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SEDIMENTATION, SUBSIDENCE, AND EVOLUTION OF A FOREDEEP BASIN IN THE MIDDLE ORDOVICIAN, SOUTHERN APPALACHIANS

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ABSTRACT. A quantitative basin analysis was made to clarify the evolution of the Middle Ordovician Sevier Shale basin in east Tennessee. The lithofacies interpretation of the Middle Ordovician sequences indicates a distinct sequential development of shelf, slope, and basin environments (Lenoir, Whitesburg, and Blockhouse-Sevier formations respectively).

The Sevier basin experienced three main phases of subsidence. (1) An early phase of 1 to 2 m.y. duration when subsidence rate was 3 to 4 cm/1000 yrs and tectonic and sediment loading subsidence were coequal. (2) A second phase of nearly 1 m.y. in which subsidence rate was 60 to 65 cm/1000 yrs and was mainly tectonic. (3) A final phase lasting 10 to 13 m.y. when subsidence rate was 4 to 15 cm/1000 yrs and mainly caused by sediment loading by turbidite deposition.

Sedimentation and subsidence analyses show five stages of basin evolution: (1) stable shelf stage, (2) downwarping stage, (3) starved basin stage, (4) turbidite-fill stage, and (5) contour-current stage.

Based on morphologic, stratigraphic, sedimentologic, and tectonic similarities between Deep Sea Drilling Project (DSDP) Site 262 in Timor and the Sevier basin, we propose that Sevier basin evolution was analogous to foredeep basin development in Timor. This development occurred by concomitant basin subsidence and uplift of adjacent tectonic land due to basinward migration of a topographic wave.

INTRODUCTION

A quantitative analysis of sedimentation and subsidence is critical in portraying the geologic history of a sedimentary basin, for sedimentation and subsidence play the key roles in basin evolution. Furthermore, quantification of stratigraphic data (sediment thickness, water depth, geologic time, et cetera) greatly facilitates "Geohistory analysis" (*sensu* Van Hinte, 1978). Such an analysis not only reveals the timing and magnitude of geologic events but also has potential practical applications in petroleum geology.

Geohistory analysis in Paleozoic sequences is much more complex than in Mesozoic and Cenozoic sequences because microbiostratigraphic information is insufficient. However, by using physical, biological, chemical, and stratigraphic criteria, one can still quantify stratigraphic data with some accuracy in Paleozoic rocks. Hence, this paper is a quantitative attempt to portray the geologic history of the Middle Ordovician Sevier Shale basin in east Tennessee.

The purposes are: (1) to compute sediment thickness through time using sediment accumulation rates; (2) to quantify water depth in each

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sedimentary environment; (3) to analyse timing, magnitude, and causes of subsidence; and (4) to synthesize basin evolution using a modern analogue.

GEOLOGIC SETTING

A complex mosaic of carbonate and terrigenous clastic sequences constitute the Middle Ordovician of Tennessee in the Valley and Ridge Province of the Southern Appalachians. These sequences have been studied earlier by Rodgers (1953) and Neuman (1955). The ecostratigraphy of the Middle Ordovician of Tennessee has been studied by Walker (1974, 1977, and in preparation). He has suggested a facies pattern composed of three parts: (1) a western shelf with a shelf-edge skeletal sand bank/reef tract; (2) a deep-water basin southeast of the shelf; (3) a shallow-water, near-shore environment southeast of the basin (Walker, 1977, p. 16).

In this study, attention is focused on the western shelf to basinal sequences exposed at Nina, Deep Springs, and Boyds Creek (fig. 1). These sequences are in the fault block bounded by the Dumplin Valley Fault to the northwest and the Great Smoky Fault to the southeast. Major folding and minor faulting of these sequences are common at Nina and Deep Springs but absent at Boyds Creek.

Shelf, slope, and basinal sediments are developed in ascending vertical sequence at the three study localities (fig. 2). The shelf and slope facies are well developed at Nina and Deep Springs, and the basinal facies at Boyds Creek. The pebbly lime-mudstones of the Whitesburg Formation,

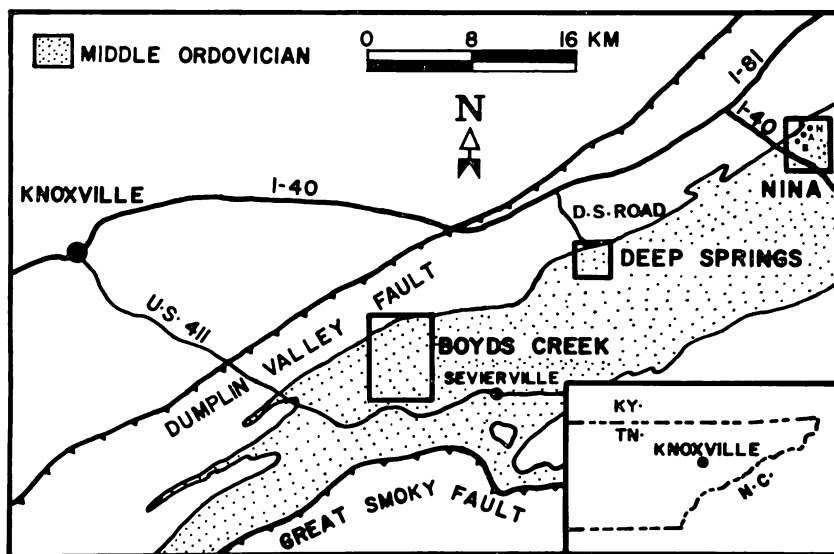


Fig. 1. Location map showing Boyds Creek, Deep Springs, Nina-B, Nina-A, and Nina-N study sections. Middle Ordovician rocks north of the Dumplin Valley fault are not shown.

which are present at Nina though absent at Deep Springs and Boyds Creek, have been interpreted as fine-grained carbonate debris-flow deposits (Shanmugam and Benedict, 1978). The basin facies at Boyds Creek composed of pelagites and prototurbidites in the Blockhouse Formation and distal turbidites and contourites in the Sevier Formation (Shanmugam and Walker, 1977a,b, 1978).

We have chosen the section at Boyds Creek for this study because of its sediment thickness of more than 1000 m, distinct vertical lithofacies variation, and minimal structural complexities. Conodont biostratigraphy of the Boyds Creek section (Shanmugam, ms) suggests *Pygodus serrus*, *Pygodus anserinus*, and *Amorphognathus tvaerensis* Zones. Graptolite biostratigraphy suggests *Nemagraptus gracilis* Zone for the measured stratigraphic interval at Boyds Creek. Based on conodont and graptolite information, the section at Boyds Creek may be assigned to Whiterockian to lower Wilderness stages (fig. 2).

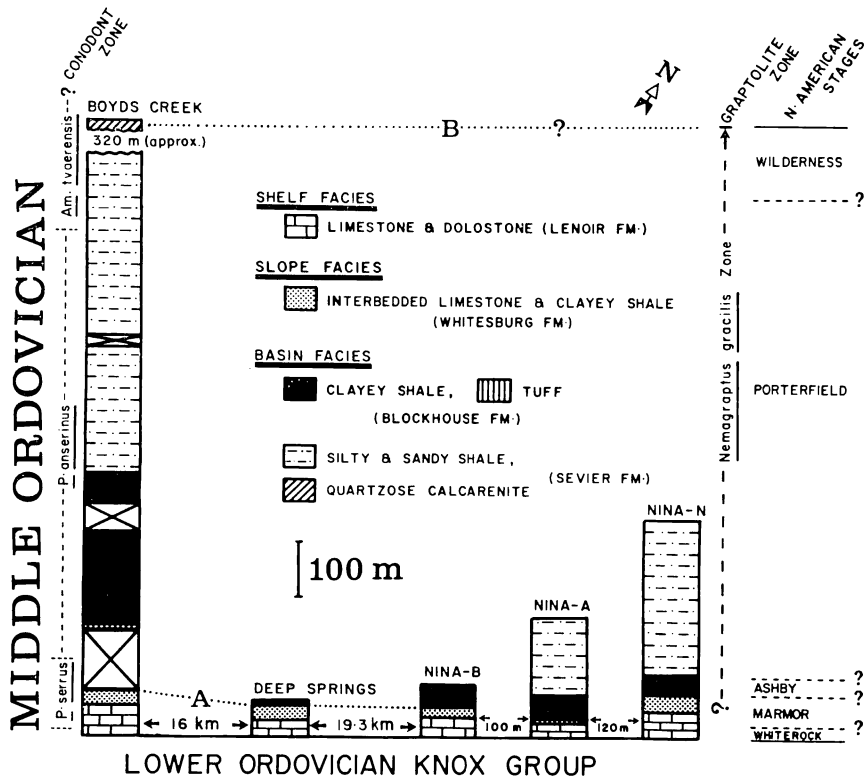


Fig. 2. Lithofacies and biostratigraphic interpretations of stratigraphic sections (Shanmugam, ms). Typical reef deposits (absent in these sections) were studied by Walker and Ferrigno (1973) northwest of the study area. Dotted line A marks the top of *Eoplacognathus foliaceus* Subzone of the *Pygodus serrus* Zone. Dotted line B marks the base of *Prioniodus gerdæ* Subzone of the *Amorphognathus tvaerensis* Zone.

SEDIMENT THICKNESS COMPUTATION

Computation of sediment thickness for a specific period of time in an Ordovician sequence without radiometric dates is a difficult task. However, it is possible to estimate the age of the entire section by using sediment accumulation rates. Use of sediment accumulation rates is a standard procedure in the DSDP to determine the age of acoustic basement.

Rate of sediment accumulation varies with the type of sedimentary deposits (for example, slow rates for pelagites and high rates for turbidites). Type of sedimentary deposit and corresponding sediment accumulation rates used in this report are given in table 1. It must be noted that these values have been obtained mainly from modern sedimentary basins and should therefore be increased to account for higher sediment influx into the basin during the Ordovician due to lack of vegetation, and subsequently modified to account for post-depositional compaction of fine-grained clastics. Because of these and other complexities, we have used ranges of sediment accumulation rates from published sources for different types of sedimentary deposits (see table 1). Using these analogous rates in cm/1000 yrs and our knowledge of the environments represented by successive stratigraphic units, sediment accumulated during successive 1-m.y. periods can be computed. We have used the median value of the range of sediment accumulation rates and have shown this rate through time in figure 3 by a vertical dotted line connecting mid points of horizontal bars representing the total range of possible sediment accumulation rates. This technique suggests that at least 16 m.y. (the time units numbered 1 through 16 in fig. 3) are represented in the Boyds Creek stratigraphic section. Gradual upward increase in the rate of sediment

TABLE 1
Types of sedimentary deposits and their accumulation rates

Formation	Deposit	Rate in cm/1000 yrs (modified from original source) of modern analogous deposits	Original source of analogue information
Sevier	Turbidite	10-35 (compacted)	Kuenen, 1968; Huang & Stanley, 1972
Blockhouse	Pelagite	1-3 (compacted)	Revelle and others, 1955; Kuenen, 1968; Stanley and others, 1972
Whitesburg	Slope	5-20 (Alboran Sea)	Huang and Stanley, 1972
Lenoir (main body)	Back reef lagoon	30-40 (Area in between Florida bay and reef tract is the modern analogue of Lenoir)	Milliman, 1974
Lenoir (Mosheim Member)	Tidal flat	1-2 (world wide average)	Kukul, 1971

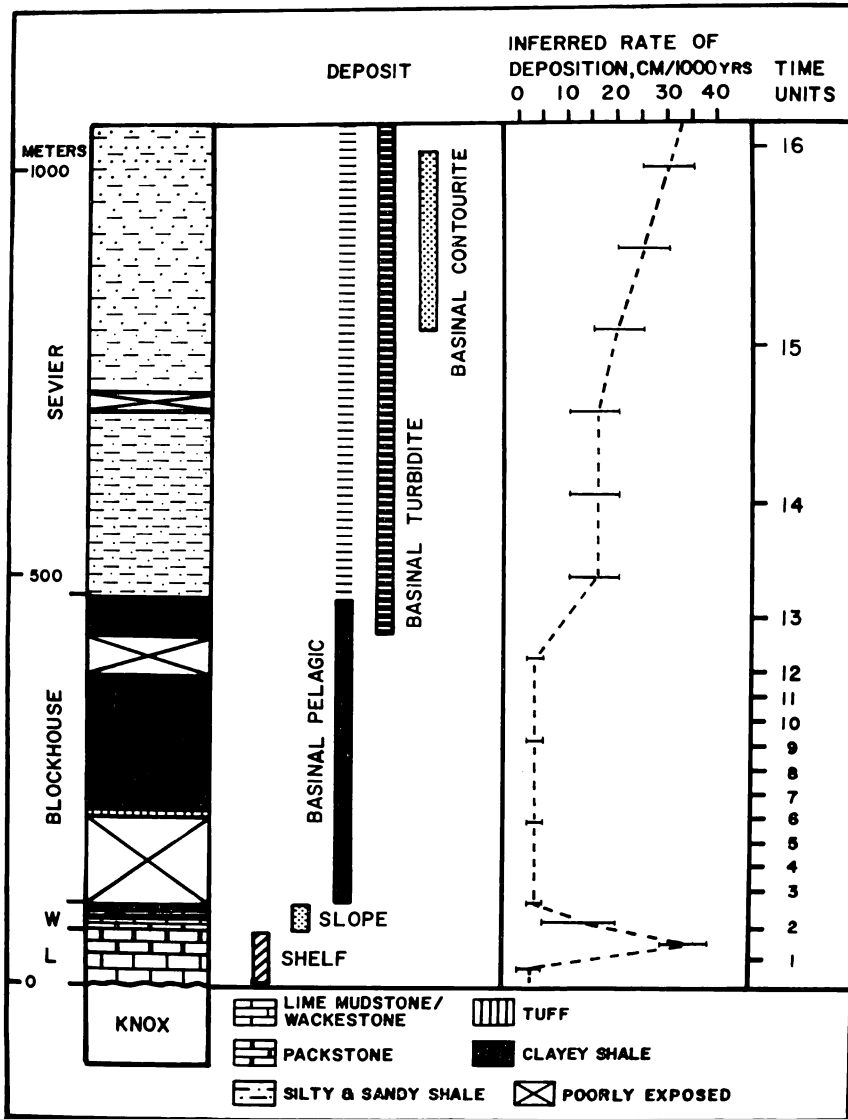


Fig. 3. Computation of sediment thickness for every progressive 1 m.y. at Boyd's Creek using sediment accumulation rates given in table 1. Vertical lithofacies variation is from Shanmugam and Walker (1978). Horizontal bars represent approximate range of sediment accumulation rates, and vertical dotted line connecting mid points of horizontal bars represents median value. Each time unit is 1 m.y. L = Lenoir. W = Whitesburg.

accumulation in the Sevier Formation is suggested by the coarsening and thickening upward sequence (Shanmugam and Walker, 1978, p. 571), indicating more proximal conditions and hence higher rates of sedimentation. Influence of contourites on the rate of sediment accumulation has been neglected, because contour currents only rework sediments. Correlation of the Boyds Creek section with absolute dates is shown in figure 4, and this shows a remarkable agreement of time units obtained from biostratigraphic data (see fig. 2).

QUANTIFICATION OF PALEO-WATER-DEPTH

Paleobathymetric analysis of shelf, slope, and basinal sequences at Boyds Creek has been given by Shanmugam and Walker (1978). Benedict and Walker (1978) discussed techniques of paleobathymetric analysis and regional paleobathymetric changes in the Middle Ordovician of east Tennessee. Therefore, we discuss here only the quantification of paleo-water-depth at our localities.

The birdseyes in the basal Mosheim Member (lime mudstones) of the Lenoir Limestone suggest an Exposure Index of 90 to 100 percent (Ginsburg and others, 1977), and thus we assign a water depth of 0 m. The main body of the Lenoir Limestone (algal wackestones and packstones) shows features of shallow subtidal deposition and the abundance of algae (especially oncoids) suggests water depths of 5 to 20 m (see Walker, 1974, 1977).


N. AMERICAN SERIES	N. AMERICAN STAGES	BRITISH SERIES	HARLAND, SMITH, AND WILCOX, 1964	CHURKIN, CARTER, AND JOHNSON, 1977	B·C·
CINCINNATIAN	RICHMOND MAYSVILLE EDEN	ASHGILL	↖ 430-440 M·Y·	← 438 M·Y·	
CHAMPLAINIAN	TRENTON -----? WILDERNESS	CARADOC	← 451 M·Y·		
	PORTERFIELD -----? ASHBY	LLANDEILO		← 455 M·Y·	
	-----? MARMOR	LLANVIRN			
	-----? WHITEROCK			← 469 M·Y·	
	CANADIAN	CASSIN JEFFERSON DEMING GASCONADE	ARENIG	↖ 500 M·Y·	

Fig. 4. Correlation of Boyds Creek section (16 m.y. obtained from fig. 3) with absolute dates. North American and British Ordovician series are shown for comparison. B.C. = Boyds Creek section range based on biostratigraphic data (see fig. 2). Note close correspondence of absolute age range to that computed by sediment accumulation rates.

The graptolite assemblages in the Whitesburg Formation (*Nemagraptus gracilis*, *Pseudoclimacograptus angulatus*, *Glyptograptus teretiusculus*, *Glyptograptus euglyphus*), the Blockhouse Formation (*Glyptograptus teretiusculus*, *Glyptograptus euglyphus*, *Dicranograptus irregularis*, *Pseudoclimacograptus angulatus*), and the Sevier Formation (*Dictyonema* sp.) represent the argillite-chert belt of Erdtmann (1976). These graptolitic assemblages suggest pelagic, open marine, and probably bathyal environments (below 200 m) for the slope and basinal deposits. The Whitesburg, Blockhouse, and Sevier Formations are also characterized by the presence of deep-water fossils such as tintinnids and probable radiolarians (Shanmugam, ms).

An alternate paleobathymetric interpretation for the graptolitic shales of the Blockhouse-Sevier Formations would be a shallow-euxinic environment. But the regional environmental facies pattern for the Middle Ordovician (Walker, 1974, 1977, and in preparation) shows that such an interpretation of the Blockhouse-Sevier would be completely inconsistent with known stratigraphic relationships.

In order to determine the absolute water depth for the Blockhouse Formation at Boyds Creek, a simple trigonometric computation is employed using angle of inclination for the slope environment (Whitesburg Formation) in the environmental framework of Walker (1974). Average inclination of modern continental slopes is 4° (Ross, 1977), and slopes off stable coasts are about 3° (Shepard, 1973). Modern steeper slopes are generally characterized by large-scale sediment slumping and other gravity-induced features. Absence of such slope features in the Whitesburg Formation suggests a slope value of 3° or less. However, debris-flow deposits of the Whitesburg Formation at Nina, 40 km east-northeast of Boyds Creek, imply low-flow strength by their small bed thickness (3-4 cm). Down-slope movement of such debris flows with low strength implies a need for a slope approaching unstable inclinations. We have thus chosen a conservative value of 2.5° for the slope environment.

Using the slope of 2.5° and the palinspastic distance (Roeder and Witherspoon, 1978) between the well developed basin (Boyds Creek) and the nearest coeval shelf (Midway Road, Benedict and Walker, 1978, p. 592) during the conodont *Pygodus serrus* zone (Bergstrom and Carnes, 1976), the depth of basin at Boyds Creek has been computed to be 700 m (fig. 5). As this computation does not account for already existing bathymetry in the shelf region (Benedict and Walker, 1978, p. 593), the total depth at Boyds Creek should be more (perhaps $800 \pm$ m).

In summary, the Lenoir Formation indicates a water depth of 0 to 20 m. The Whitesburg Formation represents an intermediate deep-water bathyal environment between shelf and basin. The Blockhouse Formation suggests the deepest conditions — more than 700 m in a starved basin (Shanmugam and Walker, 1978, p. 574). The Sevier Formation also suggests bathyal environments, but a shallowing upward trend is inferred from the turbidite fill of the basin and the appearance of shallow-water fauna during later Sevier time.

SUBSIDENCE ANALYSIS

Subsidence-sinking of the Earth's surface has received considerable attention in recent literature. Major subsidence studies include: (1) general mechanisms of basin subsidence (Wyllie, 1971; Fischer, 1975; Bott, 1976; Dickinson, 1976); (2) sinking of the ocean floor with increasing age (Sclater, Anderson, and Bell, 1971; Morgan, 1975); (3) subsidence due to sediment loading (Scheidegger and O'Keefe, 1967; Watts and Ryan, 1976); (4) subsidence along rifted continental margins (Kinsman, 1975); (5) subsidence caused by eclogite sinker (Ringwood, 1976); and (6) compaction subsidence (Rieke and Chilingarian, 1974).

Source of Information

Information required for short-term subsidence analysis includes: (1) sediment thickness, (2) water depth, (3) age, (4) compaction, (5) facies changes, (6) time span of unconformities, and (7) thickness reduction along pressure-solution surfaces. In this study, we have attempted to satisfy the first five requirements; the sixth and seventh do not apply because unconformities (representing lengthy depositional breaks) and stylolites are absent at Boyds Creek.

Subsidence History

The subsidence curve for the Boyds Creek section (fig. 6) has been constructed by plotting water depth and cumulative sediment thickness (value from fig. 3) through time. The nature of subsidence is depicted by the downward movement of the Knox "basement." The slope of the Knox base-line is directly proportional to rate of subsidence. Three phases of subsidence (Shanmugam, 1978) have been recognized at the Boyds Creek section. They are: (1) a moderate rate of subsidence (3-4 cm/1000 yrs) during deposition of the Mosheim-Lenoir (units 0-2); 2) a high rate of subsidence (60-65 cm/1000 yrs) during deposition of the Whitesburg

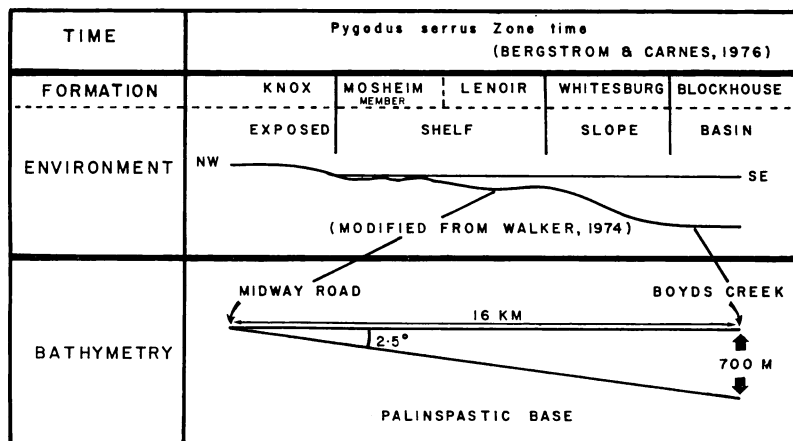


Fig. 5. Trigonometric computation of basin depth at Boyds Creeks (see text for details). Palinspastic base of Roeder and Witherspoon (1978) is used.

(units 2-3); and (3) a moderately high rate of subsidence (4-15 cm/1000 yrs) during deposition of the Blockhouse-Sevier (units 3-16).

Subsidence due to Sediment Loading and Driving Forces

In order to estimate the amount of subsidence due to sediment loading as opposed to tectonic driving forces, the "backstripping" method of Watts and Ryan (1976) has been used (see app for theoretical derivations). The results are plotted in figure 7, where the bottom curve represents Knox "basement" (same as in fig. 6) and the middle curve represents "basement" after sediment unloading (Z in app 1).

The curves show the following characteristics: (1) during Lenoir time (units 0-2), subsidence due to sediment loading and driving forces are more or less equal; (2) during Whitesburg time (units 2-3), subsidence due to driving forces is extremely high compared to sediment loading; and (3) during Blockhouse-Sevier time (units 3-16) influence of sediment loading progressively increases through time, more so during time units 12 to 16 because of the influx of turbidites.

Subsidence unaccounted for by sediment loading is termed here "driving forces" subsidence. The driving forces may be related to tectonic attenuation (Fischer, 1975), lithogenetic subsidence (Briggs and Roeder, 1975), eclogite sinker (Ringwood, 1975), or other possibilities.

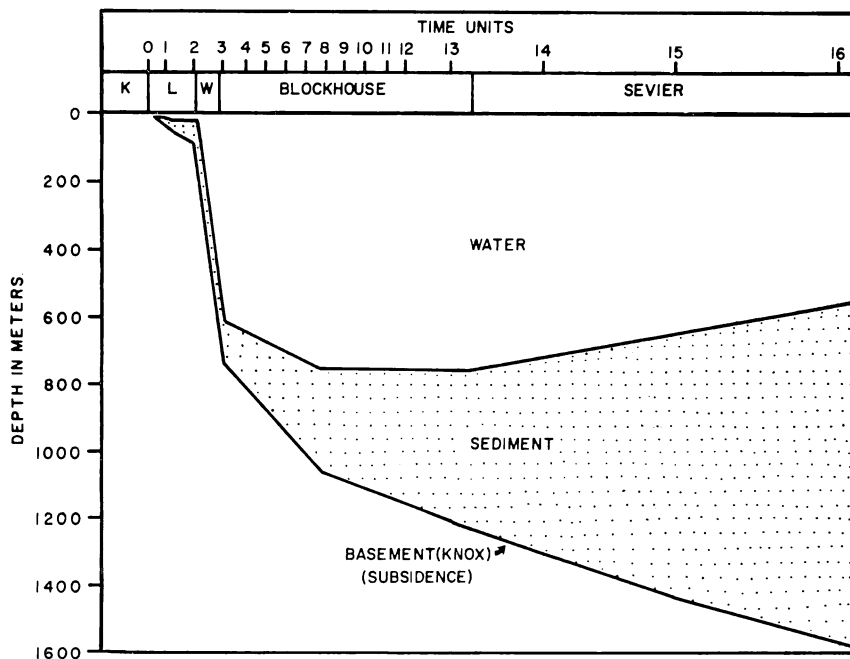


Fig. 6. Subsidence history at Boyds Creek. Time units are from figure 3. K = Knox. L = Lenoir. W = Whitesburg.

Phases of Subsidence

Phase 1.—Subsidence during time units 0 to 2 is due to sediment loading as well as driving forces. One of the driving forces responsible for shelf subsidence could be lithogenetic subsidence (Briggs and Roeder, 1975). Under this mechanism, aging oceanic lithosphere (Sclater, Anderson, and Bell, 1971) drags the attached continental lithosphere down, causing shelf subsidence. The influence of such a mechanism in this case would have been minimal, because the Sevier basin is located too far inland to be affected significantly by cooling oceanic lithosphere.

Phase 2.—Major subsidence of more than 600 m during time units 2 to 3 (1 m.y.) cannot be explained simply by sediment loading, as total sediment thickness at that time is only 100 m. Loading of the crust by tectonic thrust sheets (King, 1964) to the southeast might conceivably have played a role, however, in a flexural model (Walcott, 1972; Sweeney, 1976, p. 191), maximum subsidence occurs immediately below the site of the load, and thus tectonic loading to the southeast may not be a suitable mechanism to explain rapid subsidence in the study area.

Sudden deepening of the basin without evidence for a major load (sediment or tectonic) in the study area precludes flexural bending of a rigid crust due to loading and favors basement downwarping due to tectonic attenuation. Belts of tectonic attenuation, characteristic of rifted

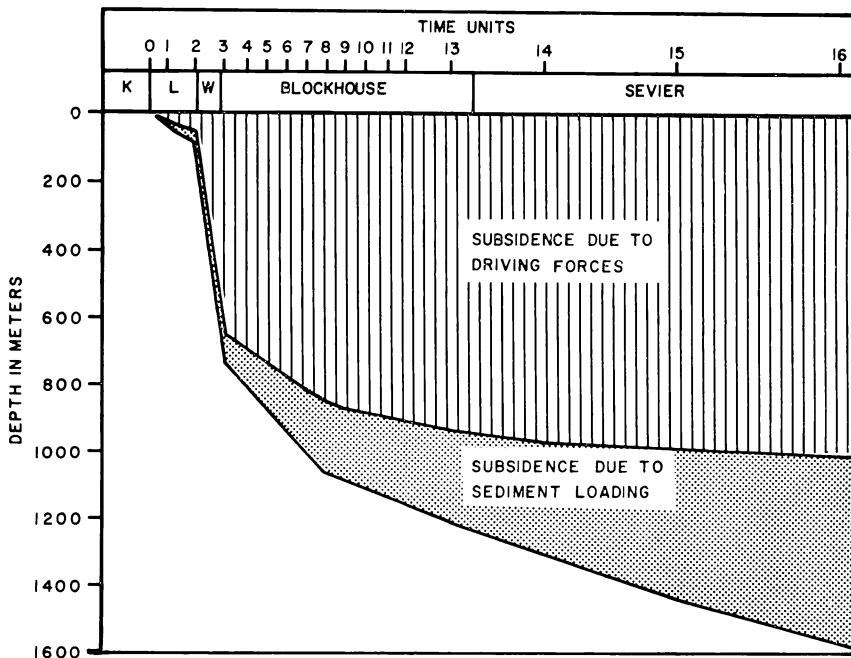


Fig. 7. Isolation of amount of subsidence due to sediment loading and driving forces. The lower curve is the Knox "basement" (same as in fig. 6). The middle curve is plotted using Z values (see app 1), which represents Knox "basement" after "backstripping" through time. K = Knox. L = Lenoir. W = Whitesburg.

continental margins, have also been reported from continental interiors and from convergent plate margins (Fischer, 1975). Therefore, in this study we prefer basement downwarping as an explanation of basin subsidence as opposed to our earlier explanation by flexural bending (Shanmugam and Walker, 1978).

Should this localized but rapid subsidence be related to a Taconic climax, then it may be due either to anisostatic downdragging in the vicinity of subduction zones (trenches), or to the development of heterogeneities in the asthenosphere, causing the lithosphere to rise in some places and sag in others (Fischer, 1975, p. 75). Evidence at present is too scanty to choose between these various possibilities.

In summary, we are still uncertain as to exactly what caused the initiation of the second phase of subsidence. However, we believe that basement downwarping was responsible for most, if not all, basin subsidence during the second phase.

Phase 3.—Subsidence during time units 3 to 16 was primarily due to sediment loading caused by turbidite influx. Driving forces played only a minor role during this time. Such minimal tectonic influence on basin subsidence during this phase implies basin maturity through time.

STAGES OF BASIN EVOLUTION

Using the depositional environments, sedimentary processes, and subsidence history, we may now synthesize various stages involved in basin evolution. At least five major stages occurred during the evolution of the Sevier basin.

Stable Shelf Stage (Lenoir)

During this stage, shallow-shelf environments prevailed in the study area. Carbonate rocks of biogenic origin were deposited in tidal-flat and shallow subtidal environments not unlike modern Florida lagoonal areas.

Downwarping Stage (Whitesburg)

During this time, a major tectonic event caused the stable shelf to subside rapidly in the study area so that areas of shelf facies became areas of basin facies, although shallow-water carbonate deposition persisted to the northwest. This event also initiated fine-grained carbonate debris flows along the western basin margin. Although no normal faulting has been recognized in the study area, the abrupt lateral increase in sediment thickness and sudden deepening of the basin suggest "block" faulting or a faulted monocline.

Starved Basin Stage (Blockhouse)

The paleobathymetric reversal of the preceding stage resulted in a starved basin and accumulation of pelagic deposits. During this time, bathymetry of the basin was at its maximum of more than 700 m. An altered tuff 2 to 3 m thick in these pelagic deposits suggests the possibility of a nearby volcanic island-arc source. Syntectonic prototurbidites (*sensu* Abbate and others, 1970, p. 632) began to appear at the end of this stage.

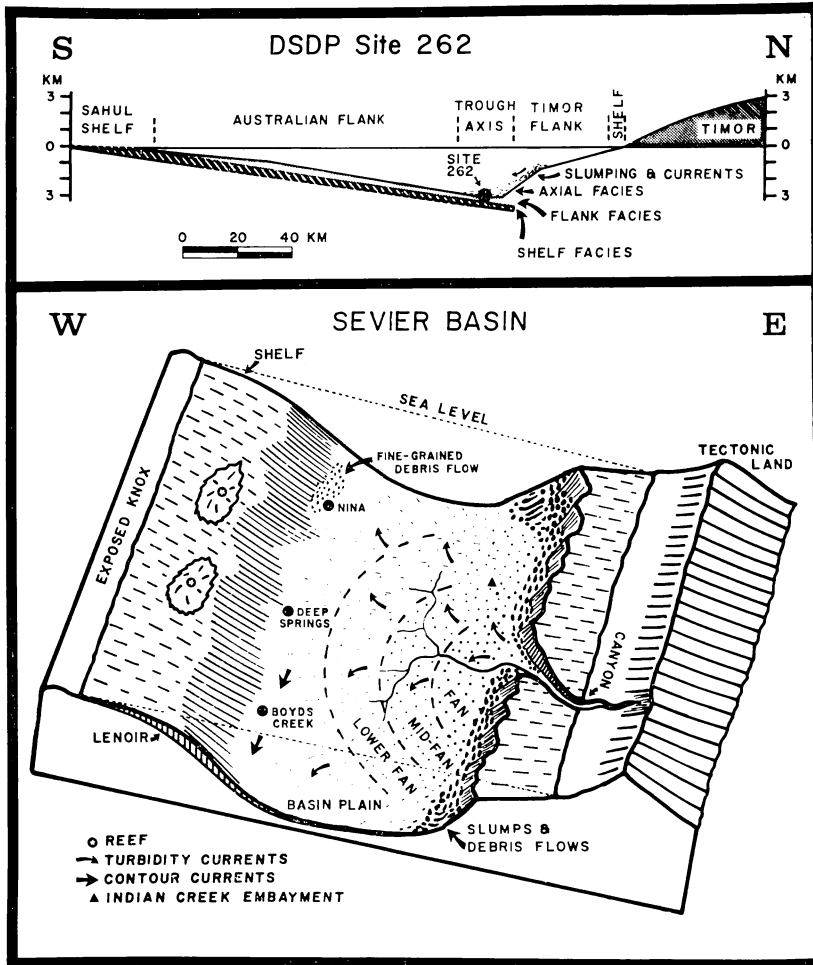


Fig. 8. Morphological and facies similarities between DSDP Site 262 in Timor basin and Sevier basin. Top: Simplified composite diagrammatic morphological transect from southern Sahul shelf to northern Timor island shown with vertical exaggeration (compilation of figures 2, 3, and 5 from Veevers, Falvey and Rohu, 1978). Approximate boundaries of shelf, flank, and axis are shown. Bottom: Paleogeography of the Sevier basin in its embryonic stage, immediately after paleobathymetric reversal due to major tectonic subsidence (not to scale). Notice that shelf facies (Lenoir) has reached oceanic depths. Approximate locations of 3 study areas are shown by solid circles. Indian Creek Embayment (solid triangle) has equivalent proximal turbidites (see text). Contour current directions are speculative. Western reef model is modified after Walker (1974). Eastern submarine fan model is modified after Nelson and Kulm (1973).

Turbidite-Fill Stage (Sevier)

During this time, distal turbidites became the dominant sedimentary fill in the basin, in addition to open ocean pelagic mud. Proximal turbidites of about the same age, which occur east of Boyds Creek at Indian Creek Embayment (Keller, 1977; reported as conglomerates by Kellberg and Grant, 1956), suggest an easterly source for these clastics. Heavy mineral analysis by Cummings (1965) also indicates an eastern source for the clastics.

The conglomeratic beds suggest a concomitant uplift in the eastern source region while the basin was subsiding to the west. The upward coarsening and thickening turbidite sequence (Shanmugam and Walker, 1978, p. 571) reflects the gradual westward encroachment of material from the eastern source. This stage resembles (but, we believe, does not represent) the turbidite-fill stage of rifted continental margins (Schneider, 1972).

Contour-Current Stage (Late Sevier)

During this stage, cessation of tectonic influence on basin subsidence led to development of a matured basin. Thermohaline contrasts initiated contour currents that flowed along the ancient basin margin. The contour currents reworked and deposited sediments while turbidity currents continued to supply terrigenous clastics into the basin. This stage is analogous to the deep-ocean current stage of Schneider (1972).

The basin filling process continued and terminated with shallow-water/subaerial clastics by the end of Middle Ordovician.

THE SEVIER BASIN: A FOREDEEP

Any attempt to classify the Sevier basin in a plate-tectonic framework must account for its (1) paleogeographic setting, (2) stratigraphic sequence, (3) sedimentary processes and environments, (4) major subsidence events, (5) stages of basin evolution on continental crust, and (6) convergent tectonics.

Roeder and Walker (1975) proposed a backarc setting for the Sevier basin. Unfortunately, they did not specify the type of backarc setting as backarc areas include Interarc as well as Retroarc basins (Dickinson, 1974). Furthermore, their model was based on a west-dipping subduction model, whereas in this study we assume an east-dipping subduction zone based on gravity data (Slaymaker and Watkins, 1978).

A survey of modern sedimentary basins and their plate-tectonic settings points out that DSDP Site 262 in the Timor foredeep and the adjoining Sahul shelf with reefs could be considered as a modern analogue of the Sevier basin. Morphological and facies similarities between the Timor and Sevier basins are shown in figure 8. Analogous features characteristic of both basins are given in table 2. Based on this analogy, we propose that the Sevier basin evolved in a way not unlike the foredeep basin in Timor (Veevers, Falvey, and Robins, 1978), by concomitant basin subsidence and uplift of an eastern tectonic land due to westward migration of a topographic wave. It must be stressed, however, that our com-

parison of the Sevier basin to Timor is primarily based on stratigraphic similarities and facies migration. It is beyond the scope of this paper to discuss the deep crustal structure similarities (if any) between these two basins.

The major difference between the two is the absence of olistostrome (Bobonaro Scaly Clay) gravity-slide deposits (Audley-Charles, 1968; Carter, Audley-Charles, and Barber, 1976) in the Sevier basin. Olistostrome deposits, if present, are more likely to be found on the eastern flank of the Sevier basin, which is missing due to later thrusting.

TABLE 2
Analogous features of DSDP Site in Timor and Sevier basin

Features	Correlation of seismic profiles with the Pliocene and Quaternary facies at DSDP Site 262 in Timor (Vevers, Falvey, and Robins, 1978)	Sevier basin, Southern Appalachians (Middle Ordovician)
1. Stratigraphy	Lower shelf, middle flank (Australian), and upper axial facies.	Lower shelf (Lenoir), middle slope (Whitesburg), and upper basin (Blockhouse-Sevier) facies.
2. Shelf facies	Calcarenite and dolomitic mud.	Lime mudstone, wackestone, packstone, and dolostone.
3. Flank (or) Slope facies	Pelagic sediment.	Pelagic shale and lime mudstone.
4. Axial (or) Basin facies	Deposition of mud from pelagic settling and sands from turbidity currents and bottom currents.	Shales composed of pelagite, turbidite, and contourite.
5. Migration of facies	North to south.	East to west.
6. Slope gradient	Sahul shelfward flank: 0.2-0.9° Central flank: 0.9-2° Timor Troughward flank: 2-3.5°	Inferred value for Whitesburg: 2.5°.
7. Bathymetric reversal	Areas of shelf facies became areas of axial facies due to a major subsidence (Pliocene).	Areas of shelf facies became areas of basin facies due to a major subsidence (Middle Ordovician).
8. Depth of water	3000 m.	More than 700 m (inferred).
9. Rate of maximum subsidence	More than 50 cm/1000 yrs.	60-65 cm/1000 yrs.
10. Tectonics	Convergent.	Convergent (Taconic climax).
11. Subduction zone	North dipping (controversy exists over underthrusting or overthrusting of Australian plate).	Southeast dipping (Slaymaker and Walkins, 1978).
12. Proposed mode of basin evolution	Concomitant basin subsidence and uplift of Timor island due to southward migration of a topographic wave.	Concomitant basin subsidence and uplift of eastern land due to westward migration of a topographic wave.

The Sevier foredeep basin also bears some resemblance to basins in the Northern Appalachians (Rodgers, 1971; Zen, 1972; Williams and Stevens, 1974), suggesting an analogous mode of basin evolution.

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$$Z = D + \frac{(\rho_m - \rho_s)}{(\rho_m - \rho_w)} \cdot S$$

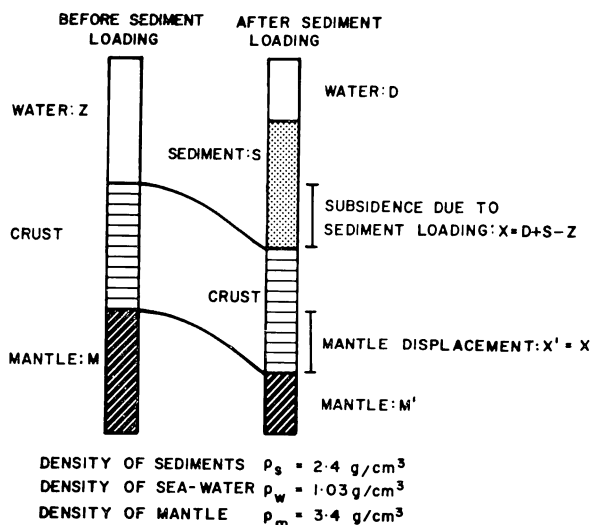


Fig. 9. Hypothetical sediment loading model used in the derivation of Z. Z is depth to Knox "basement" after "backstripping" through time.

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APPENDIX I

Theoretical considerations of local loading

It is assumed here that sediments were deposited on Airy-type crust (see text). Airy-type crust responds locally to isostatic loading. By progressive "backstripping" of sediment (Watts and Ryan, 1976, p. 29) for every 1 m.y. (values obtained from fig. 3), depth to Knox "basement" through time can be computed (neglecting sealevel changes).

Subsidence X due to sediment loading is given by

$$X = D + S - Z \text{ (fig. 9)} \quad (1)$$

where

D = depth of water
S = sediment thickness
Z = depth to the basement (water)

Subsidence per unit area caused by sediment loading is given by:

$$Z \cdot \rho_w + M \cdot \rho_m = D \cdot \rho_w + S \cdot \rho_s + M' \cdot \rho_m \quad (2)$$

where Z, D, and S are the same as in eq (1)

M = mantle before sediment loading
M' = mantle after sediment loading
 ρ_m = density of mantle
 ρ_s = density of sediment
 ρ_w = density of water

Since $X = M - M' = D + S - Z$, eq (2) can be written as

$$D \cdot \rho_m + S \cdot \rho_m - Z \cdot \rho_m = D \cdot \rho_w + S \cdot \rho_s - Z \cdot \rho_w \quad (3)$$

$$D \cdot \rho_m + S \cdot \rho_m - D \cdot \rho_w - S \cdot \rho_s = Z \cdot \rho_m - Z \cdot \rho_w \quad (4)$$

$$D (\rho_m - \rho_w) + S (\rho_m - \rho_s) = Z (\rho_m - \rho_w) \quad (5)$$

Solving for Z:

$$Z = D + \frac{(\rho_m - \rho_s)}{(\rho_m - \rho_w)} \cdot S \quad (6)$$

where

Z = depth to Knox basement after crustal rebound due to sediment unloading or "backstripping" through time.

D, S, ρ_m , ρ_s , and ρ_w have been previously defined.

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