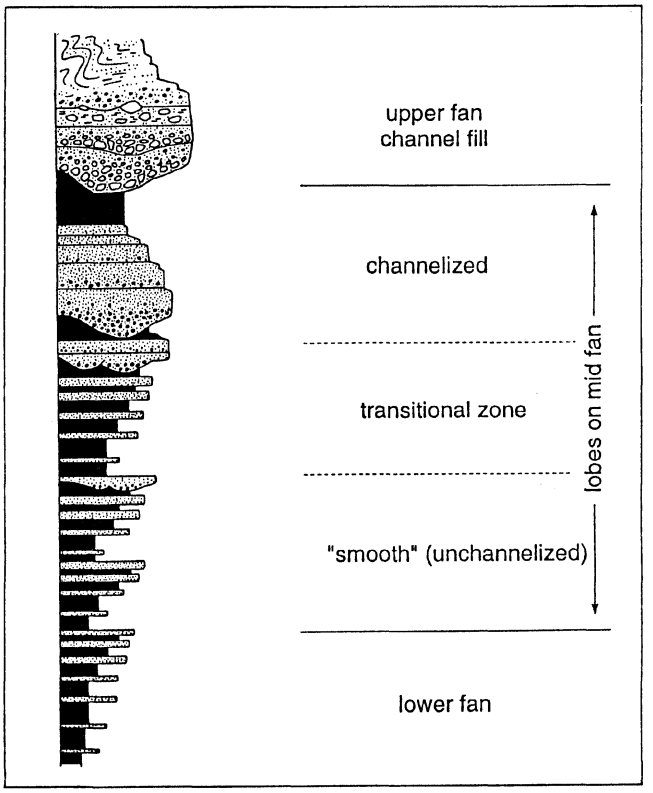


Figure 10. Walker model -- hypothetical columnar view. Modified from Walker (1978).

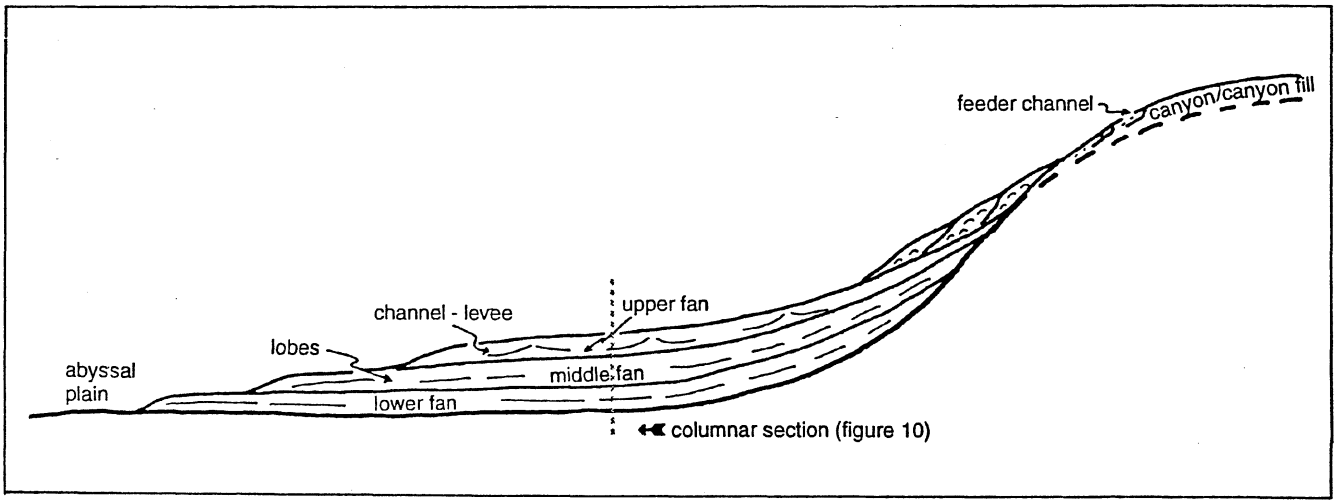


Figure 9. Walker model -- hypothetical cross section. Developed from Walker (1966, 1978).

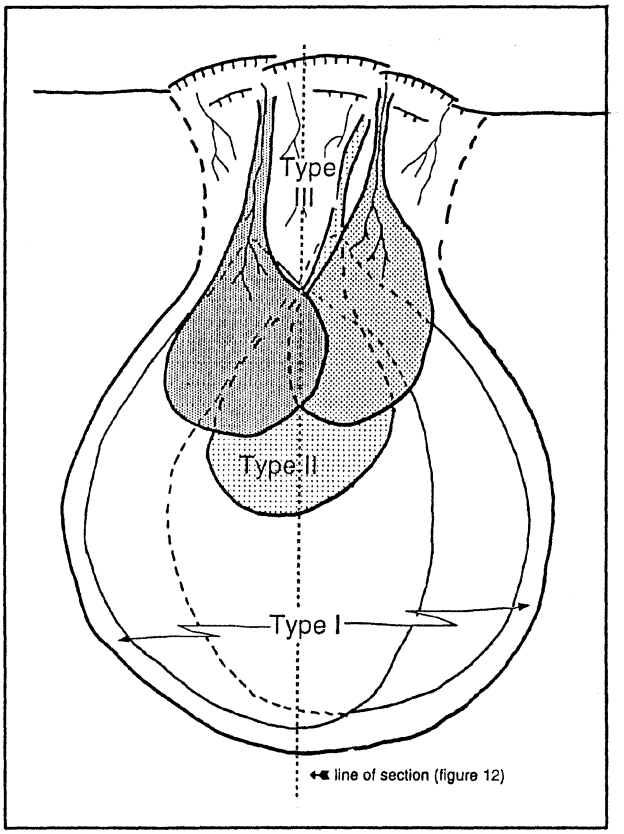


Figure 11. Mutti model -- hypothetical planar view. Developed from Mutti (1985).

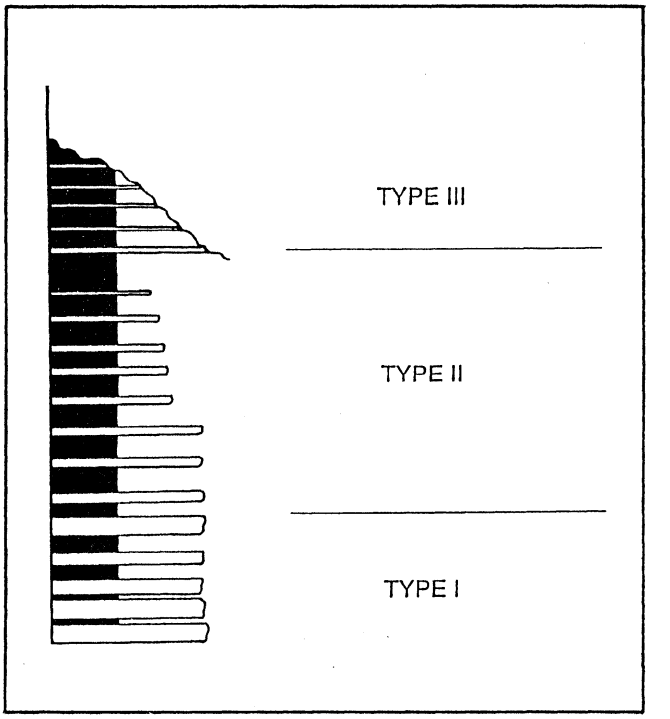


Figure 13. Mutti model -- hypothetical columnar view. Developed from Mutti (1985).

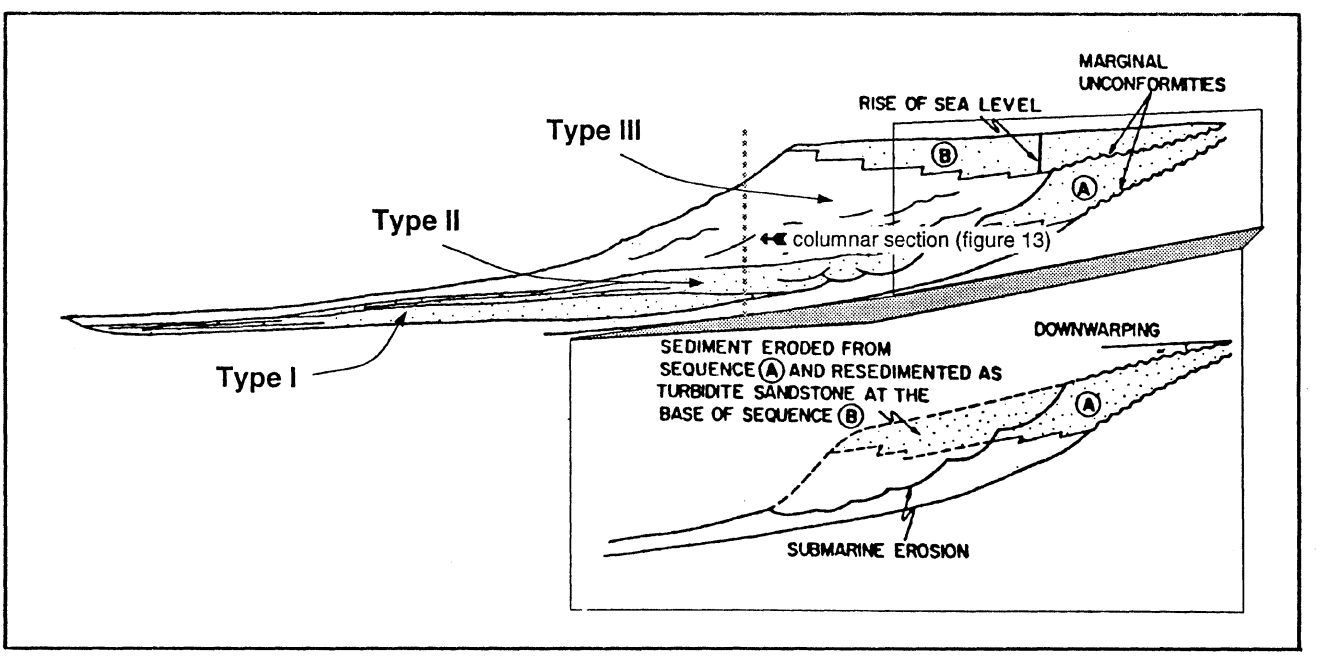


Figure 12. Mutti model -- hypothetical cross section. Modified from Mutti (1985).

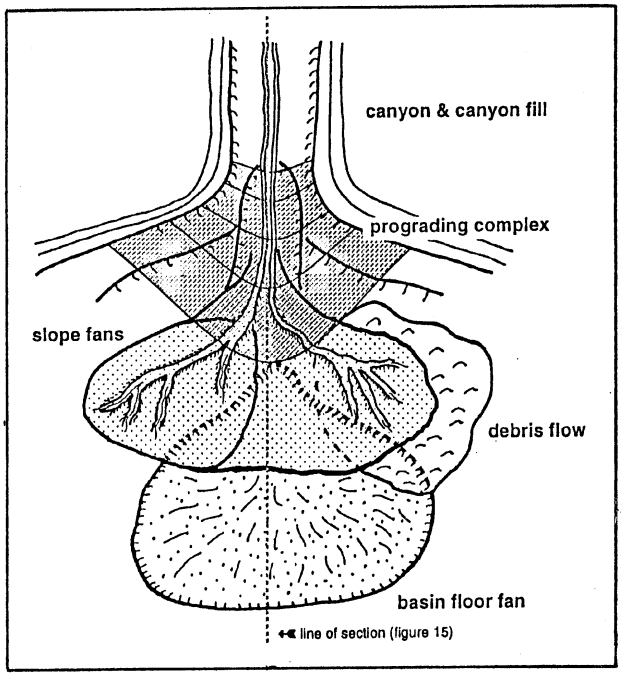


Figure 14. Vail model -- hypothetical planar view. Developed from Mitchum (1985); Posamentier et al. (1988); Vail (1987); Vail et al. (1991).

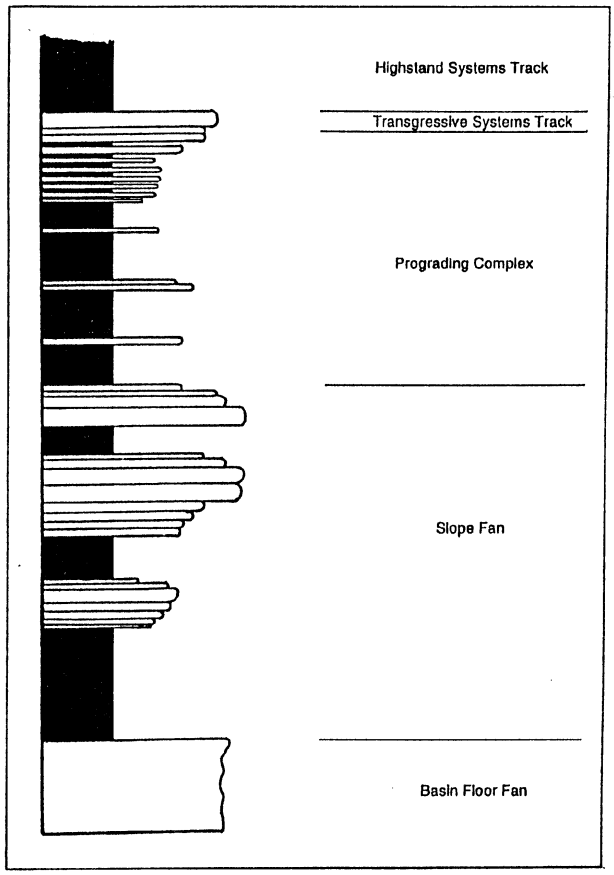


Figure 16. Vail model -- hypothetical columnar view. Developed from Mitchum et al. (1990); Vail and Wornardt (1990).

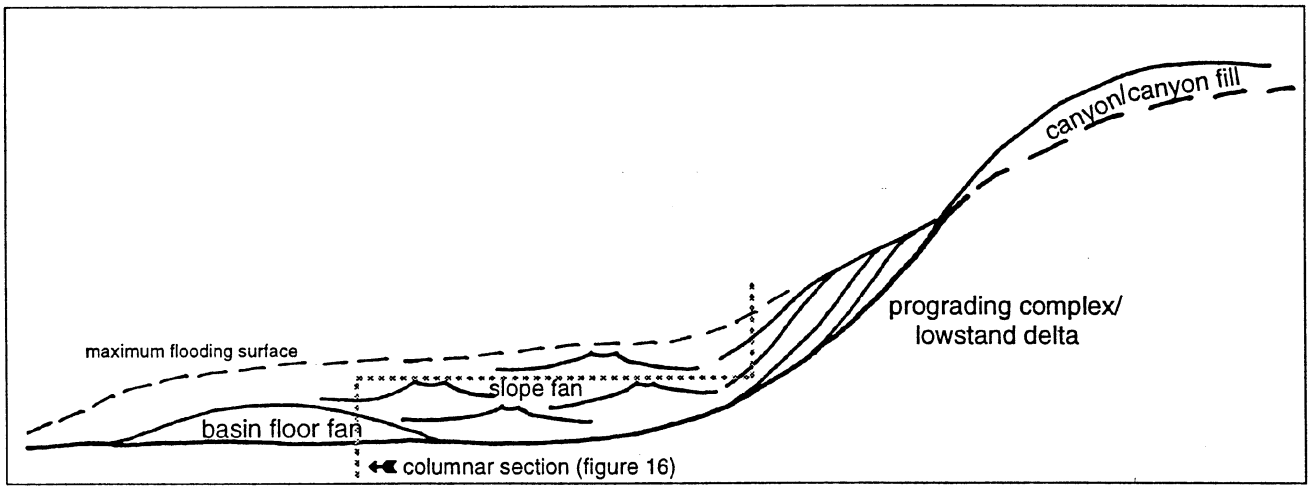


Figure 15. Vail model -- hypothetical cross-section view. Developed from Vail and Wornardt (1990); Vail (1987); Posamentier et al. (1988).

FIELD TRIP AGENDA

(All stops in the vicinity of DeGray Lake)

DEPART LITTLE ROCK FOR DEGRAY LAKE AREA (8:00 AM)

A. Stop 1 (9:30 AM) -- *Hwy 7 road cut* above swimming beach -- base of Jackfork

Board party barges at swimming beach.

B. Stop 2 (10:15 AM) -- *Lakeshore* "drive-by" -- lower Jackfork (BOAT STOP)

C. Stop 3 (11:00 AM) -- *DeGray Dam intake section* -- "middle" Jackfork (BOAT STOP)

Leave party barges at spillway boat launch

LUNCH AT DEGRAY SPILLWAY BOAT LAUNCH (12 NOON)

Hike to spillway section

D. Stop 4 (1:00 PM) -- *DeGray Spillway* section -- "middle" Jackfork

Board bus/vans and drive to dam outfall tunnel.

E. Stop 5 (2:30 PM) -- *DeGray Dam outfall tunnel* -- upper Jackfork

Drive to Murray Quarry.

F. Stop 6 (3:30 PM) -- *Murray Quarry* -- top of Jackfork

DEPART FIELD AREA FOR LITTLE ROCK (4:30 PM)

DESCRIPTIONS OF FIELD-TRIP STOPS

The field trip will be conducted entirely in the vicinity of DeGray Lake and State Park (Figure 17). The area is located in the flooded valley of the Caddo River. DeGray Lake spreads out over 13,800 acres upstream from the water gap through Chalybeate Mountain at DeGray Dam. Construction on the dam began in 1963 and was completed in 1972 at a cost of $63,800,000. The dam contains about 7 million cubic yards (5.4 million cubic meters) of compacted earth fill. It measures 1500 feet (460 m) at the base, 50 feet (15 m) at the top, and has a total length of 3400 feet (1036 m). It stands 243 feet (74 m) above the river, with an elevation at the crest of 453 ft (138 m) msl. The powerhouse, on the downstream (or south) side of the dam holds two turbine generators with a combined power output of 68,000 kw (anonymous, undated).

The lake and dam were originally approved in 1950 as a flood-control project. Changes in 1961 and 1965 inserted water supply and recreation as authorized project purposes. Only after these changes were instituted was the dam built. At optimum storage, the lake holds 427,200 acre-feet (.53 million cubic km), with a maximum depth of 202 feet (62 m) and an average depth of 49 feet (15 m). The shoreline is 225 miles (362 km) long when filled to flood-control level (anonymous, undated).

This field trip gives us an opportunity to study the Jackfork Formation as it was deposited well out into the Ouachita Basin. In the process of building and maintaining DeGray Lake, the Corps of Engineers created a nearly complete cross section of a major deep-sea fan complex. These exposures enable us to examine the continuum that is deep-sea fan deposition and to develop an critical eye for unraveling the apparent mysteries of these types of deposits. We will traverse the complete fan complex and compare and contrast the beginning, the middle, and the end, as well as everything in between. We will test the power of the three models to predict the stratal sequences of the Jackfork. Additionally, we will discuss reservoir, source, seal, and trap conditions which might make deposits analogous to the Jackfork prospective in the exploration and production of minerals or hydrocarbons.

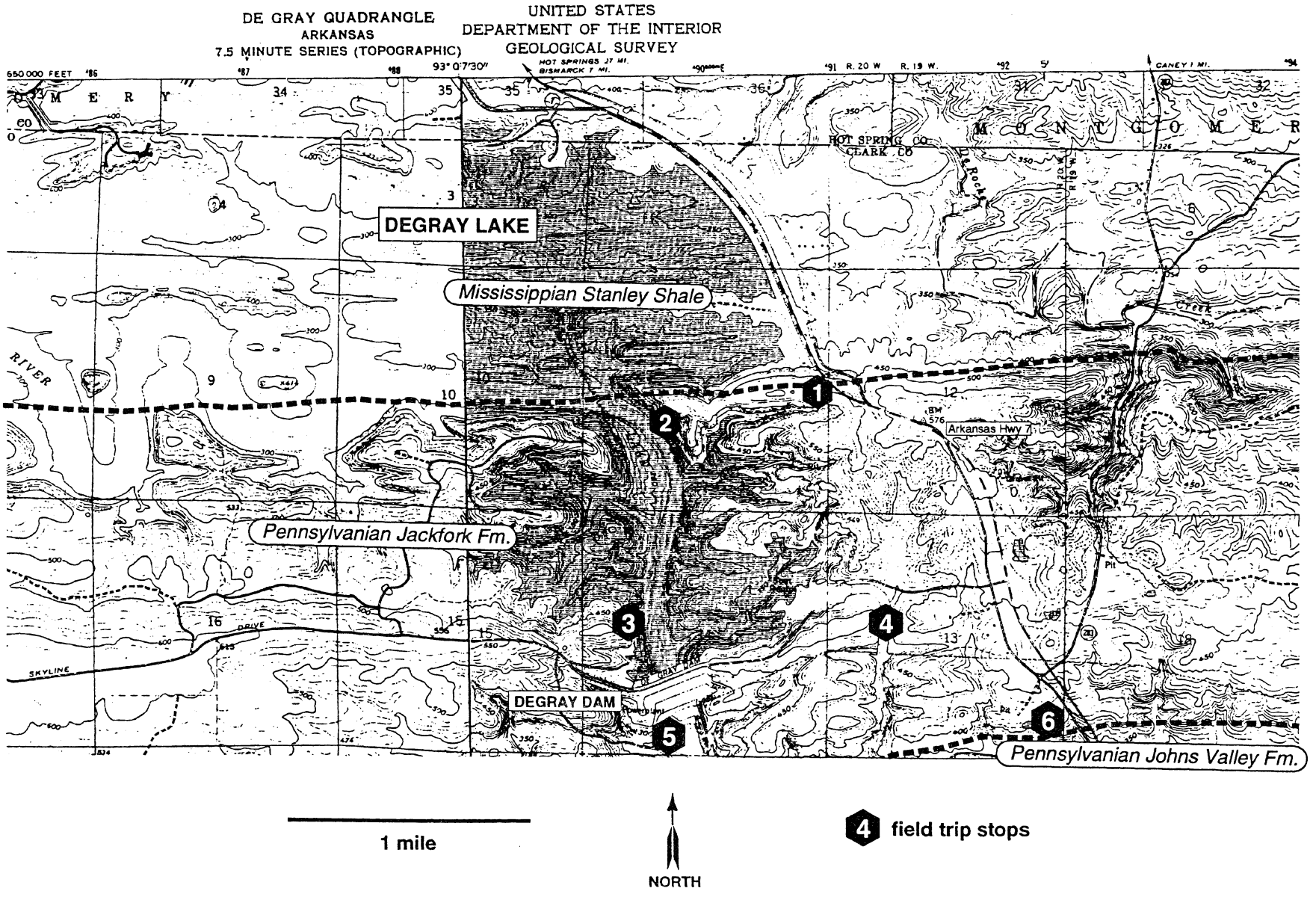


Figure 17. Generalized geologic map, DeGray Lake area, Clark County, Arkansas, with field-trip stops.

STOP 1: DeRoche Ridge Highway 7 Road Cut

LOCATION: Road cut along Arkansas Highway 7, near the entrance to the swimming beach; E/2-11-6S-20W, Caddo Valley Quadrangle, Clark County, Arkansas.

KEY REFERENCE: Morris, 1974a.

PURPOSE: The purpose of this stop is to begin a complete traverse of a deep-sea fan complex. At this stop, we will examine the basal units and discuss the depositional environments of the lowermost Jackfork.

DISCUSSION: We will begin our transect of the Jackfork Formation of the DeGray area at the base of the unit, where it rests with apparent conformity on the Mississippian Stanley Shale. The actual contact is commonly covered by vegetation, but occasionally, after park road work, it is exposed in the drainage ditch, near the Highway 7 junction with the road to the swimming beach. The Jackfork is approximately 7000 feet (2133 m) thick in the DeGray area (Plate 1) and is 150 miles (240 km) from the northern shelf, 180 (290 km) miles from the eastern shelf, and an estimated 100 miles (161 km) from the southern shelf (palinspastically restored, Coleman, 1990). For all intents and purposes we are out in the middle of the basin, and at this point, on the basin floor (Figure 7). Paleo-water depth is difficult to determine, but is estimated by trace fossils and sequence stratigraphy to be approximately 6500 feet (2000 m) or less (Chamberlain, 1978; Coleman, 1990).

This exposure shows alternating massive-to thin-bedded, fine-to medium-grained (locally some grit layers with crinoid fragments), graded, bottom-marked, convoluted, sub-graywacke to quartzitic sandstone; rather soft sandy siltstone with coalified plant fragments; and gray to black shale (containing some small iron carbonate concretions). Bottom marks indicate the paleocurrent was generally from an easterly direction.

Is this sequence of beds what you might expect at the bottom of a thick deep-sea fan complex? Notice that a pattern of debris flow-->>thick sandstone-->>thin sandstones-->>shale develops at about 10 feet above the base and is repeated, with variations, six times up to the fault at about 340 feet (107 m) on the section (Figure 18)(Morris, 1974a). Are these channels? Is this a "basin-floor fan" section? Are each of these intervals "sequences"? Is there anything especially significant about the Mississippian - Pennsylvanian unconformity at this location?

STOP 2: DeGray Lake Exposures (eastern shore)

LOCATION: Exposures along the eastern shore of DeGray Lake; SW/4-11-6S-20W, Caddo Valley Quadrangle, Clark County, Arkansas.

KEY REFERENCES: Hunt, 1965; Breckon, 1988.

PURPOSE: The purpose of this stop is to contine our traverse through the Jackfork complex, observing the changes from the basal section at DeRoche Ridge up into the middle of the unit. We will attempt to determine which fan facies, channel-levee or lobe, dominates this interval.

DISCUSSION: We will board a boat at the swimming beach and motor slowly along the eastern shore of DeGray Lake to look at the section stratigraphically above the DeRoche Ridge exposure (Stop 1). Breckon (1988) measured the section along the lake, and, except for notes along the margin of his Plate 2, did not discuss it in detail. He found approximately 1170 feet

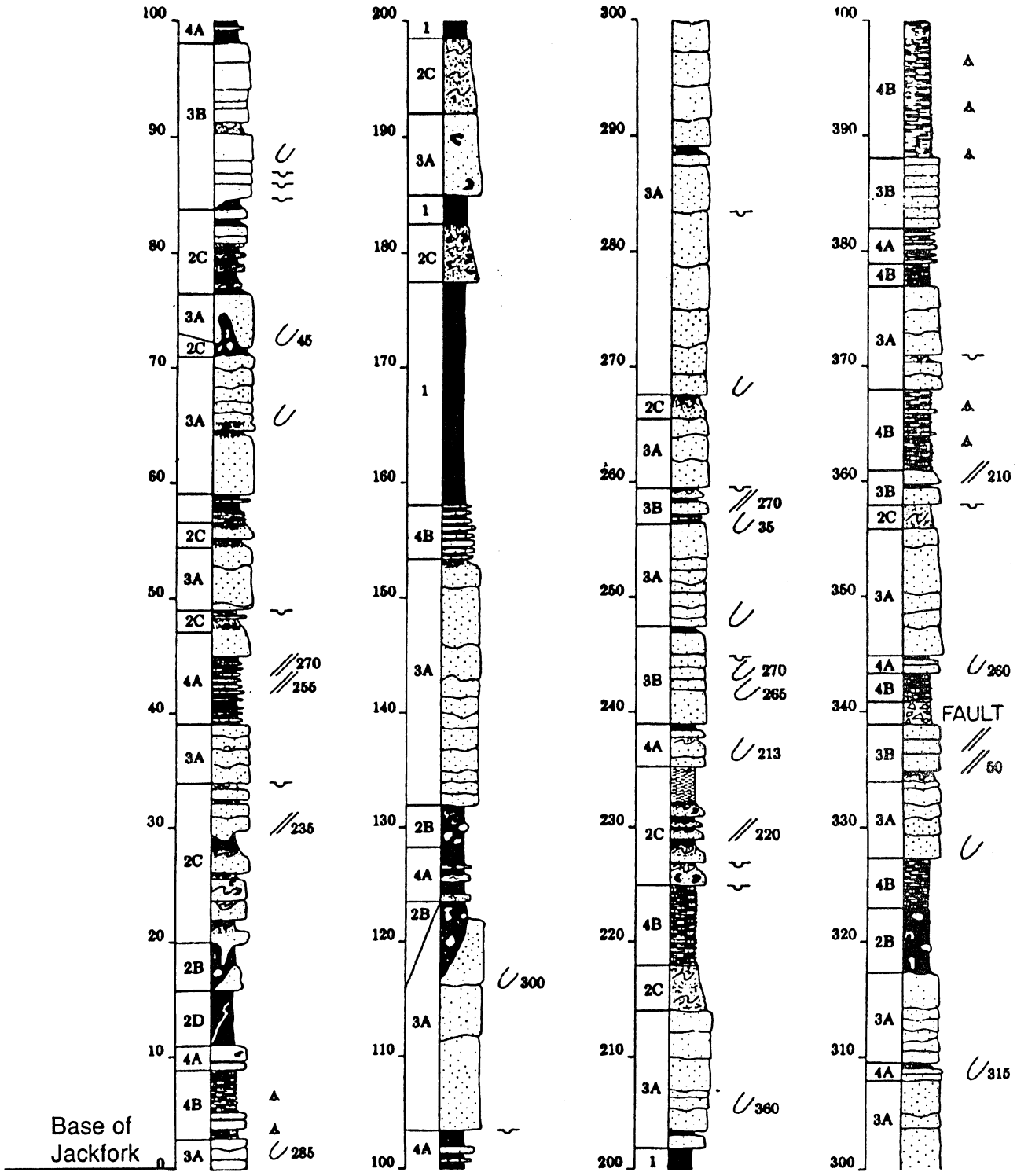


Figure 18. Measured stratigraphic section of lower Jackfork Formation, DeRoche Ridge highway cut. Measurements in feet; paleocurrent azimuths shown to right of lithologies; alphanumeric code is Morris' (1974a) flysch subfacies designations. Modified from Morris (1974a).

Figure 19. Photograph of lower Jackfork Formation, DeRoche Ridge highway cut.

(350 m) of section, most of which was exposed. He interpreted the interval as one of a series of active, then abandoned channel complexes. Where he found thickening and coarsening upward sequences, he interpreted them as lobes and lobe-fringes. Within these coarsening and thickening upward sequences, individual bed sets thin and fine upward.
Following an examination of the Jackfork along the lake, we will motor over to the DeGray intake cut, where we will look at laterally equivalent strata to the spillway section. Our stop will be 145 feet (44 m) above the 35-foot (11-m) high intake tunnel, which conducts the water of DeGray Lake to the turbines in the power house below.

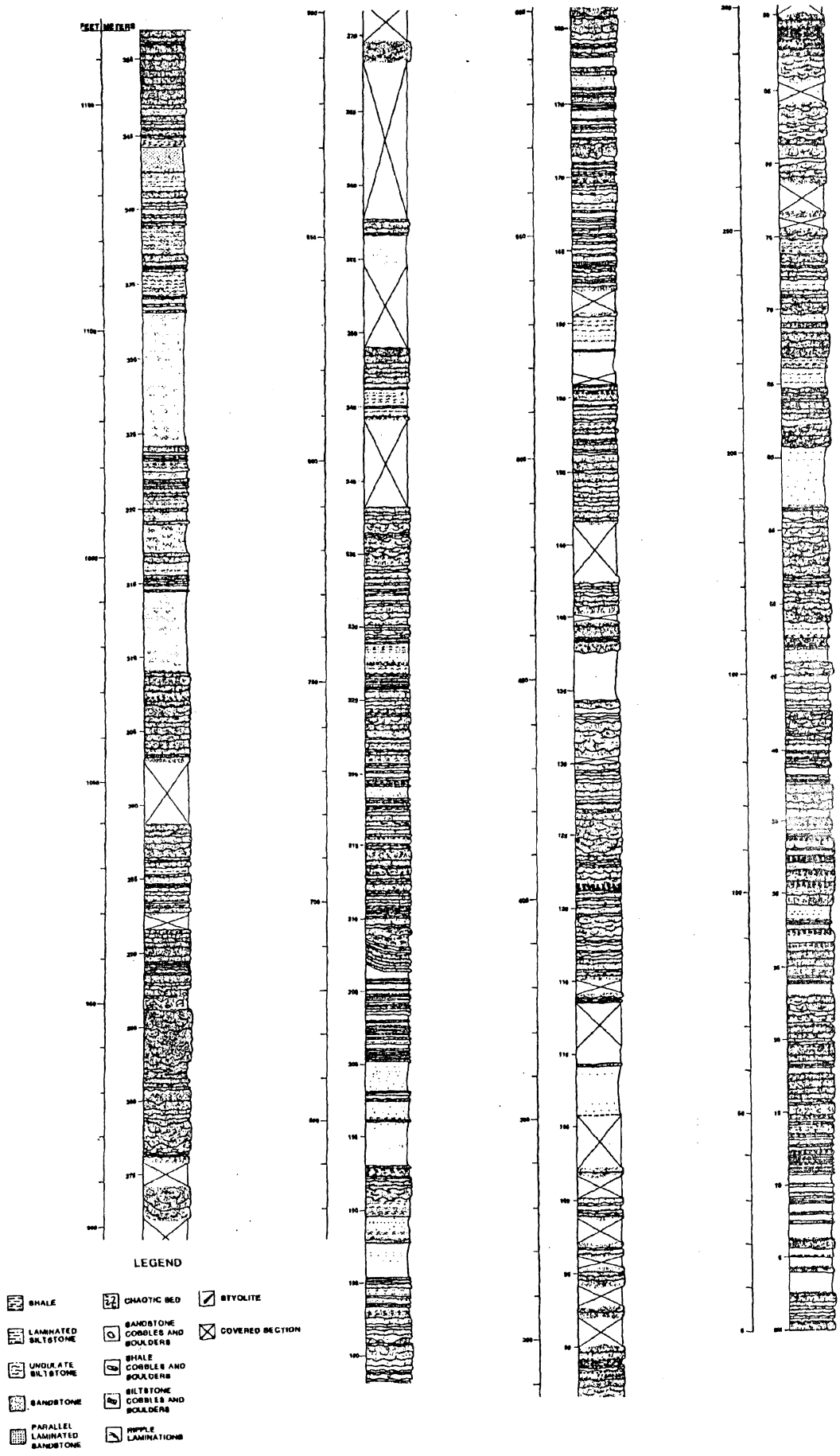
Stop 3: DeGray Dam Intake Section

LOCATION: Exposures along the eastern shore of DeGray Lake; SW/4-14-6S-20W, Caddo Valley Quadrangle, Clark County, Arkansas.

KEY REFERENCES: Hunt, 1965; Breckon, 1988; Jordan et al., 1991a.

PURPOSE: The purpose of this stop is to examine a major change in sedimentary processes as revealed in the Jackfork along the Caddo River.

DISCUSSION: The DeGray Dam intake section is, unfortunately for us, covered by a chainlink fence to keep the outcrop out of the dam's turbines. If our boat captain is capable, we should be able to motor right up the outcrop and get a close hand look at this remarkable exposure. Hunt (1965), Breckon (1988), and Jordan et al., (1991a) have studied this section in detail. Of obvious


FEET METERS
LEGEND
SHALE
LAMINATED SILTSTONE
UNDULATE SILTSTONE
SANDSTONE
PARALLEL LAMINATED SANDSTONE
CHAOTIC BED
SANDSTONE COBBLES AND BOULDERS
SHALE COBBLES AND BOULDERS
SILTSTONE COBBLES AND BOULDERS
RIPPLE LAMINATIONS
BENTONITE
COVERED SECTION

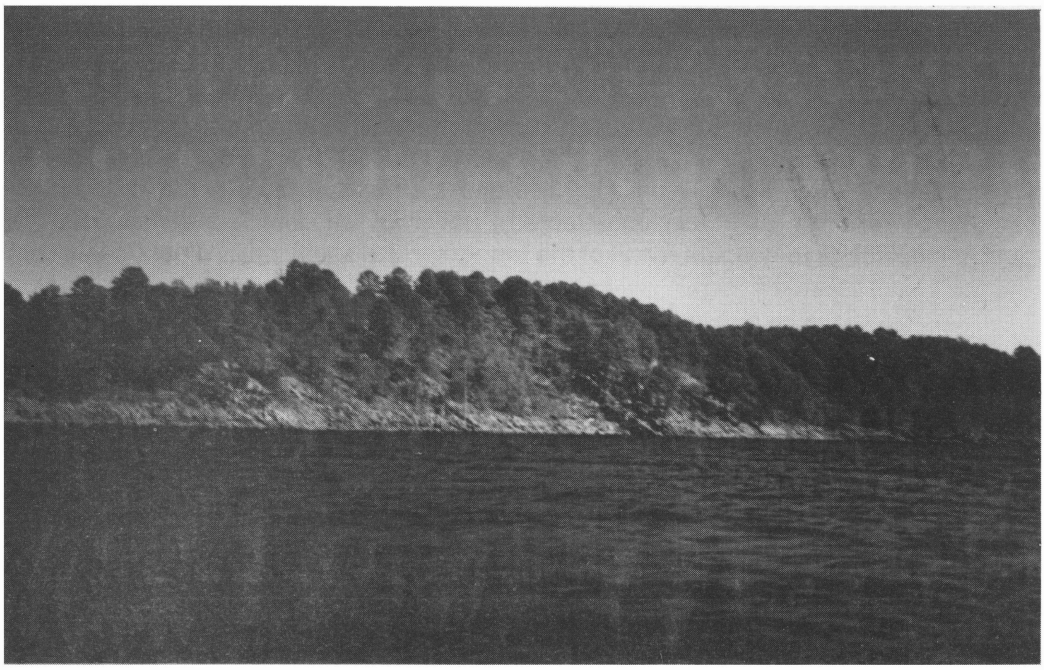


Figure 21. Photograph of DeGray lakeshore exposure of Jackfork Formation.

interest here is the thick, channel-fill complex of chaotically-bedded shale and pebbly conglomerate "cannonballs", capped by a thick quartz-pebble conglomeratic sandstone. This quartz-pebble conglomerate appears to be the same bed/interval which caps the spillway cut ("1000-foot sand") (Breckon, 1988) and is probably the same interval present in the Friendship I-30 cut (Mile Marker 81) section at 0 to 20 feet (0 to 6 m) (Stone, 1981). This interval has been correlated by ARCO and BP America workers to similar zones in the Shell No. 1 Rex Timber (6 miles (10 km) south of DeGray Lake) and the Hollywood Quarry (12 miles (20 km) southwest of DeGray Lake) (Leander, 1988, personal communications; Jordan et al., 1991a, b). Additional work by Coleman (this volume) modifies the interpretation by Jordan et al. (1991a, b) and confirms this correlation (Plate 1). Based on this conclusion, this pebble zone extends for at least 13 miles (21 km) west to east (down current) and 17 miles (27 km) north to south (palinspastically restored; based on Coleman, 1990). This interval may be one of the most regionally consistent units within the Jackfork of the southern Ouachita Basin.

Breckon and Mansfield (1985), through aerial photography mapping, determined that, even though individual beds are all less than 4 feet (1.2 m) thick, and are difficult to trace laterally, the entire sandstone section which underlies Chalybeate Mountain can be traced as a unit for 4 to 5 miles. This suggests that we should be able to go laterally for a mile or so along strike and still be able to correlate back to the intake area. Later this afternoon, we will try to do just that at DeGray Dam spillway, 1.2 miles (1.9 km) east of the intake cut.

Correlation of the sections at the intake tunnel and the spillway above and below the thick,

Figure 20. Measured stratigraphic section, lower Jackfork Formation, DeGray lakeshore. From Breckon (1988).

channel-fill, chaotic zone is not that straightforward. Examination of Jordan et al. (1991, figure 70)(our Figure 25) does not give much comfort to a strong position on lateral correlation. Examination of Breckon (1988, figure 72) (our Figure 26) seems only slightly better. Study of a topographic map of the area, suggests that the dam intake section may be depositionally separate from the adjacent strata, based on the changes in strike directions of the sandstone ridges from the spillway area westward across the lake (idea from Leander, 1988, personal communication) (Figure 27). Hunt (1965) found a strike-slip fault in the valley of the Caddo River (over which the dam was constructed); however, the lateral translation on the fault is probably insufficient to account for all of the topographic disharmony. What do you think?

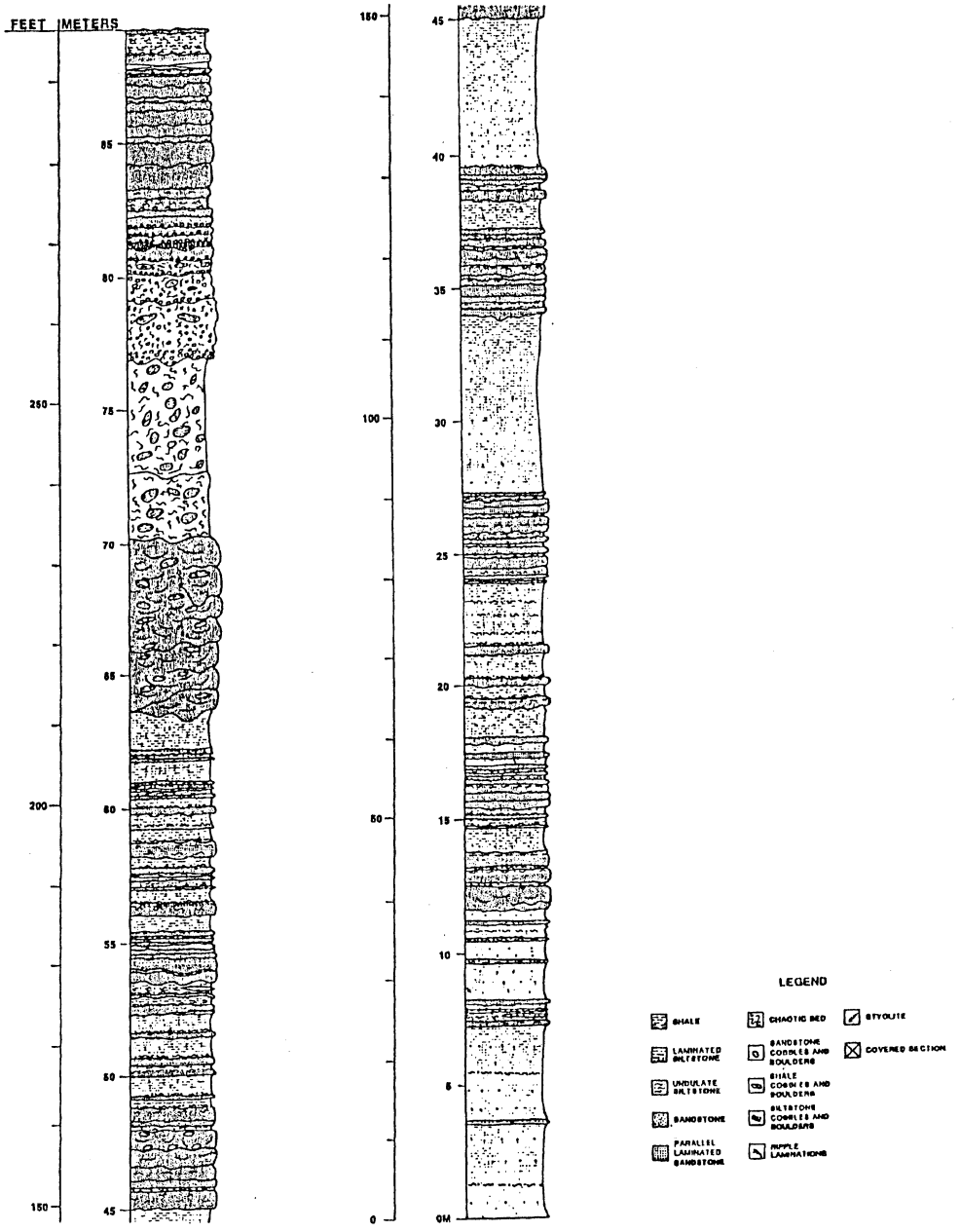


Figure 22. Measured stratigraphic section of middle Jackfork Formation, DeGray Dam intake cut. From Breckon (1988).

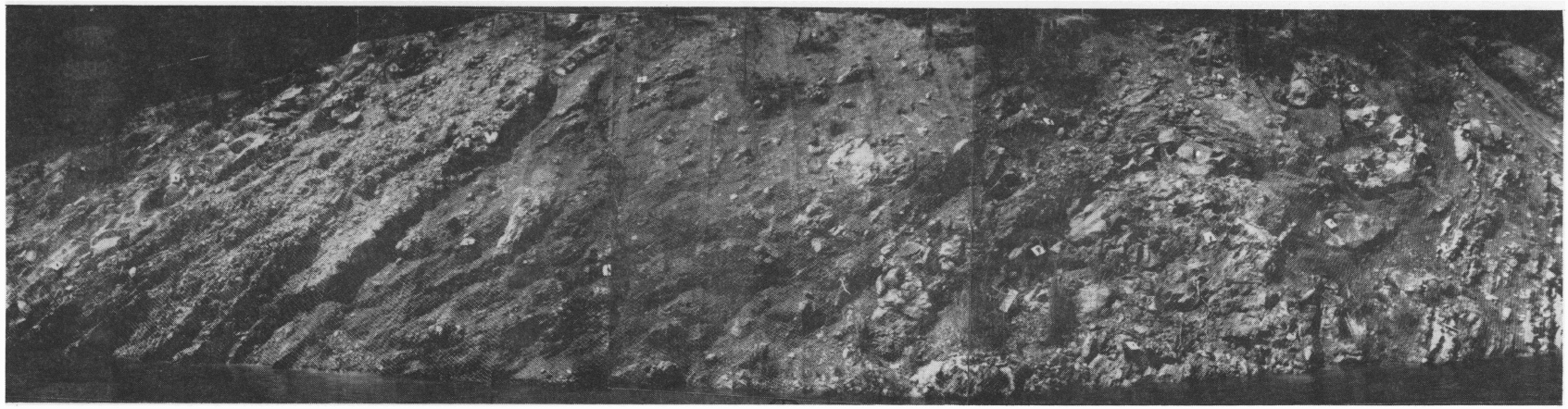
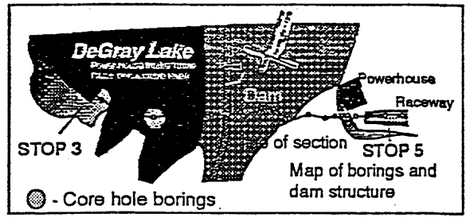


Figure 23. Photograph of DeGray intake cut.



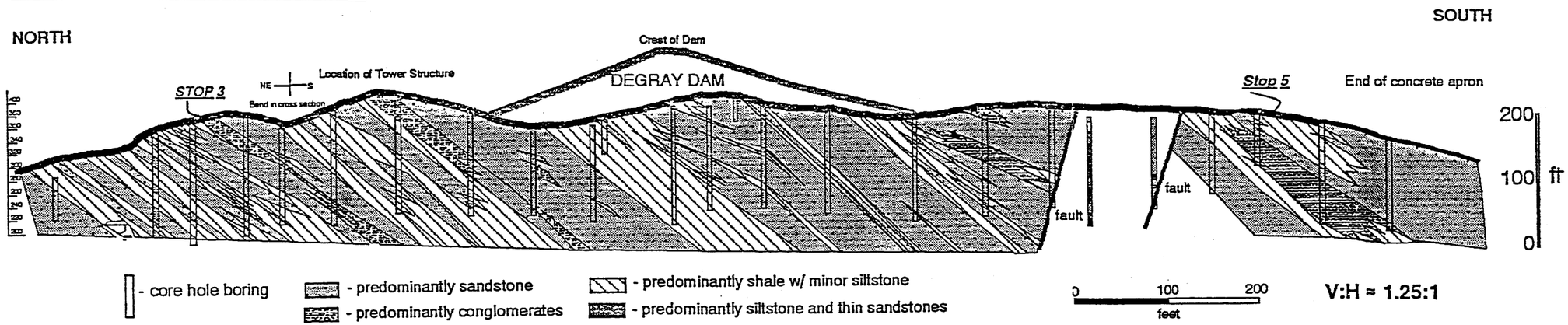


Figure 24. Generalized structural cross section, DeGray Dam. Modified from Hunt (1965).

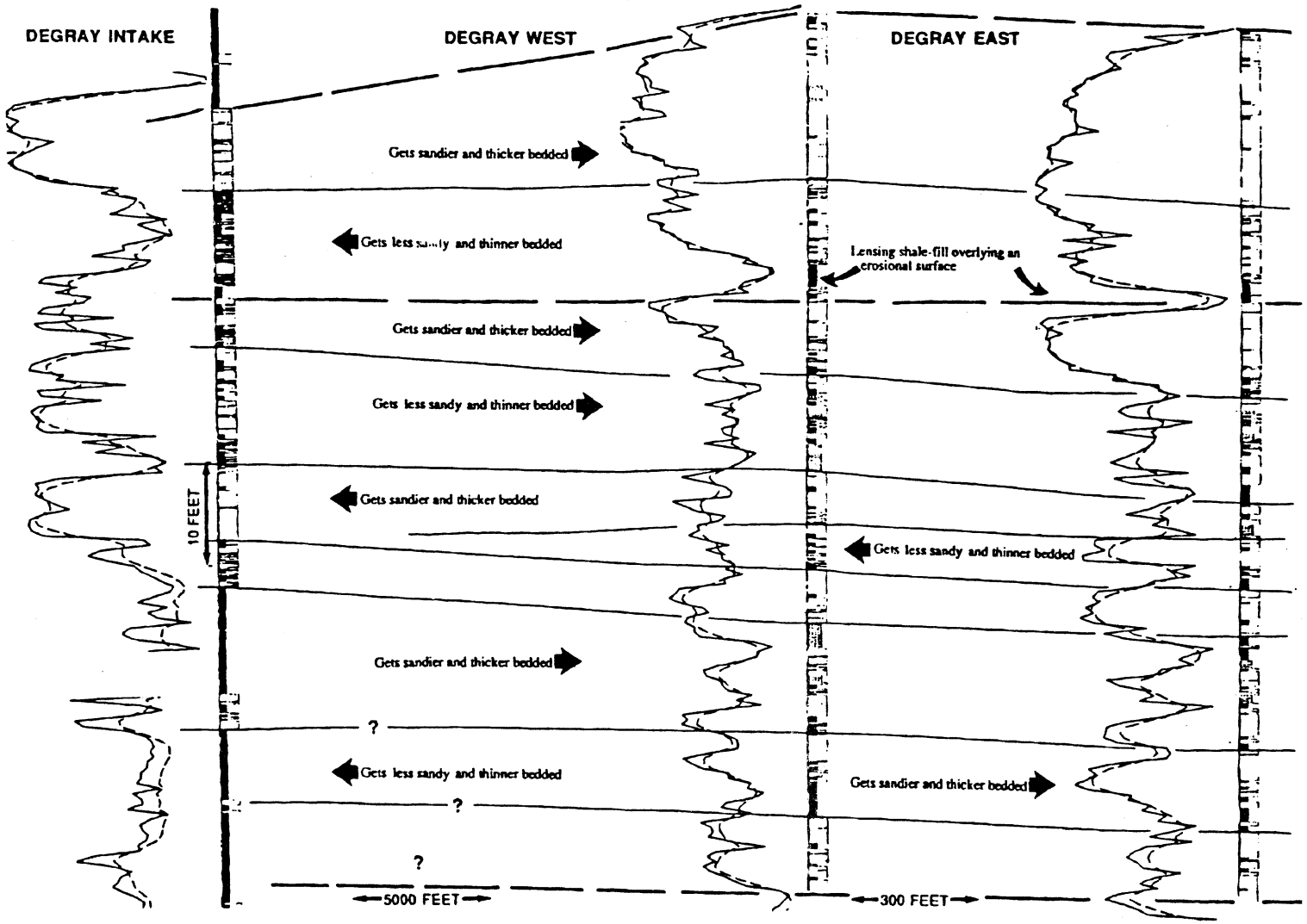


Figure 25. Correlation cross section of the Jackfork Formation between DeGray Dam and DeGray Spillway. From Jordan et al. (1991a).

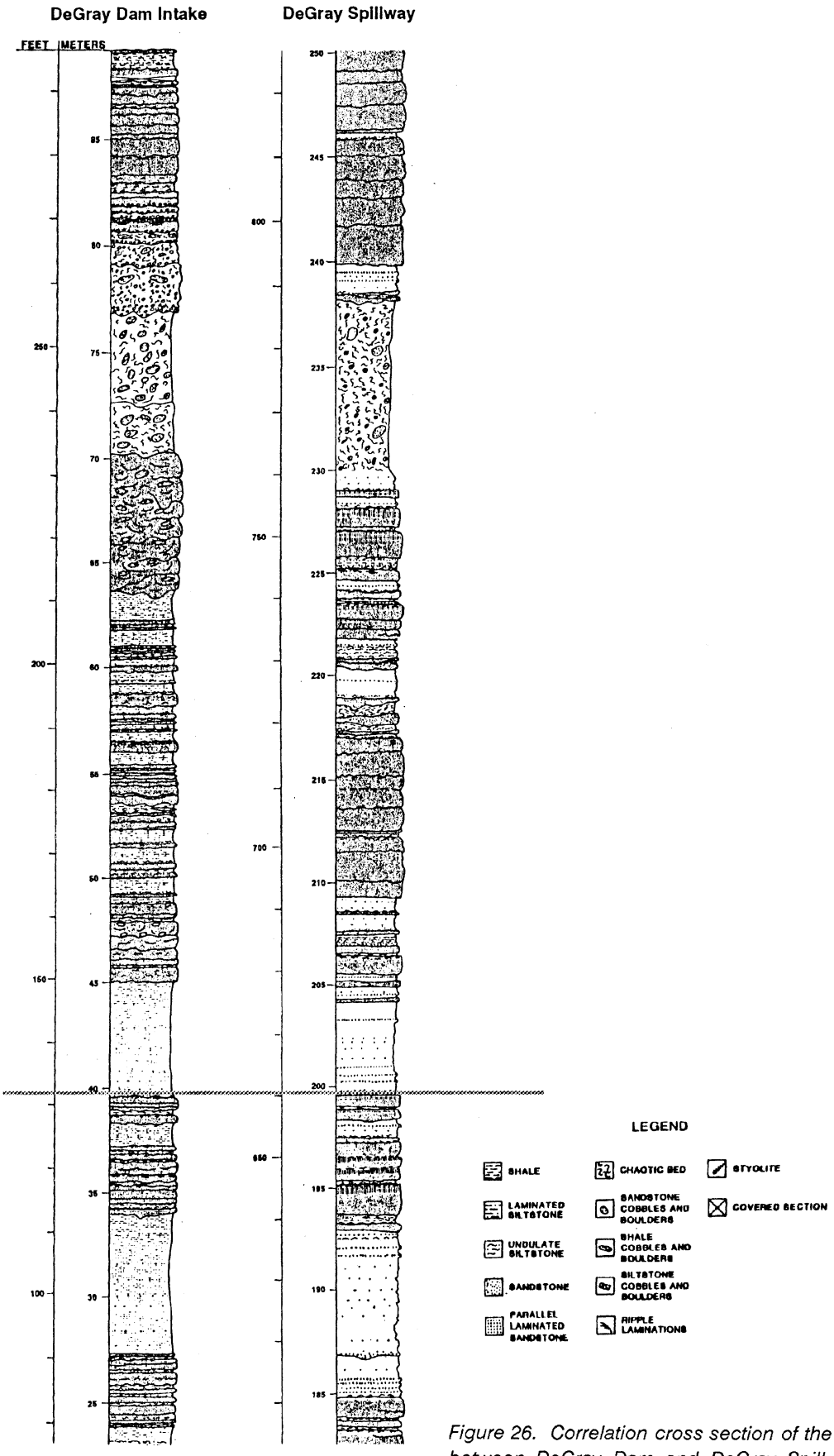


Figure 26. Correlation cross section of the Jackfork Formation between DeGray Dam and DeGray Spillway (from Breckon, 1988).

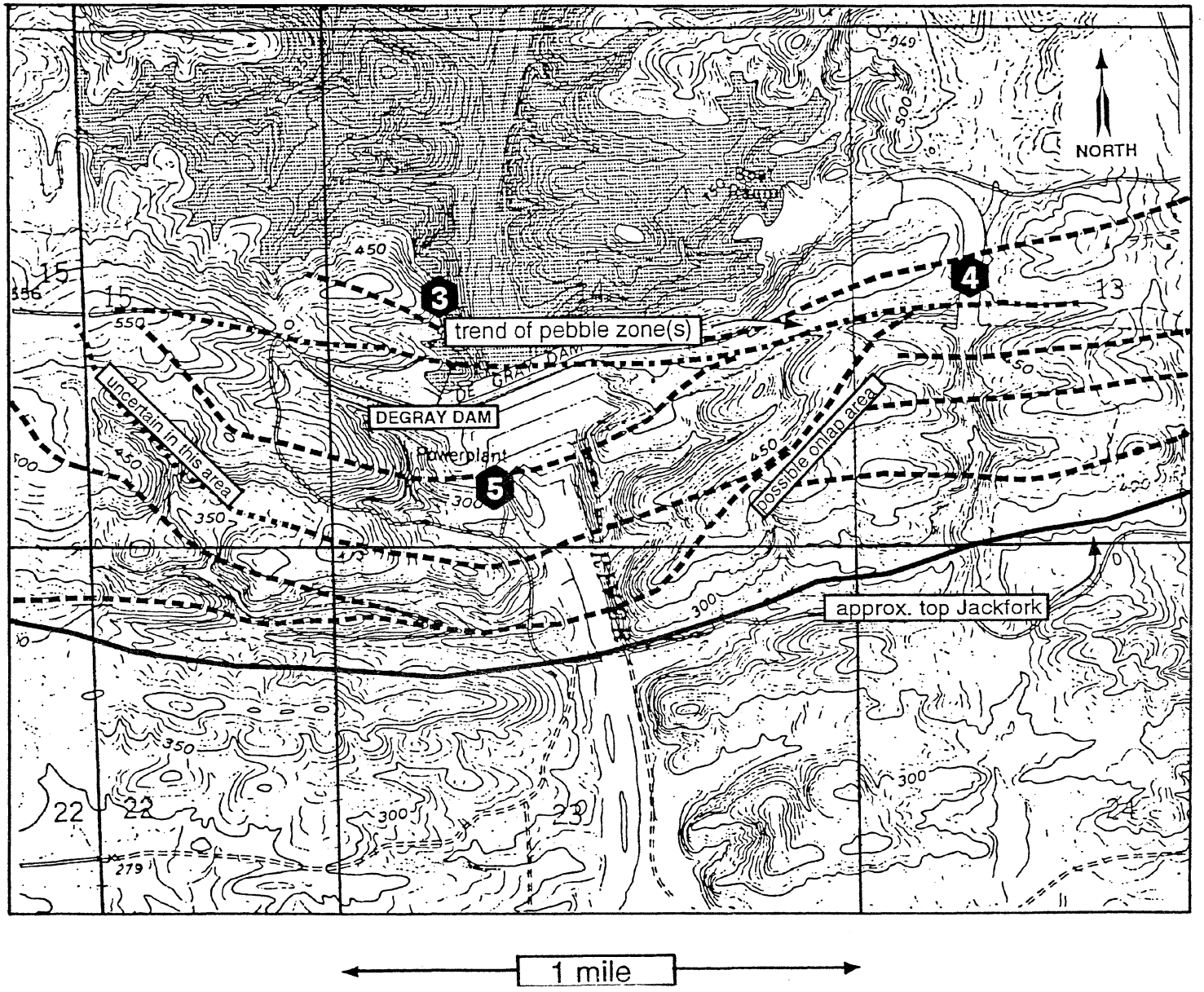


Figure 27. Potential upper Jackfork allignments, DeGray Dam area. Field-trip stops shown in hexagons.

STOP 4: DeGray Spillway

LOCATION: Spillway cuts near the intersection of the DeGray Dam Visitors Center access road and the boat ramp entrance; W/2-13-6S-20W, Caddo Valley Quadrangle, Clark County, Arkansas.

KEY REFERENCES: Morris, 1977; Breckon, 1988; Jordan et al., 1991a.

PURPOSE: The purpose of this stop is to look at laterally equivalent sections to the intake section. Secondly, this worldclass exposure offers many interesting hours of study in and of itself and demands to be visited by all geoscientists at least once. We will study it to interpret the depositional environments and facies-tract successions. We will also look at the "middle" of the Jackfork below (and 1.2 mi (1.9 km) east of) the pebble zone at Stop 3. The degree of correlatability should help us interpret what portion of the fan complex we are on at Stop 4.

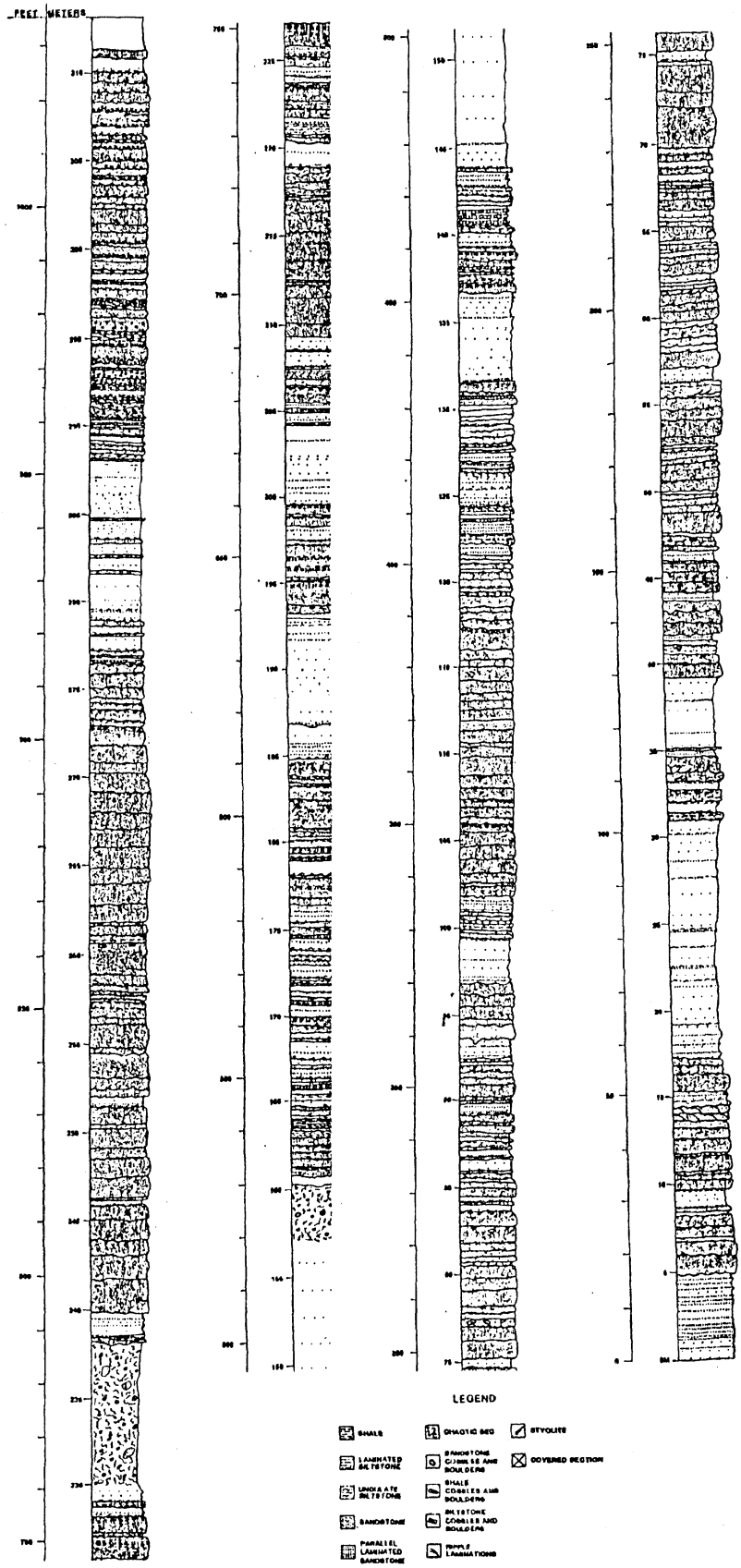
DISCUSSION: This section was drilled by the Shell #1 Rex Timber well, 5 miles (8 km) south of this location. The gamma ray log of this well, as well as the hand-held gamma ray logs of ARCO field geologists in the DeGray area well illustrate the log nature of this section (Plate 1). Exposures at the spillway allow close examination of clues for interpreting the depositional environments of the sandstones and shales. The spillway exposes over 1000 feet (300 m) of south-dipping (approximately 45 due south), quartz sandstone, subgraywacke, gray siltstone, and dark gray shale. The sandstones contain Bouma sequences, graded bedding, load structures, dish and pillar structures, bottom marks, ripple marks, broad scours, clay balls, and other very interesting features. Thick, contorted shale beds and sandstone olistoliths are present in a few intervals. Beds of coalified plant fragments are quite common. Where found in the Ouachitas, these are commonly called "blue beds", for their steel-gray or bluish color. Invertebrate fossil remains have been reported from several beds in the exposure. Other than the abundant, fragmented plant material and fairly common trace fossils, most fossil remains are very illusive.

Footage numbers in this discussion are from Morris' (1964, 1974a) original numbering scheme and are closely equivalent to 1000 minus that number on Jordan's et al. (1991a) logs (Plate 1).

The thickest, "cleanest" shale interval is at 100 foot (30 m) in the exposure. Is this a basinal (i.e., abyssal shale) or a distal overbank shale? How can you tell? Breckon (1988) places this lower "shale" section on the outer fan. Since this shale is easily correlated with a similar shale in the Shell well (Plate 1), it may be that this unit marks a subregional cessation of coarse-grained fan deposition. With this cessation, the outer fan facies prograded into the overall middle-fan environment, indicated by its regional perspective (Figure 7).

The spillway bends to the south at the "400-foot" ("120-m") sand (at the small waterfall). This is the first of two thick sandstone packages in the spillway; the other is the "1000-foot" ("300-m") sand at the top of the interval (final portion of this stop at the south end of the spillway). It is apparently a channel complex sandstone. We will want to compare it with the rock types of the "1000-foot sand" ("300-m") when we get there. This sand type dominates the sandstone units of the lower 400 feet (120 m) of the section.

Figure 28. Measured section of Jackfork Formation, DeGray Spillway. From Breckon (1988).


FEET
METERS
LEGEND
SHALE
LAMINATED SILTSTONE
LIMONITE SILTSTONE
SANDSTONE
PARALLEL LAMINATED SANDSTONE
CHAOTIC BED
SANDSTONE COBBLES AND BOULDERS
SHALE COBBLES AND BOULDERS
SILTSTONE COBBLES AND BOULDERS
RIPPLE LAMINATIONS
STYLOLITE
COVERED SECTION

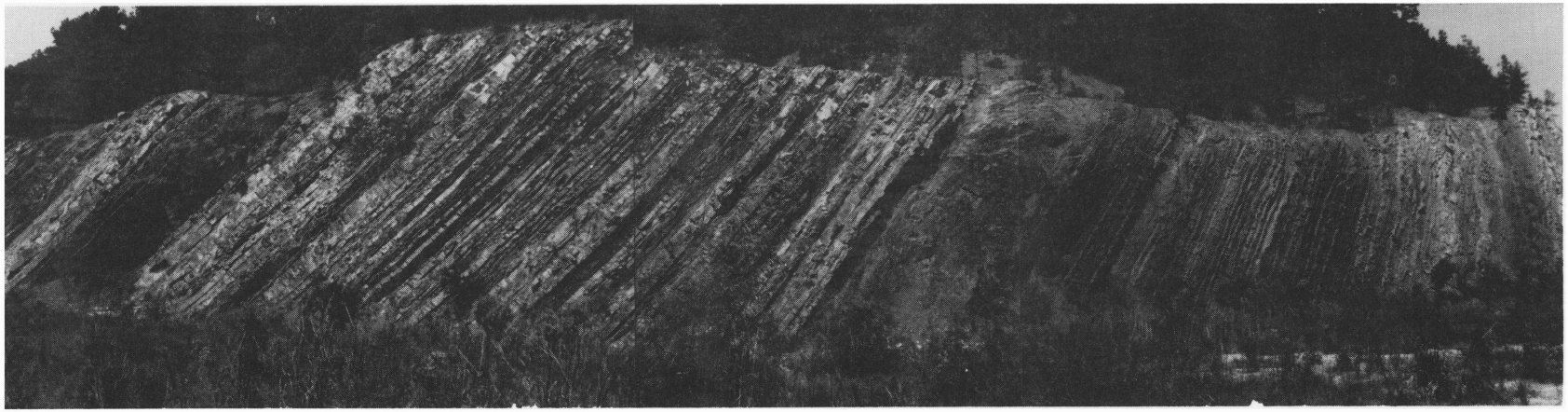


Figure 29. Photograph of middle portion of DeGray Spillway.

Figure 30. Photograph of southern end of DeGray Spillway.

Throughout this lower portion of the section are so-called "slurried" beds (247- foot/75-m), rippled beds (170 - foot/52-m), convolute (or contorted) laminations (133 - foot/40-m), and sedimentary(?) imbricates (70 -foot/21-m) (Morris, 1973; LoPiccolo, 1977). Shanmugam et al., (1988) interpreted a set of unusual, sedimentary slump duplexes at the 70-foot (21-m) interval. All of these "typical" deep-water sedimentary structures are very common in this lower section, yet relatively uncommon in the intervals above. Is there a difference in the bottom marks (i.e., sole marks) which might suggest a different direction of movement, or perhaps, less persistent sediment movement?

At 550 feet (168m) two moderately thick shale beds crop out, one on top of the other. They are obviously different; but why? From a sequence stratigraphy point of view, where are we? Could this be a sequence boundary? Could you discriminate between these two shales on logs or seismic?

As we move further up the section, the exposure is one of mostly thin-bedded sandstone, siltstones, and shales (Figure 29). These are what could be called "classical turbidites" in the literature. Are these levee deposits or outer fan deposits? How can you tell? Would these sandstones make good reservoirs? Why? Do these sandstones vary in thickness across the spillway? Is this, perhaps, a clue to their depositional environment and potential reservoir properties?

An unusual bed occurs at about 630 feet (192 m) in the section and does not extend across the spillway floor to the other wall. How was this bed deposited? If you drilled this section and were able to detect this bed either by logging the samples during drilling or by examining the FDC-CNL-GR or GR-Acoustic log afterwards, how would your interpretation of this bed relate to your overall interpretation of the sequence? What if it were slightly thicker and detectable on seismic as a bright spot prior to reaching it with the well bore?

We will conclude the spillway stop at the "1000-foot sand" ("300-m sand") at the south end of the spillway (Figure 30). This sandstone is part of a 200-foot (61 m) sequence of generally graded beds, with at least 15 cycles of granule or "grit" deposition. In places these grit beds have rather large scour features. Here we may test conventional theories of the Bouma sequence and the gradation of grain size through each sequence.
These sandstones apparently are part of a large channel complex. Can we determine the base of the channel? Is it the base of the massive sandstone package? What does the base of the channel look like on the Shell log? If this sandstone package had porosity, would it make a good reservoir section? Why? (or, why not?)

Channel-complex sandstones just don't occur by themselves. Their companion overbank and levee facies are present either lateral to the main body or stratigraphically above or below it, if no unconformity has removed them (remember Walther's Law*). Conversely, if overbank-and levee-facies sedimentary rocks are found, then a channel complex should be nearby. How do you know where it is/will be? How can you know it will have sandstone in it, such as this example?

** Walther's Law, as stated by Middleton, 1973, says, "The various deposits of the same facies areas and similarly the sum of the rocks of different facies areas are formed beside each other in space, though in cross section we see them lying on top of each other. As with biotopes, it is a basic statement of far-reaching significance that only those facies and facies areas can be superimposed primarily which can be observed beside each other at the present time." This has been distilled to: "THE SAME FACIES SEQUENCES ARE SEEN LATERALLY AS VERTICALLY".*

Recall your impressions of the "400-foot" ("122-m") sand. Were the "400-foot" and "1000-foot" sand both deposited by the same processes? Is the "400-foot sand" a better reservoir candidate than the "1000-foot sand"? Why?

DeVries and Bouma (1992) and Bouma et al., (1993) closely examined two sections in the spillway which have laterally correlative intervals on both east and west sides and further compared the spillway to the intake section at the dam. An upward increase in correlatability of bed thickness within two stratigraphic intervals, in conjunction with azimuthal variations in paleocurrent indicators, indicate that the spillway section preserves the record of a progressively migrating, channel-levee-overbank. This analysis is consistent with the detailed interpretations of Lowe and LoPicollo, (1974) and Breckon (1988) and the regional work by Link and Roberts (1986) and Coleman (1990).

Breckon (1988) places the middle part of the spillway in the middle fan, whereas Coleman (1990) (Figure 7) puts the entire section within a channel complex within the channel-lobe transition zone, between the mid and upper fan.

STOP 5: DeGray Dam Powerhouse

LOCATION: Roadcut and sluiceway exposures along the powerhouse access road below DeGray Dam; SW/4-14-6S-20W, Caddo Valley Quadrangle, Clark County, Arkansas.

KEY REFERENCES: Hunt, 1965; Breckon, 1988; Jordan et al., 1991a.

PURPOSE: The purpose of this stop is to continue our traverse of the Jackfork fan complex, comparing the dominant bed forms and associated processes of the upper Jackfork with those observed in the middle and lower Jackfork.

DISCUSSION: We will return to the parking lot, and drive along and over the crest of Chalybeate Mountain to the downstream side of the dam to a section that is stratigraphically above the section at the spillway. The strata here are thick channel-levee-complex sandstones and thin shales, with a probable upper fan-slope component, based on the degree of chaotic bedding and slumping, especially in beds exposed in the raceway outlet.

The stratigraphic top of the Jackfork is not well exposed along the river. However, it is located near the topographic slope change from high ridge to low, flat plain, and is approximately where the small bridge crosses the river. Exposures on the east side of the river, and stratigraphically above the raceway exposure, are poor, but generally confirm a shaly section with thin, minor sandstone beds.

STOP 6: Murray Quarry

LOCATION: Abandoned quarry; SE/4-13-6S-20W, Caddo Valley Quadrangle, Clark County, Arkansas.

KEY REFERENCES: Stone, 1981; Breckon, 1988; Jordan et al., 1991a.

PURPOSE: The purpose of this stop is to look at the capping strata of a 7000-foot (2133-m) thick deep-sea-fan complex. We will attempt to understand why Jackfork fan deposition ceased.

DISCUSSION: As currently interpreted, the top of the Jackfork is exposed in the Murray Quarry. Jordan et al., (1991a) interpret the contact of the Jackfork with the overlying Johns Valley shale

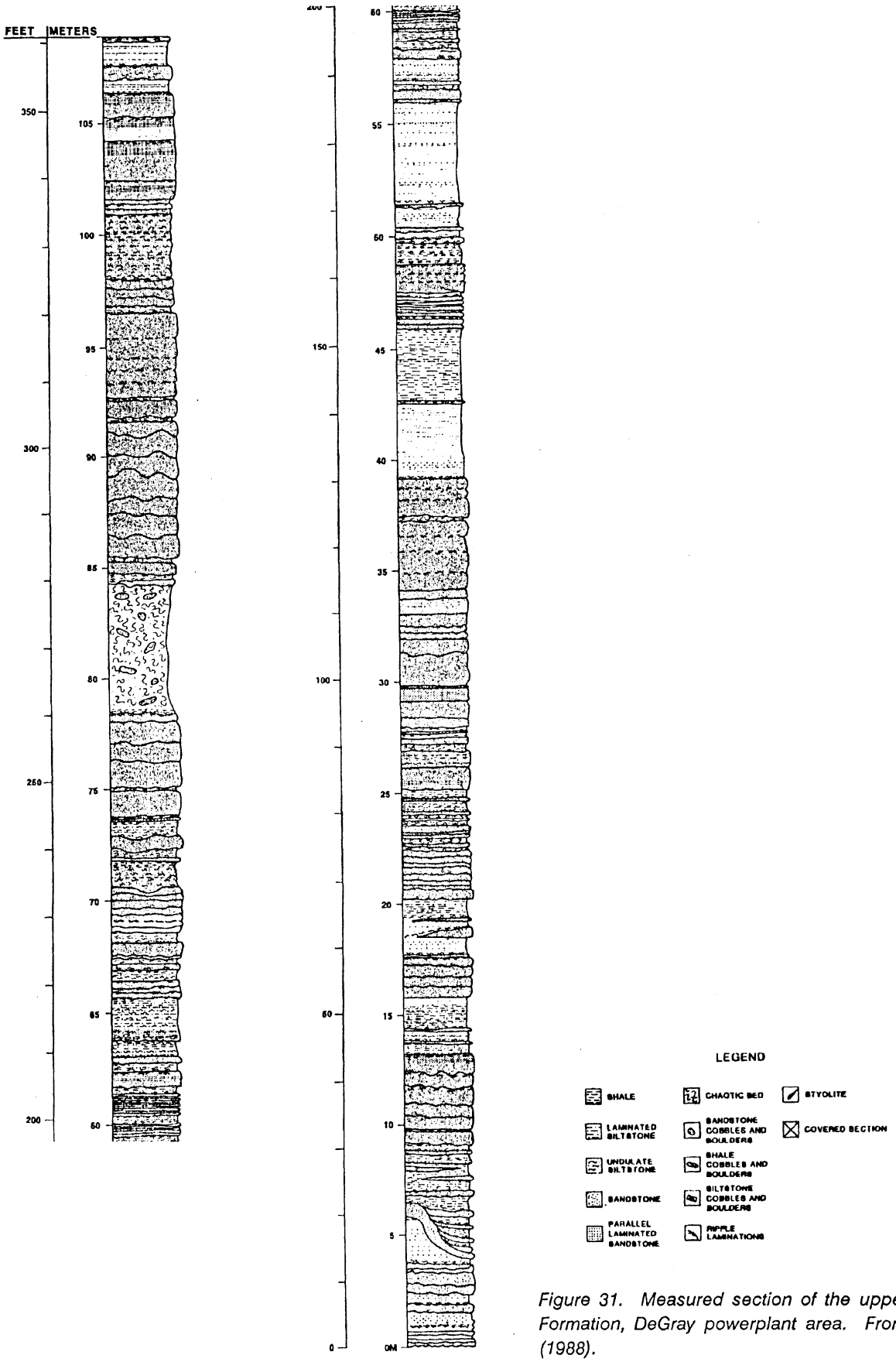


Figure 31. Measured section of the upper Jackfork Formation, DeGray powerplant area. From Breckon (1988).

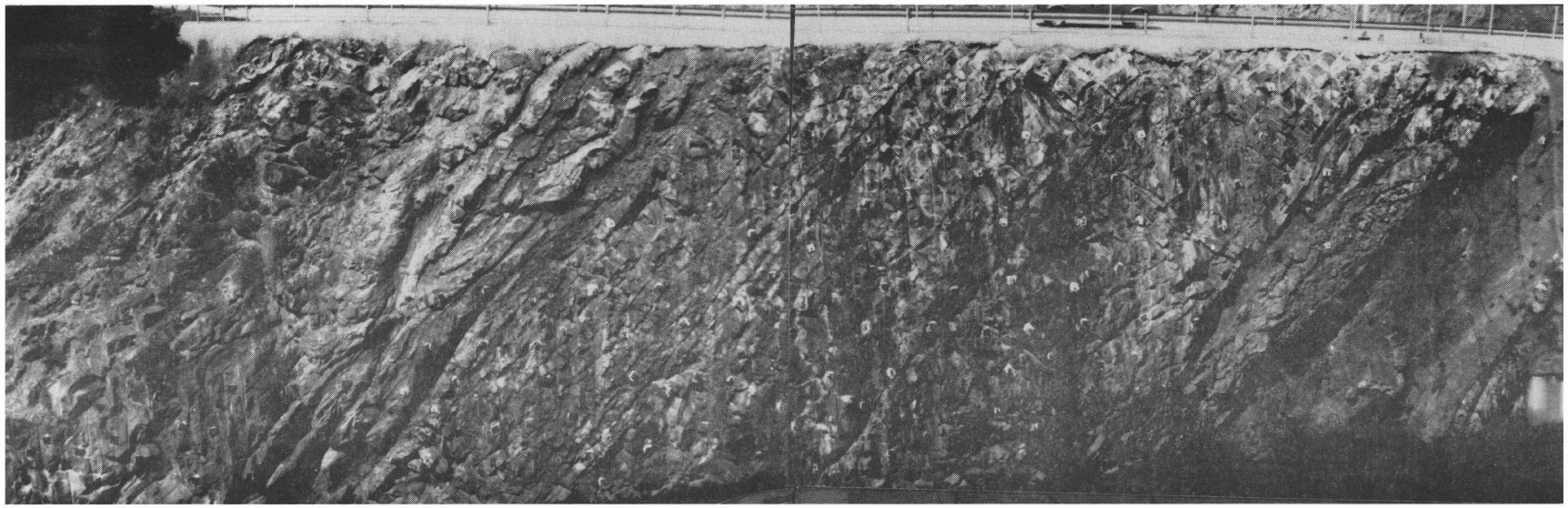


Figure 32. Photograph of DeGray outfall cut.

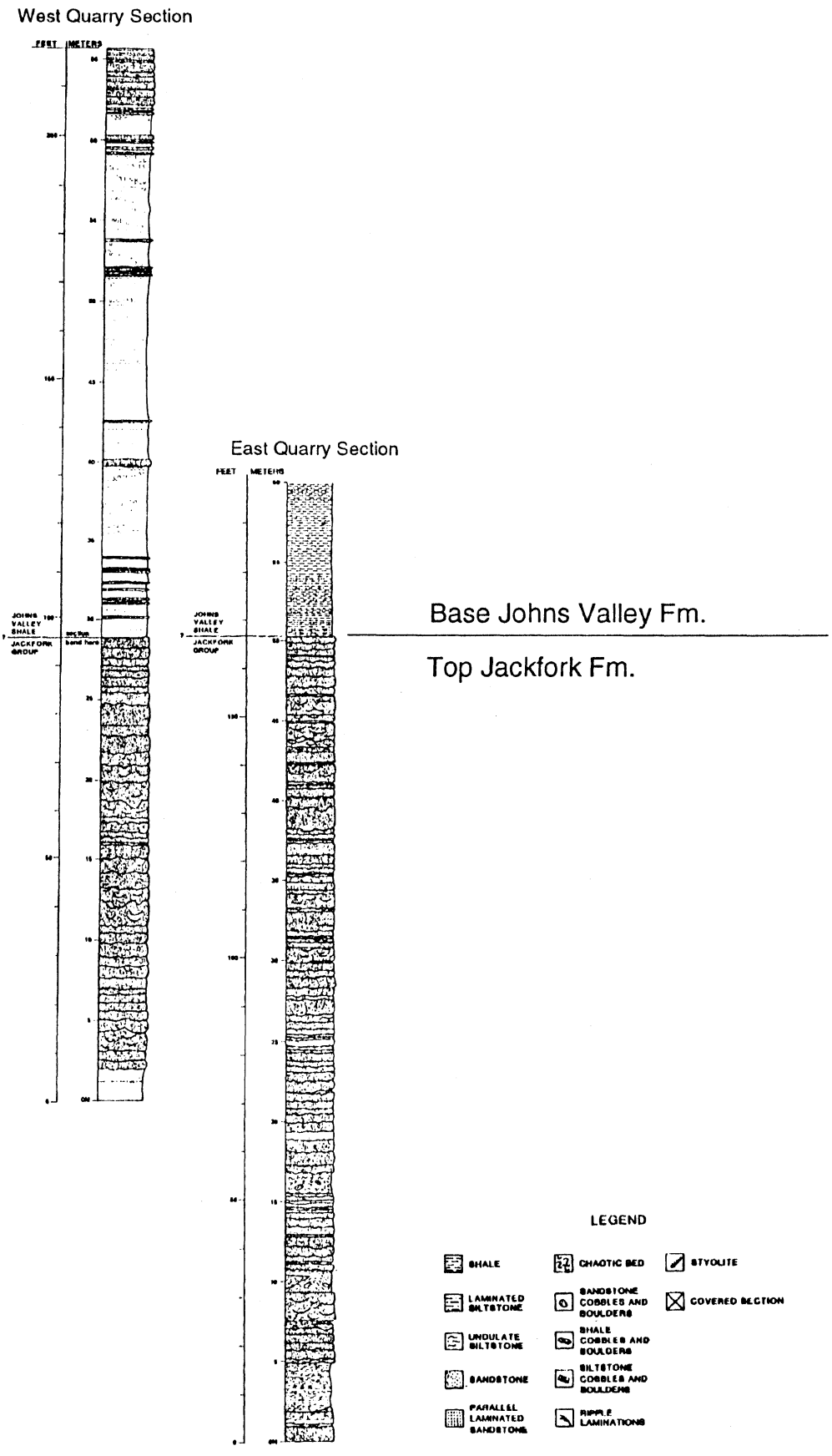


Figure 33. Correlation of the upper Jackfork Formation within Murray Quarry. Modified from Breckon (1988).

as erosional, with deep incisement and shale infilling. The Jackfork here is interpreted to be upper-fan, channel-levee complex. Is this how a deep sea-fan complex dies?

The west quarry section (Figure 33, Plate 1) is approximately 0.6 mi. (1 km) down-current from the east quarry section and allows detailed correlation attempts in the upper-fan section. A 49 ft (15 m) thinning is apparent in the quarry wall in a down current direction.

Figure 34. Photograph of Murray Quarry.

DISCUSSION

You have now seen a major, deep-sea fan in a vertical section. Our original purpose was to examine the functionality of three widely used models to adequately predict facies associations of a deep-sea fan complex.

Each of you probably has "solved the problem." Each of you probably has a favorite model that is easier employed than the others. Whether or not this is a case of beauty-in-the-eye-of-the-beholder; whether or not we crave order more than chaos; whether or not we want models more than need them, we really cannot say.

Before addressing the question in detail, we must first compare the constraints of the models with the attributes of the data. A key point to consider is the model scale and the scale of the data. Data often range in size from thin section to core or outcrop to extremely large outcrop or seismic; or, in other words, from a detailed, intra-fan level to basinal to extra-basinal in scope. The models we have discussed range across this spectrum (Figure 35).

From an earlier review of the models (pages 7 through 15), we determined that the Walker Model looks at fans from the viewpoint of a detailed sedimentologist seeking to relate spatial and temporal sedimentary events and facies to each other. It works well within one outcrop or a set of related outcrops. The model works best when limited to application within the fan complex. The Mutti Model is expressed from the viewpoint of an experienced field geologist correlating one sedimentary area or structural panel to another within the same stratigraphic age. It functions best at the basin scale. The Vail Model is the most far-ranging of "our" three models. It has a sequence stratigraphic viewpoint developed from years of seismic and well-log profile stratigraphic analysis. Its application allows the user to work from the bordering shelf areas into the deep basin.

In a effort to test these models we have given you a review of the regional basin setting for the Jackfork Formation, and we have examined in some detail a vertical section near the center of the basin. This vertical profile is essentially a 7000-foot (2133-m) core. While more detailed, sedimentologic data would be nice, this amount resembles what many of us deal with in real-world geoscience investigations.

So what do we have? What characterizes the Jackfork at these localities?

How effective have "our" three models been to:

(1) predict vertical relationships?

(2) predict horizontal relationships?

Within our field area, the actual contact between the Jackfork Formation and the underlying Stanley shale is usually not clearly exposed. However, northwest of the DeGray area, it is commonly well exposed, and there it comonly consists of a transitional zone of shales, siltstones, and thin-bedded sandstones. A thin, but widespread, siliceous shale, the Chickasaw Creek Shale, is picked as the top of the Stanley. Where this marker bed is absent, the base of the Jackfork is defined arbitrarily as the lowest occurrence of clean, well-bedded, sandstone at the top of the Stanley Shale. The massively bedded sandstones, similar to those exposed at the DeRoche Ridge road cut, occur a few meters to ten's of meters above this "arbitrary" formation boundary. In central Arkansas, massive channel-levee sandstone complexes

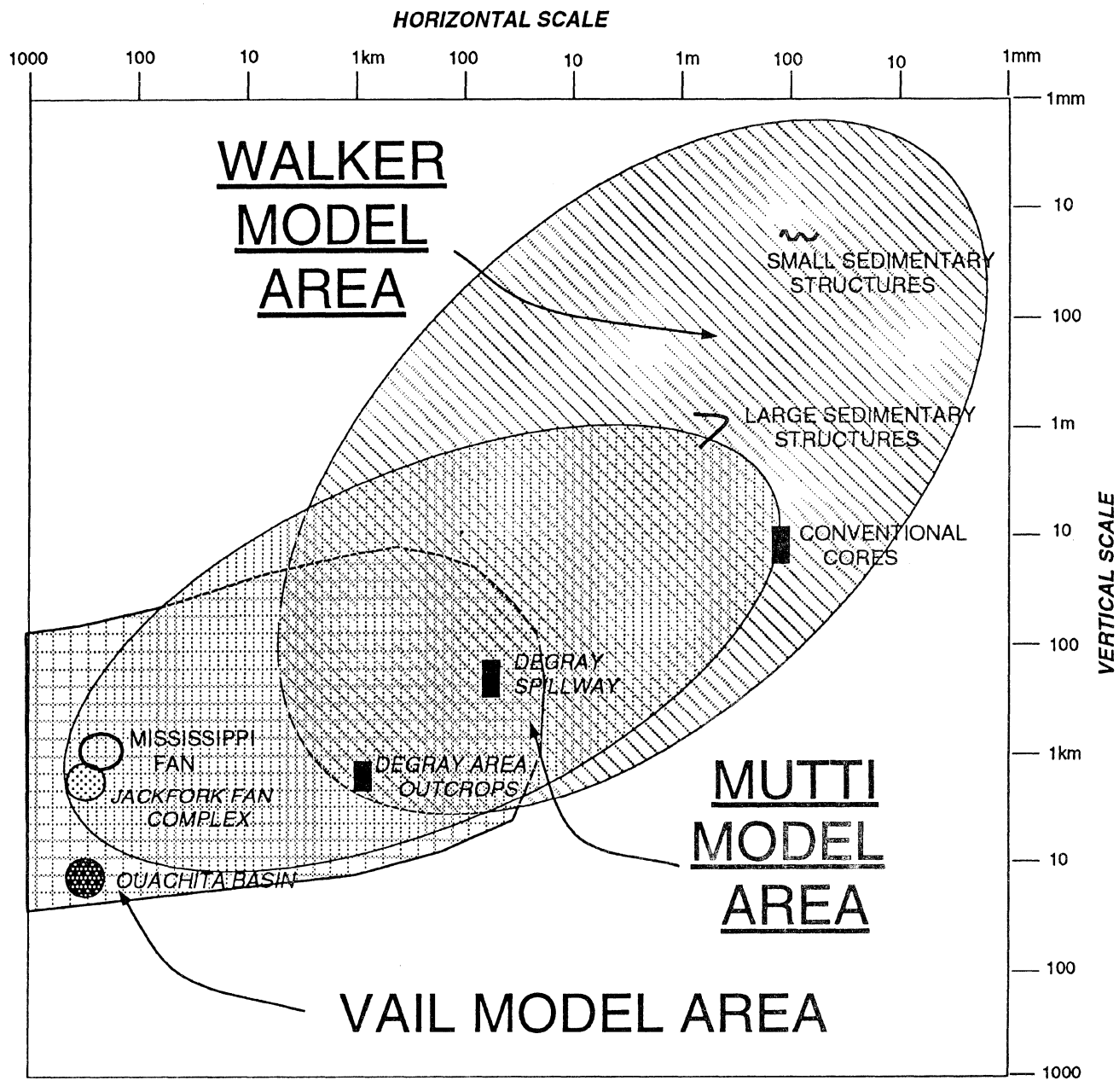


Figure 35. Effective scales of deep sea fan models. Log-log cross plot of the sizes of various deep-sea fan features which we have seen on the trip, ranging in size from small-scale sedimentary structures to large deep-water basins. Superimposed on these notations are the three areas of effective use for the three deep-sea fan models discussed in the text. Notice that there is substantial overlap of all three, as well as areas of single coverage for the Vail and Walker models. This figure emphasizes the importance of applying the appropriate model to the appropriate data sets.

dominate the section from top to bottom, whereas in western Arkansas and Oklahoma, they constitute a minor element. There, most of the sedimentary rocks are composed of thin- to medium-bedded sandstones and shales, with moderate to minor channelization features, all generally suggestive of a lobe (outer-to middle-fan) depositional environment. In northeastern and eastern Arkansas, organized, bedded units are less common and generally restricted to thick channel-levee complexes; however, thick intervals of disorganized, poorly bedded

sandstones and shales become more significant. These thick intervals are indicative of slope deposits and debris flows.

At first glance, it would appear that the Jackfork Formation nicely fits the Walker Model. This is because the Walker Model is best applied to local vertical and lateral associations of strata. The dominant depositional elements associated with each of the depositional areas are found in their "proper" place in the basin, as viewed in plan view (Figures 7 and 8). Upper-fan facies are primarily in the northern and eastern reaches of the complex. Middle-fan facies are in the middle, and outer-fan lithofacies are primarily in the western areas of the fan system. However, the model loses some of its predictive power, in that we see that the overall section does not necessarily thicken (and coarsen) upward as illustrated in the columnar section (Plate 1, Figure 10). Jackfork sandstones become thick, early in the depositional regime. The prograding of proximal over distal as predicted by the columnar section in a thickening-upward succession is not observed. What is apparent is that the Jackfork transitions from lower to upper fan and/or slope within the DeGray area by the upward change in dominant depositional elements.

Mutti's perspective is of a regional field geologist interested in tying together separate, but complete, vertical sections, and from these, interpreting a map view at a basinal scale. The Mutti model calls for a back-stepping, thinning-upwards succession, potentially culminating in either a highly slumped slope section or a shelf-margin deltaic-marine interval. Emplacement of a Mutti Type I system is initiated by mass wasting on the slope and outer shelf, resulting is several thick, widespread, generally tabular sandstone units at or near the base of the complex. Succeeding this are the Type II outer channel-lobe and Type III channel-levee systems. This succession is not evident at all in the DeGray area. What we may be seeing, however, is the updip, featheredge of the Type I system below the massive sandstones at DeRoche Ridge, followed by almost 6450 feet (1966 m) of Type II system rocks (the lakeshore up to the upper powerhouse section), capped by approximately 500 feet (150 m) of Type III deposits (powerhouse cut to top of section)(Plate 1). Down current from DeGray (i.e., to the west), there is no obvious evidence of thicker Type I deposits as predicted by the model. As such, the Mutti model is apparently insufficient in its abilities to predict future observations.

The Vail Model is developed from analyses of regional profiles using sequence-stratigraphic principles. Use of his model is best done at an extra-basinal scale. The Vail model includes many elements of the Mutti model, in that a thick, generally homogeneous basin-floor fan should lie at the base of the sequence, followed by a relatively thick interval of channel-levee sedimentary rocks, and capped by sandstones and shales of the prograding complex and/or shelf margin delta. In large, open basins, the initial sedimentary event -- the basin-floor fan -- may not always be anomalously thick, as they are in restricted, interslope basins, where bathymetry controls sedimentary ponding. If this is true, and permissible within the Vail Model, then the lowermost, thin- to medium-bedded sandstones at DeRoche Ridge may correspond to the Jackfork basin-floor fan. Based on its regional location, the lowermost Jackfork at this location was deposited on the floor of the basin during or immediately after a global fall in sea level. Succeeding this moderately thin interval is a very thick section of obvious debris flow and channel-levee complex sandstones and shales. The section is capped by a series of thick, disorganized, poorly bedded and slumped sandstones and shales which could represent elements of the prograding complex. No clear components of a shelf-margin delta have been found; however, the erosional top of the Jackfork indicates a substantial change in base level or basinal oceanographic conditions occurred, resulting in the end of Jackfork deposition.

CONCLUSIONS FROM THE EXERCISE

In conclusion, our study has shown that any "fair" test of models will be biased by the scale of the data and its relative goodness-of-fit with the scale of the modeler's eye, if not the model itself. Each model was conceived from data of a specific scalar range and should be used inside that range.

Secondly, and in all cases, the models only work within an intact, genetic unit. Just as Walther's Law warns against crossing bounding unconformities in interpreting vertical and lateral associations, each of "our" three models works only with a succession of strata within its bounding unconformities (or correlative, down-dip conformities).

In reality, we do not have the predominance or preference of one model over another, but rather three sets of tools (Walker - Mutti - Vail), all of which are useful when applied correctly (Table 4). The Vail Model is best used in a frontier-basin setting, where the geoscientist has little point data and must rely on seismic profiles and global tectono-eustatic concepts. Application of the Vail model in a first-look effort leads to a regional correlation framework of sequence boundaries.

The Mutti Model is most viable in correlation within basins after the basin margins have been found. After these margins have been located and some detailed point data become available, then it may be used as a correlation and interpretation method. If major slump scars are observed at the shelf-slope break, then the key initiation event for a Mutti system has been found.

The Walker Model is most effective as a tool for close-in development or exploitation work, when sedimentological detail is available and critical for lateral facies associations.

TABLE 4:

DeGray Section vs. the Models

ESSENTIAL INGREDIENTS	*WALKER*	*MUTTI*	*VAIL*
NORM	+	+	+
FRAMEWORK AND GUIDE	+	— [scale]	±
VERTICAL PREDICTOR	±	— [scale]	+
LATERAL PREDICTOR	+	— [scale]	— [model limitations]
INTEGRATED BASIS FOR INTERPRETATION	+	— [model limitations]	±

\+ - functionally succeeds

— - functionally fails

± - fails partially/succeeds partially

ACKNOWLEDGMENTS

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ADDENDA

Table 1: Sources for Regional Jackfork Cross Section (Fig. 4)

S.W. Lynn Mountain 24-3S-15E Pushmataha Co., Okla. Leding, 1986	Honobia 32-1N-23E to 11-1S-23E LeFlore & McCurtain Cos., Okla. Shelburne, 1960
Albion 30-2N-22E to 1-1N-21E Pushmataha Co., Okla. Cline & Moretti, 1956 Cline, 1960	Kiamichi Mtn. 23,27-2N-25E to 5-1N-25E LeFlore Co., Okla. Cline & Moretti, 1956; Cline, 1960; Leding, 1986; Danielson, 1987
East Rich Mountain 6-2S-30W to 20-1S-32W Polk Co., Ark. Danielson, 1987; Seely, 1963; Naz, 1984	Brushy Knob 23-1S-28W to 14-1S-28W Montgomery Co., Ark. Morris, 1965, 1971
Forked Mountain Composite 4-2N-19W to 36-3N-19W Perry Co., Ark. Morris, 1964; Morris, et al, 1975	Lion #1 Nalley 33-8N-7W White Co., Ark. Maher & Lantz, 1953
Exxon #1 City of Searcy, 22-7N-7W, White Co., Ark. Texaco-Exxon #1 Ivey, 36-27N-3W, Coahoma Co., Miss. Exxon #1 Fulgham, 33-19N-12E, Oktibbeha Co., Miss. General electric log characteristics	

TABLE 3:
Chart of Model Diagrams

Model	*map*	*profile*	*columnar section*
Walker	✗	✓	✗
Mutti	✗	✗	✓
Vail	✓	✗	✓

✓ - created new, or extensively modified from existing diagrams

✗ - slightly modified from existing diagrams

TABLE 2:
Factors Controlling Carboniferous Basin Deposition

	SOURCE AREA(S)	*EUSTASY*	*CLIMATE*	*TECTONICS*
Atoka	Ozark Shelf, Black Warrior Basin Ouachita Orogen	Rising	Transitional	High
Johns Valley	Ozark shelf, Ouachita Basin(?)	Medium	Wet	Increasing
Jackfork	Black Warrior Basin, Ozark Shelf, Ouachita orogen,	Low	Wet	Increasing
Stanley	Ouachita orogen, Black Warrior Basin	High	Arid	Low