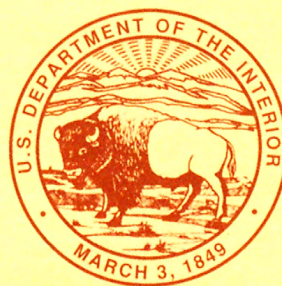
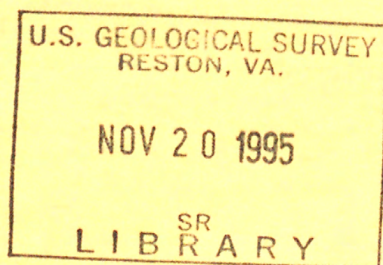


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# Stratigraphic Notes, 1994

U.S. GEOLOGICAL SURVEY BULLETIN 2135





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# Stratigraphic Notes, 1994

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U.S. GEOLOGICAL SURVEY BULLETIN 2135

*Three short papers present changes in stratigraphic  
nomenclature in Virginia, Kentucky, and Alaska*



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**U.S. DEPARTMENT OF THE INTERIOR**  
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## CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile



# 1. Middle Ordovician Stickley Run Member (New Name) of the Martinsburg Formation, Shenandoah Valley, Northern Virginia

By Jack B. Epstein,<sup>1</sup> Randall C. Orndorff,<sup>1</sup> and Eugene K. Rader<sup>2</sup>

## ABSTRACT

Dark-gray, laminated to thin-bedded shaly limestone and calcareous shale and siltstone, previously identified as either the Oranda Formation or the lower part of the Martinsburg Formation in Virginia and West Virginia, are herein revised as the Stickley Run Member (new name) of the Martinsburg Formation. Knobby limestone that was assigned to the lower part of the Oranda Formation is now placed in the underlying Edinburg Formation. The type section for the Stickley Run is along U.S. Highway 11, 2.5 mi northeast of Strasburg, Va., where the lowest 140 ft are exposed. Cross sections indicate that the thickness of the Stickley Run is between 610 and 900 ft in Frederick and Shenandoah Counties, Va. It is recognized on both limbs of the Massanutten synclinorium, thinning to about 100 ft at the south end of the synclinorium. The member is also present for many miles north of the Virginia-West Virginia border, a total distance that probably exceeds 150 mi. The lower contact of the Stickley Run Member is defined as the base of the lowest calcareous shale or siltstone or shaly limestone above thicker bedded, knobby-weathering, medium-gray limestone of the Edinburg Formation. The upper contact is placed at the top of the uppermost platy limestone bed, generally about 2 in. thick, underlying non-calcareous to slightly calcareous shales and graywacke of the overlying Martinsburg Formation. The age of the Stickley Run Member is Middle Ordovician, as indicated by conodont age determinations of younger and older rocks.

## INTRODUCTION

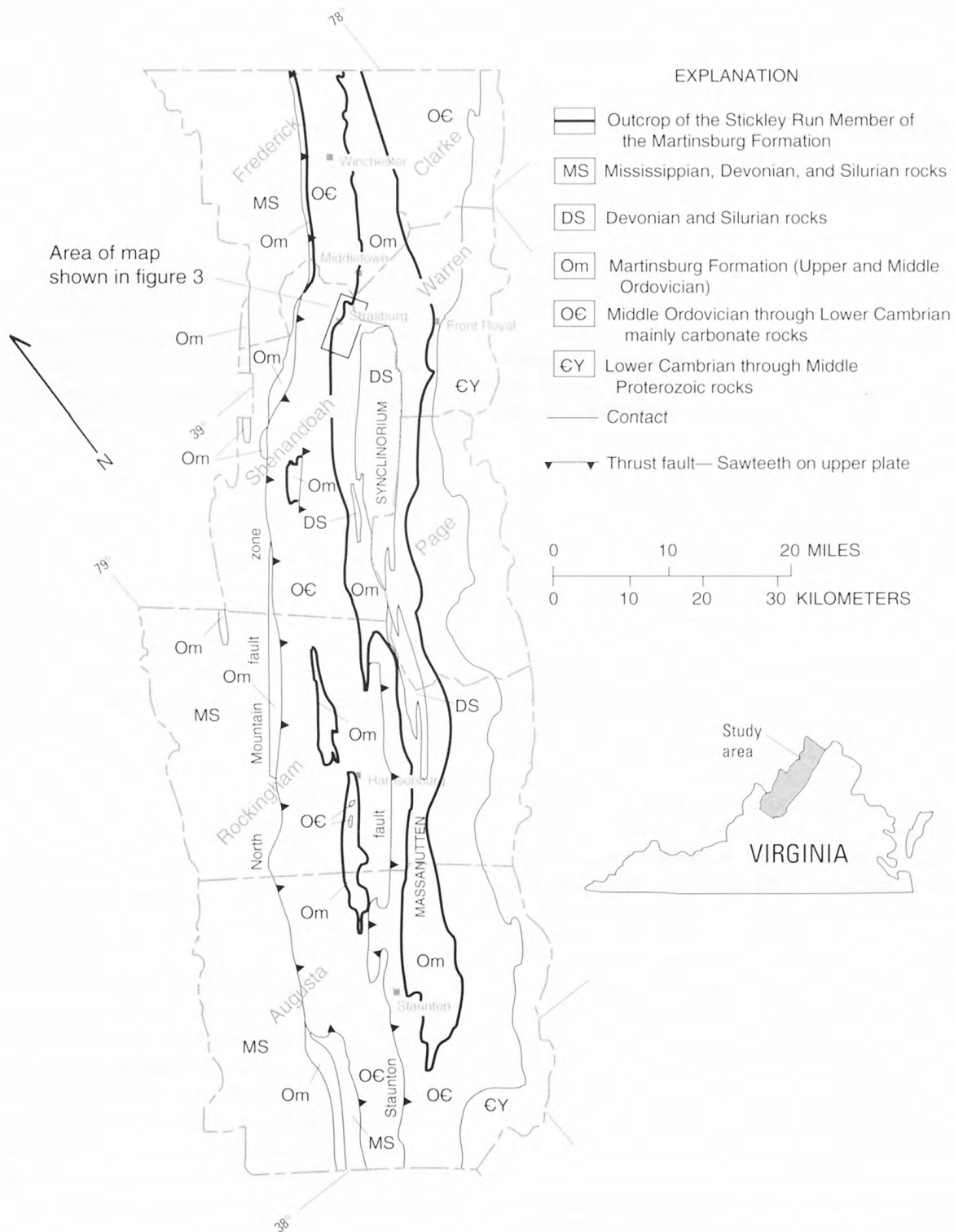
Limestone, cherty limestone, and calcareous shale of Middle Ordovician age overlie dolomite and limestone of the Beekmantown Group (Lower and Middle Ordovician)

and underlie shale and graywacke of the Martinsburg Formation in the Shenandoah Valley of northern Virginia (fig. 1). In ascending order, the Middle Ordovician carbonate rocks consist of the New Market Limestone (light-gray, very fine grained limestone), the Lincolnshire Limestone (dark-gray, cherty limestone), and the Edinburg Formation (irregularly bedded and knobby limestone and calcareous shale). Butts (1940) identified the limestones immediately beneath the Martinsburg as the Chambersburg Limestone (fig. 2). Later, approximately 50 ft of calcareous shale and siltstone, shaly limestone, and scattered thin beds of metabentonite immediately underlying the Martinsburg were named the Oranda Formation by Cooper and Cooper (1946) and mapped as such by many subsequent workers. Cooper and Cooper (1946) also changed the Chambersburg Limestone to the Edinburg Formation and changed the underlying Lenoir Limestone to the Lincolnshire Limestone. A lithofacies similar to that of the Oranda is repeated lower within the Edinburg Formation (the Liberty Hall facies of Cooper and Cooper, 1946). The original definition of the Oranda was based primarily on the occurrence of the *Reuschella "edsoni"* fauna. Platy shaly limestone and calcareous shale that overlie the Oranda were placed in the lower part of the Martinsburg by Cooper and Cooper (1946) and subsequent workers.

Recent mapping by the U.S. Geological Survey in the Winchester 30'x60' quadrangle and in the Strasburg, Va., area to the south and mapping by the Virginia Division of Mineral Resources south of Strasburg indicate that the Oranda of previous usage and the calcareous shale and platy limestone that have been placed in the lower part of the Martinsburg Formation compose a distinct mappable unit, herein named the Stickley Run Member of the Martinsburg Formation. The type section is along the northbound lane of U.S. Highway 11 immediately east of Cedar Creek and approximately 2.5 mi northeast of Strasburg. The member is named for Stickley Run, a tributary to Cedar Creek, 0.6 mi north of the type section. The overlying Martinsburg consists of shale and graywacke and is not divided into members in the area of this report.

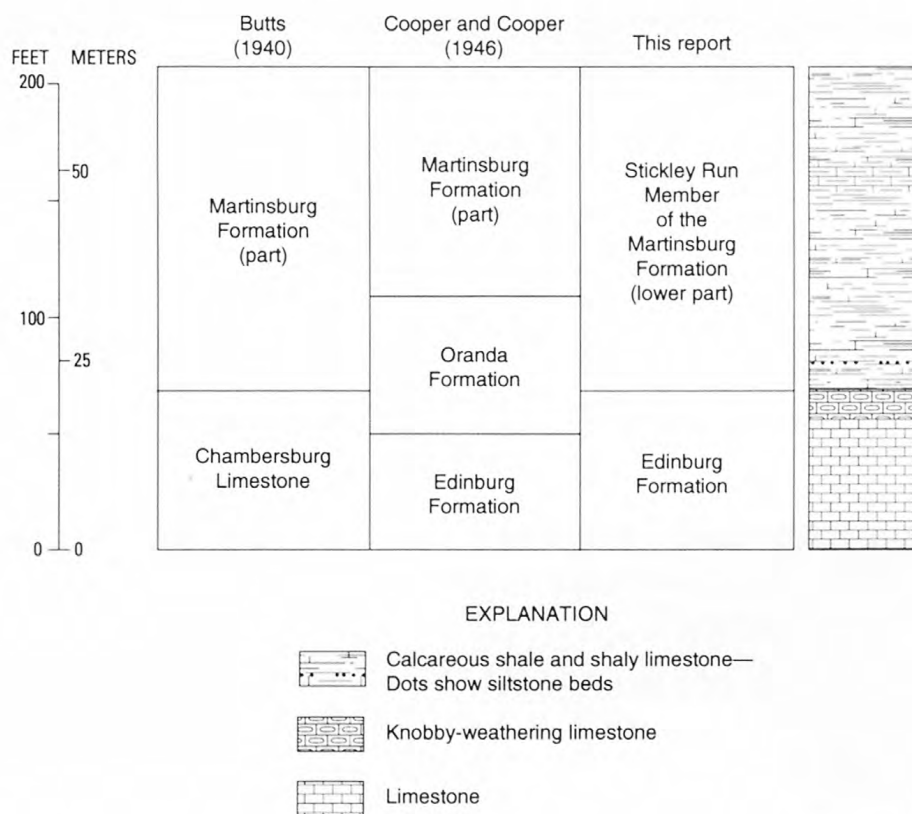
<sup>1</sup>U.S. Geological Survey, Reston, VA 22092.

<sup>2</sup>Virginia Division of Mineral Resources, Charlottesville, VA 22903.



**Figure 1.** Generalized geologic map of the northern Shenandoah Valley of Virginia showing the outcrop of the Stickley Run Member of the Martinsburg Formation.





**Figure 2.** History of nomenclature of the Middle Ordovician Stickley Run Member of the Martinsburg Formation and underlying rocks.

The lower part of the Stickley Run is well exposed in three localities in the Strasburg, Va., area:

- (1) the type section along U.S. Highway 11 (locality a in fig. 3), where the lowest 140 ft are exposed (fig. 4; table 1);
- (2) along Virginia Highway 55, 0.4 mi northwest of U.S. Highway 11 in Strasburg (the type section of the Oranda Formation of Cooper and Cooper, 1946), where 215 ft are exposed (locality b in fig. 3); and
- (3) along Tumbling Run and U.S. Highway 11, 1.7 mi southwest of Strasburg, where about 300 ft are exposed (locality c in fig. 3).

The upper part of the Stickley Run is poorly exposed, and descriptions are derived from scattered exposures examined during mapping.

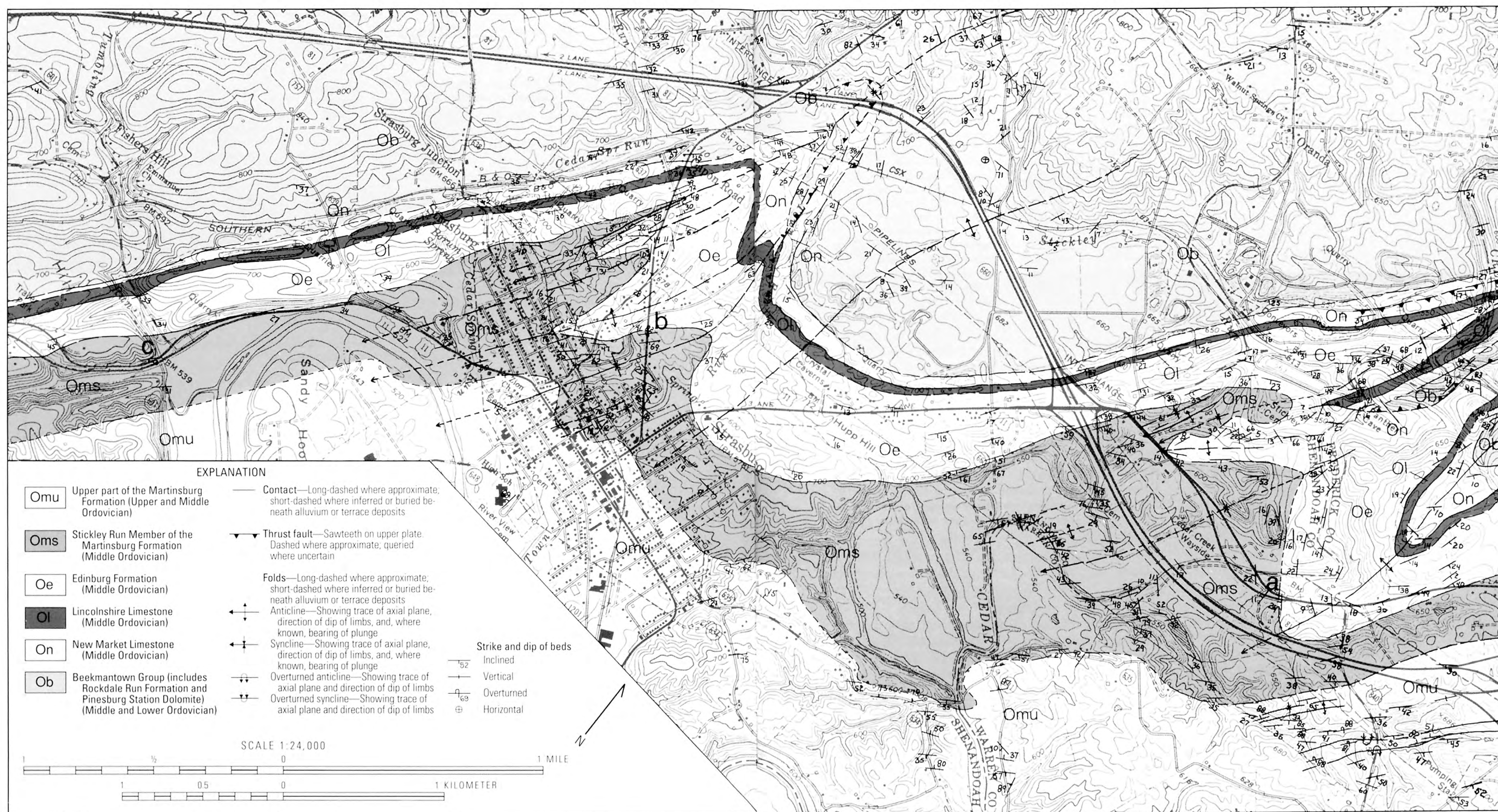
The thickness of the entire Martinsburg Formation has been estimated to be between 1,500 and 4,500 ft by previous workers, with the most recent estimate being 2,800 ft (Rader and Read, 1989). These figures do not include about 50 ft assigned to the Oranda Formation. Because of complex folding in the Martinsburg, thickness estimates are subject to alternate interpretations. On the basis of detailed mapping and construction of cross sections north of Strasburg and southwest down-plunge projections to the top of

the Martinsburg at the contact with the overlying Massanutten Sandstone, the thickness of the Martinsburg, including the Stickley Run Member as defined in this report, is determined to be between 4,600 and 6,500 ft, the higher figure probably being more accurate (Epstein, 1993).

## PREVIOUS USAGE OF THE EDINBURG, ORANDA, AND MARTINSBURG FORMATIONS

The Martinsburg Formation was first used as a stratigraphic name by Geiger and Keith in 1891, but no satisfactory definition was given for the unit. The name was derived from the town of Martinsburg, W. Va. They erroneously believed that the shales at Martinsburg are the same as rocks exposed in the Harpers Ferry, W. Va., area that were later identified as the Harpers Shale by Keith (1894) and all subsequent workers.

Darton (1892) first described the Martinsburg as consisting of dark slates, shales, and some sandstone. He noted that the formation contains thin-bedded limestone at its base, whereas Keith (1894) stated that the Martinsburg "consists of black and gray calcareous and argillaceous

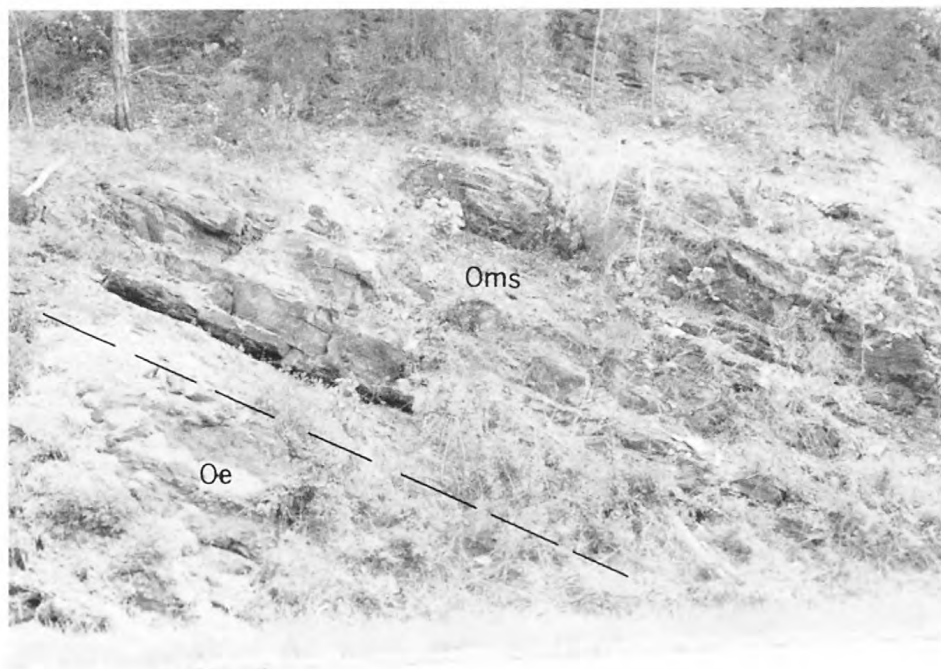


**Figure 3.** Geologic map of the Strasburg, Va., area showing three localities (a-c) where the lower part of the Stickley Run Member of the Martinsburg Formation is well exposed: (a) type section of the Stickley Run Member, (b) type section of the Oranda Formation of Cooper and Cooper (1946), and (c) well-exposed section of the Stickley Run Member along Tumbling Run.

Quaternary alluvium and terrace deposits not shown. Geology from Orndorff and others (1993), Rader and Biggs (1976), and J.B. Epstein and R.C. Orndorff (unpub. data). Base from U.S. Geological Survey topographic maps of the Middletown (1986), Mountain Falls (1965), Strasburg (1986), and Toms Brook (1978) 7.5-minute quadrangles. Contour interval 20 ft.

**Figure 3.—Continued.**





**Figure 4.** Type section of the Stickley Run Member of the Martinsburg Formation (Oms) overlying the Edinburg Formation (Oe) along U.S. Highway 11, 2.5 mi northeast of Strasburg, Va., immediately east of Cedar Creek (locality a in fig. 3).

shale of fine grain, and shows no variation within this area. It contains 80 per cent. of argillaceous and siliceous matter, and the remainder is chiefly carbonate of lime."

Cooper and Cooper (1946) named the Oranda Formation for 56 ft of interbedded argillaceous limestone, shale, calcareous mudstone, cobbly limestone, siltstone, and metabentonite that are transitional between the Martinsburg Formation and the underlying Edinburg Formation. The type section was established along Virginia Highway 55, 0.4 mi northwest of U.S. Highway 11 in Strasburg (locality b in fig. 3). The definition was based principally on fossil content, for they (Cooper and Cooper, 1946, p. 86) described the Oranda as "characterized by the occurrence of *Reuschella 'edsoni'* and its associates, which overlies the Edinburg and directly underlies the *Sinuities* beds of the Martinsburg." The lowest bed of the overlying Martinsburg was described as a very impure limestone with *Cryptolithus tessellatus*, *Isotelus*, and abundant *Sinuities*. Above this bed are shale and lesser siltstone, metabentonite, and minor limestone. They did not indicate whether the shales are calcareous. Thus, the base of the Martinsburg originally was poorly defined, a fact noted by Woodward (1951, p. 333).

Many subsequent workers have mapped and described the Martinsburg in the northern Shenandoah Valley (for example, Butts and Edmundson, 1939; Butts, 1940; Thornton, 1953; Cooper, 1960; Page and others, 1964; Edmundson and Nunan, 1973; Young and Rader, 1974; Rader and Biggs, 1975, 1976; Gathright and others, 1978a,b,c,d; Gathright and Frischmann, 1986). Although most workers noted the transitional contact between the Oranda and Martinsburg Formations, the quality of lithologic descriptions varied. Both the Oranda and lowest part of the Martinsburg

have been described as containing calcareous shale, siltstone, and argillaceous limestone, along with scattered metabentonite.

Our recent mapping of the Oranda of previous usage, the lower part of the Martinsburg Formation, and the uppermost beds of the Edinburg Formation in the Shenandoah Valley indicates that these units were not satisfactorily delimited, that the Oranda is poorly defined, and that some published descriptions of the lithology of the Oranda Formation and the lower part of the Martinsburg are vague. Several mappers (Thornton, 1953, for example) included some of the underlying Edinburg Formation within the Oranda.

The original description of the Oranda Formation includes knobby limestone at its base with shale and siltstone, in part calcareous, above. Because of difficulties in recognizing the Oranda as a readily mappable lithologic unit, we are herein abandoning the name. The lower knobby-weathering limestones are assigned to the underlying Edinburg Formation. The overlying calcareous shale and siltstone and shaly limestone are included in the base of the lower member of the Martinsburg Formation, herein named the Stickley Run Member.

## STRATIGRAPHY

The Martinsburg Formation is exposed in a belt that is between 2 and 3.5 mi wide in the Shenandoah Valley in the Winchester 30'x60' quadrangle and is generally less than 1.2 mi wide along the North Mountain fault zone (McDowell, 1991). In places, it is cut out along this fault zone. The

**Table 1.** Type section of part of the Stickley Run Member of the Martinsburg Formation, along a roadcut on the southeast side of the northbound lane of U.S. Highway 11, immediately east of Cedar Creek, about 2.5 mi (4 km) southwest of Middletown, Va., at lat 39°00'57" N., long 78°18'52" W. (locality a in fig. 3).

[Rock-color terms from Goddard and others (1948). Measurements were made in feet]

Martinsburg Formation (part):		Thickness		Martinsburg Formation (part)—Continued		Thickness	
Stickley Run Member (part):		Feet	Meters	Stickley Run Member (part)—Continued		Feet	Meters
16. Limestone, thin-bedded and laminated, and calcareous shale; medium-dark-gray (N 4) limestone beds as much as 9 in. (23 cm) thick. Covered above to Cedar Creek.....	28.0	8.5		5. Shaly limestone, medium-dark-gray (N 4), medium-olive-gray (5Y 5/1)-weathering, very fine grained, containing graptolites; stands out in relief. Abrupt lower contact. Not fissile like underlying shales .....	0.3	0.1	
15. Shaly limestone, laminated to thin-bedded (<0.5–3 in. (1–8 cm) thick), medium-dark-gray (N 4), medium-olive-gray (5Y 5/1)-weathering, very fine grained, interbedded with grayish-black (N 3) calcareous shale.....	21.0	6.4		4. Calcareous shale, platy to laminated, grayish-black (N 3), and minor laminae of dark-gray (N 3), medium-dark-gray (N 4)-weathering, shaly limestone, which stand out in slight relief. Partly covered near base; may include thin metabentonite. Lower contact with Edinburg Formation is abrupt.....	13.5	4.1	
14. Limestone, thin-bedded and laminated, medium-dark-gray (N 4), and calcareous shale.....	4.6	1.4		Incomplete thickness of Stickley Run Member .....	139.7	42.6	
13. Same as unit 15.....	10.3	3.1		Edinburg Formation:			
12. Limestone, thin-bedded and laminated, medium-dark-gray (N 4), and calcareous shale; limestone beds as much as 6 in. (15 cm) thick and making up about 30 percent of the unit.....	7.3	2.2		3. Limestone, medium-dark-gray (N 4), medium-gray (N 5)- to light-olive-gray (5Y 6/1)-weathering, very fine grained, poorly bedded.....	1.5	0.5	
11. Same as unit 15. Some of the limestone beds as much as 6 in. (15 cm) thick.....	20.8	6.3		2. Limestone, dark-gray (N 3), medium-dark-gray (N 4)-weathering, knobby (nodules average about 4 in. (10 cm) long), very fine grained, interbedded with dark-gray (N 3) to medium-dark-gray (N 4), medium-gray (N 5)-weathering, calcareous silty shale .....	6.0	1.8	
10. Shaly limestone, laminated, medium-dark-gray (N 4) .....	4.0	1.2		1. Limestone, dark-gray (N 3), medium-dark-gray (N 4)-weathering, very fine to fine-grained, medium- to thick-bedded, unevenly bedded, fossiliferous.....	51.0	15.5	
9. Same as unit 15.....	17.3	5.3		Incomplete thickness of Edinburg Formation ...	58.5	17.8	
8. Metabentonite, moderate-yellowish-brown (10YR 5/4)-weathering, sheared, interlayered with calcite slickenside .....	0.2	0.06					
7. Calcareous silty limestone, medium-dark-gray (N 4), medium-olive-gray (5Y 5/1)-weathering, that stands out in relief.....	1.1	0.3					
6. Shaly limestone, laminated to thin-bedded (<0.5–3 in. (1–8 cm) thick), medium-dark-gray (N 4), medium-olive-gray (5Y 5/1)-weathering, very fine grained, composing about 8 percent of unit and interbedded with grayish-black (N 3) calcareous shale in graded and upward-fining cycles 1–6 in. (2–15 cm) thick (fig. 5). Base of each cycle abrupt.....	11.3	3.4					

topography on the Martinsburg is a gently rolling upland surface dissected by moderately steep stream valleys and gullies with a trellis drainage pattern. Maximum relief within the Martinsburg terrane is generally less than 150 ft. The drainage pattern is controlled by both bedding and joint trends. The Martinsburg is generally poorly exposed in upland areas but well exposed in the creeks and gullies.

### STICKLEY RUN MEMBER OF THE MARTINSBURG FORMATION

The Stickley Run Member of the Martinsburg Formation includes all rocks above the highest knobby-weathering limestone of the Edinburg Formation up to and including all platy limestones that are interbedded with shale and graywacke typical of overlying Martinsburg rocks. The limestones of the Stickley Run Member are laminated and

very thin bedded to thin bedded, very fine grained, medium gray to grayish black, argillaceous, and commonly graded (figs. 5 and 6); they weather olive gray and grayish orange to dark yellowish orange. They are interbedded with medium-gray to medium-dark-gray calcareous shale. The upper contact with the younger Martinsburg is transitional; limestones become less abundant upward in the Stickley Run. A few thin beds of siltstone and very fine grained sandstone, generally less than 2 in. thick, are near the top of the Stickley Run. Rocks younger than those exposed at the type section on U.S. Highway 11 are best seen in the bed of Cedar Creek southwest of the type section (fig. 3). Graywacke becomes more abundant upward into the overlying unnamed member of the Martinsburg.

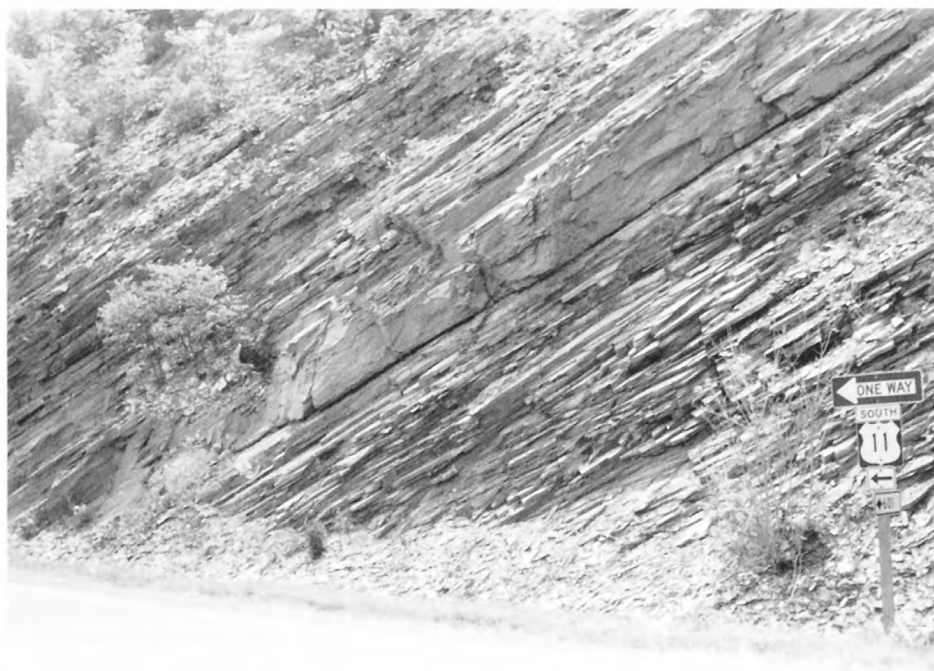
Slaty cleavage is a common secondary structure in most outcrops of the Stickley Run (fig. 7), as it is in the overlying shales of the Martinsburg Formation. Most of the rocks in the Stickley Run contain more than 50 percent



**Figure 5.** Graded shaly limestone (lighter beds) and calcareous shale in the Stickley Run Member of the Martinsburg Formation at the type locality, unit 6 of the measured section (table 1).



**Figure 6.** Platy shaly limestone and calcareous shale of the Stickley Run Member of the Martinsburg Formation exposed along U.S. Highway 11 near Tumbling Run 1.7 mi southwest of Strasburg, Va. (locality c in fig. 3).



calcium carbonate, and some contain more than 80 percent. Upon weathering, these cleaved rocks break down into thin plates, making the rock look more like a fissile shale than a shaly limestone. This appearance probably accounts for previous workers identifying these rocks as shales within the Martinsburg Formation rather than placing them in the Oranda Formation of Cooper and Cooper (1946).

At one locality in Strasburg, on the north limb of an open syncline, cleavage is poorly developed in the Stickley Run (fig. 8), and many of the sedimentary structures are

readily visible. Figure 9 shows some of the details in the rock. The rock is graded, generally from coarse calcareous siltstone to fine siltstone or mudstone. The basal laminae of some of the graded beds are disrupted. The coarser shaly limestones are microlaminated or cross-laminated, and many of these beds are amalgamated. The tops of many of the limestone laminae contain casts due to loading of the overlying finer mudstone. Many of the laminae contain soft-sediment slump folds. Serial sections of three of these slump folds show that the transport direction (the direction



**Figure 7.** Well-developed slaty cleavage (dipping moderately to the left), a conspicuous planar structure in the Stickley Run Member of the Martinsburg Formation at locality b, figure 3. Bedding is vertical in the north-west limb of an overturned fold. Parting along bedding and cleavage develops elongate "pencil" fragments, forming a shale-chip rubble. This feature gives the unit the appearance of a shale, rather than a shaly limestone. Compare with figure 8.



**Figure 8.** Platy, laminated to thin-bedded shaly limestone of the Stickley Run Member of the Martinsburg Formation, along railroad in Strasburg, 0.4 mi west of the intersection of U.S. Highway 11 and Virginia Highway 55. Beds dip moderately to the southeast and lack well-developed cleavage. Sample shown in figure 9 taken from this locality. These beds are nearly on strike with those shown in figure 7.

perpendicular to the axes of the slump folds and the same as the direction of verging of these folds) ranged from N. 2° E. to N. 31° E., with an average of N. 17° E. Interestingly, the regional strike of hard-rock tectonic folds in the Middletown area just north of Strasburg (Epstein, 1993) is within a similar range as the direction of transport shown by the slump folds.

Eight samples of limestone and calcareous shale were collected from the Stickley Run Member in the

Middletown-Strasburg area and analyzed for calcium carbonate content (table 2). The calcareous shale averaged 48 percent carbonate (range 45–53 percent), and the limestone averaged 74 percent (range 65–85 percent). The average carbonate content of all samples was 61 percent.

As defined here, the Stickley Run Member is many times thicker than the Oranda Formation of Cooper and Cooper (1946) and includes several hundred feet of rock previously included within the Martinsburg Formation.



**Figure 9.** Negative print of acetate peel of laminated and thin-bedded calcareous shale (darker beds) and shaly limestone (lighter beds) in the Stickley Run Member of the Martinsburg Formation. Stratigraphic top is up in the picture; northeast is to the right. Soft-sediment slump folds (a) indicate that the basinal down-slope direction was approximately N. 17° E. Amalgamated micro-crossbeds near bottom suggest the same direction of sediment transport. Numerous load casts indent several of the shaly limestone beds (b). Lowest units of several graded beds consist of disrupted coarse calcareous siltstone (b) containing fragments from the underlying bed. This suggests loading while currents were still active.

Along Tumbling Run and along adjacent U.S. Highway 11, the Stickley Run consists of interbedded platy limestone and calcareous shale (fig. 6) and is approximately 610 ft thick, the upper 285 ft being poorly exposed.

Mapping in the Middletown area indicates that the Stickley Run is much thicker than that exposed at Tumbling Run. The upper contact with the overlying rocks of the Martinsburg Formation is drawn with difficulty because of poor exposure and the transitional nature of the boundary. The platy limestones become less abundant toward the top of the unit, and the upper contact is defined as the top of the highest platy limestone, which may be only 1 in. thick. The platy

limestones probably make up less than 5 percent of the unit at the top of the Stickley Run. Along Virginia Road 627 between Interstate Highway 81 and U.S. Highway 11 in Middletown, the Stickley Run occupies a belt about 1,000 ft wide. Beds dip very steeply, and the member may be as much as 900 ft thick, as indicated by the construction of a cross section in this area of limited exposure.

The Stickley Run Member is recognized in the Massanutten synclinorium (fig. 1) and in the area between the Staunton and North Mountain faults as far south as southern Augusta County. In the Harrisonburg and Bridgewater quadrangles, the Stickley Run was mapped as the Oranda



**Table 2.** Calcium carbonate content of samples from the Stickley Run Member of the Martinsburg Formation.

[Calcium carbonate content determined by weight loss by acid digestion. Analyst: J.B. Epstein]

Sample description and locality	CaCO <sub>3</sub> (wt. %)
1. Calcareous silty shale, about 600 ft above the base of the Lincolnshire Limestone, 1,000 ft north of the intersection of U.S. Interstate 81 and Virginia Highway 627, Middletown quadrangle .....	45
2. Shaly limestone. Same locality as sample 1 .....	65
3. Dark-gray, very fine grained, shaly limestone, about 240 ft above the base of the Lincolnshire Limestone, along U.S. Highway 11 just south of Tumbling Run (locality c in fig. 3), Toms Brook quadrangle .....	85
4. Medium-dark-gray calcareous shale. Same locality as sample 3 ..	45
5. Slightly weathered, medium-gray to medium-dark-gray calcareous shale to shaly limestone, weathers dark yellowish orange. About 300 ft above the base of the Lincolnshire Limestone, on knoll south of northbound lane of U.S. Highway 11, about 2,000 ft southwest of Tumbling Run, Toms Brook quadrangle ..	65
6. Slightly weathered, medium-dark-gray and dark-gray argillaceous limestone. Same locality as sample 5 .....	81
7. Very slightly weathered, medium-light-gray to medium-gray, poorly bedded, calcareous shale about 25 ft above the base of the Lincolnshire Limestone, immediately above a 2.5-in. bed of metabentonite, Virginia Highway 55, 0.4 mi northwest of U.S. Highway 11 in Strasburg, Strasburg quadrangle (locality b in fig. 3). The type Oranda Formation of Cooper and Cooper (1946) .....	53
8. Same rock as sample 7, but weathered medium light gray, light olive gray, and grayish orange .....	50

Formation and the calcareous slate member of the Martinsburg Formation by Gathright and Frischmann (1986). The Oranda was not recognized south of Harrisonburg, where 100–200 ft of black, graptolitic, calcareous slate with interbedded argillite was mapped as the basal member of the Martinsburg by Gathright and others (1978a,b,c,d). These rocks, which also contain beds of platy limestone, are now placed within the Stickley Run Member of the Martinsburg Formation. In Shenandoah County, the Stickley Run was mapped as the Oranda Formation and the lower black, calcareous shale member of the Martinsburg by Young and Rader (1974) and Rader and Biggs (1976). On the east limb of the synclinorium, west of Front Royal, Rader and Biggs (1975) described the lower part of the Martinsburg as black, silty, calcareous shale with interbedded black, silty, argillaceous limestone.

Numerous fossils have been reported from rocks herein defined as the Stickley Run Member (see Cooper and Cooper, 1946; Woodward, 1951). Several samples were collected at the type section for conodont determination, but they were barren (Harris and others, 1994). A sample collected from the uppermost bed of the underlying Edinburg Formation, however, yielded a conodont fauna of the *Amorphognathus tvaerensis* Zone, indicating a late Middle

Ordovician age (Harris and others, 1994). The Stickley Run Member is probably only slightly younger.

The lithologic character of correlatives of the Martinsburg Formation and their thickness are markedly different west of the North Mountain fault (fig. 1) and the Pulaski fault in southwestern Virginia (Rader and Evans, 1993). Here, the Eggleston Formation, Dolly Ridge Formation, Trenton Limestone, and Reedsville Shale are characterized by thin, coquinooid limestone with interbedded, dark-gray, calcareous shale. The thickness of these units averages about 1,500 ft.

During the present study, the Stickley Run Member of the Martinsburg Formation was traced a few miles north of the Virginia-West Virginia border. Rocks similar to those of the Stickley Run were found still farther north in the Shenandoah Valley of West Virginia (Cardwell and others, 1968) and Maryland (Edwards, 1978). In south-central Pennsylvania, Craig (1949, p. 739) identified the Oranda Formation, describing it as “dark-grey to black, fine-grained, slabby to massive, blue-grey to white-weathering limestone” and “black, argillaceous, buff-weathering limestone with prominent shaly partings.” Whether the thick-bedded limestones are similar to those of the Stickley Run as described here has not been determined. However, Craig (1949, p. 742) also noted argillaceous limestones in the basal Martinsburg, which may be equivalent to the Stickley Run. If so, the Stickley Run may extend for at least 75 mi north of the Virginia-West Virginia border. Still farther northeast is the correlative Jacksonburg Limestone, which is similar to the Stickley Run and which underlies the Martinsburg Formation in eastern Pennsylvania. There, the uppermost Jacksonburg consists of dark-gray, argillaceous, carbonaceous limestone and very calcareous shale.

## OVERLYING ROCKS OF THE MARTINSBURG FORMATION

The Martinsburg Formation overlying the Stickley Run Member consists of interbedded shale and lesser siltstone and graywacke. These rocks are poorly exposed in interfluvial, where they are generally leached to depths as great as 10 ft, producing unconsolidated shale and fine sandstone debris. Rocks of the Martinsburg above the Stickley Run are well exposed in the floors of creeks, some of which have nearly continuous exposure for thousands of feet. The shales are medium gray to dark gray and light olive gray, are commonly silty, weather to grayish orange and dark yellowish orange, and are generally noncalcareous, although scattered intervals contain calcareous rocks, especially in the lower part of the member. The shales form intervals as thick as 4 ft or thicker, but they commonly are interrupted by thin to thick beds of siltstone or sandstone.

The sandstone and siltstone are estimated to compose less than 10 percent of the Martinsburg exposed in the



Middletown area. They are more abundant and thicker bedded higher in the section, approximately 2,000 ft above the base of the Martinsburg, where they form conspicuous ribs in creeks and may compose as much as 30 percent of some intervals that are several hundred feet thick. The upward coarsening within the Martinsburg is transitional, and no interval containing graywacke can be readily distinguished to make a separate mappable unit. In the lower 1,000 ft of the member, the graywacke beds are generally less than 0.5 ft thick, although rare beds may reach 2 ft in thickness. Above this interval, many of the sandstones are thicker, and a few are as much as 12 ft thick; many of these beds are amalgamated. These beds are lenticular—individual thick beds were traced for only short distances between creeks. They could not be mapped at the 1:24,000 scale for a distance greater than 2,000 ft, much less on a regional scale, because the thickness of the units differs so much over short distances and because the folding is complex.

The sandstones are immature (generally lithic graywacke, although some contain significant feldspar), commonly graded (fining upward), very fine to fine grained, slightly calcareous to noncalcareous, and medium gray on fresh surfaces; they weather grayish orange. The thicker beds are generally graded and display characteristics of complete Bouma cycles, although c–e Bouma cycles appear to be most abundant. A few load casts were seen. Many beds contain small-scale crossbeds.

The Martinsburg Formation in the Shenandoah Valley of Virginia and West Virginia lies in the core of the Massanutten synclinorium north of Front Royal (Cardwell and others, 1968; McDowell, 1991; Rader and Evans, 1993) and on the flanks of the synclinorium to the south (Rader and Biggs, 1976). The Martinsburg is complexly folded, and cleavage is present in most outcrops (Epstein, 1993). Although cleavage may be a dominant planar element in an individual outcrop, the published admonition that bedding is obliterated by cleavage (Page and others, 1964) is incorrect. Thin to thick beds of siltstone and fine-grained graywacke are common enough that bedding generally can be readily determined. Cleavage, rather than being a detriment to bedding attitude determination, aids in indicating whether beds are right side up or are overturned. The resolution of younging direction in individual outcrops aids in preparation of accurate cross sections and determination of thickness of the entire Martinsburg Formation.

## ENVIRONMENTS OF DEPOSITION

The thin-bedded shaly limestones and calcareous shales of the Stickley Run Member of the Martinsburg Formation in the Shenandoah Valley represent a deepening of the sedimentary basin following shallow-water, carbonate-bank to ramp deposition of the Edinburg Formation and older carbonate rocks (Rader and Read, 1989). Deposition

of the Stickley Run was followed by basinal turbidite deposition of the thick sequence of graywacke and shale of the overlying part of the Martinsburg Formation. The Jacksonburg Limestone in eastern Pennsylvania, which is a correlative of the Stickley Run, similarly was deposited as a deepwater clastic limestone and calcareous shale following the foundering of the carbonate bank represented by Beekmantown Group rocks rimming eastern North America during Taconic plate collision (see for example, Epstein, 1986). The fine grain size and sedimentary structures in the Stickley Run Member, such as graded beds, cross and parallel laminations, and convolute bedding, suggest deposition as distal turbidites.

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## 2. Middle Pennsylvanian Arnett Member (New Name) of the Breathitt Formation, Eastern Kentucky

By Charles L. Rice<sup>1</sup>

### ABSTRACT

A Middle Pennsylvanian marine shale and sandstone unit that commonly crops out above the Hazard coal zone in the Breathitt Formation in eastern Kentucky is here named the Arnett Member. The unit is most continuous along the western margin of its outcrop belt. The Arnett contains a variety of marine fossils, including conodonts, which suggest that the member is equivalent to the Poverty Run and Lowellville marine units in Ohio, and perhaps to the Lead Creek Limestone Member of the Mansfield Formation in Indiana.

### INTRODUCTION

Chesnut (1991) informally named a Middle Pennsylvanian marine unit the Cowcreek member of the Breathitt Formation; it consists of fossiliferous strata overlying the Hazard (5, 5A, 6) coal zone and equivalent coal beds that crop out in the Cowcreek 7.5-min quadrangle, Owsley and Breathitt Counties, eastern Kentucky. Because the name Cowcreek is formally preempted by prior usage (North American Commission on Stratigraphic Nomenclature, 1983, p. 853, article 7(c)), the unit is herein renamed the Arnett Member of the Breathitt Formation. The name is taken from the village of Arnett on Kentucky Route 28, south-central Cowcreek 7.5-min quadrangle, Owsley County, Ky.

Marine strata that apparently occur in the middle part of the Arnett Member were first identified in the Cowcreek 7.5-min quadrangle by Outerbridge (1978) as the informal limestone-siltstone marker bed above the Hazard (5, 5A, 6) coal zone. The marker bed was described as mostly limestone (as much as 1.2 m thick), which grades laterally to calcareous, fossiliferous siltstone and calcareous sandstone. The bed is identified on Outerbridge's (1978) geologic map by a red X just southeast of the gap at the head of the Right Fork of Cow Creek, about 2.7 km east of the village of Arnett. The bed is exposed about 6 m above and 5 m north-

east of an unpaved road that extends from Kentucky Route 28 to a microwave tower on the Breathitt-Owsley County line at the top of the ridge. At the red-X location, the marker bed consists of about 20 cm of sandy, brown-weathering, fossiliferous limestone that grades down to about 1 m of bioturbated fine-grained sandstone. Although a massively bedded sandstone 15 or more meters thick crops out 3 to 4 m above the marker bed, strata directly overlying and underlying the bed are not exposed at this locality.

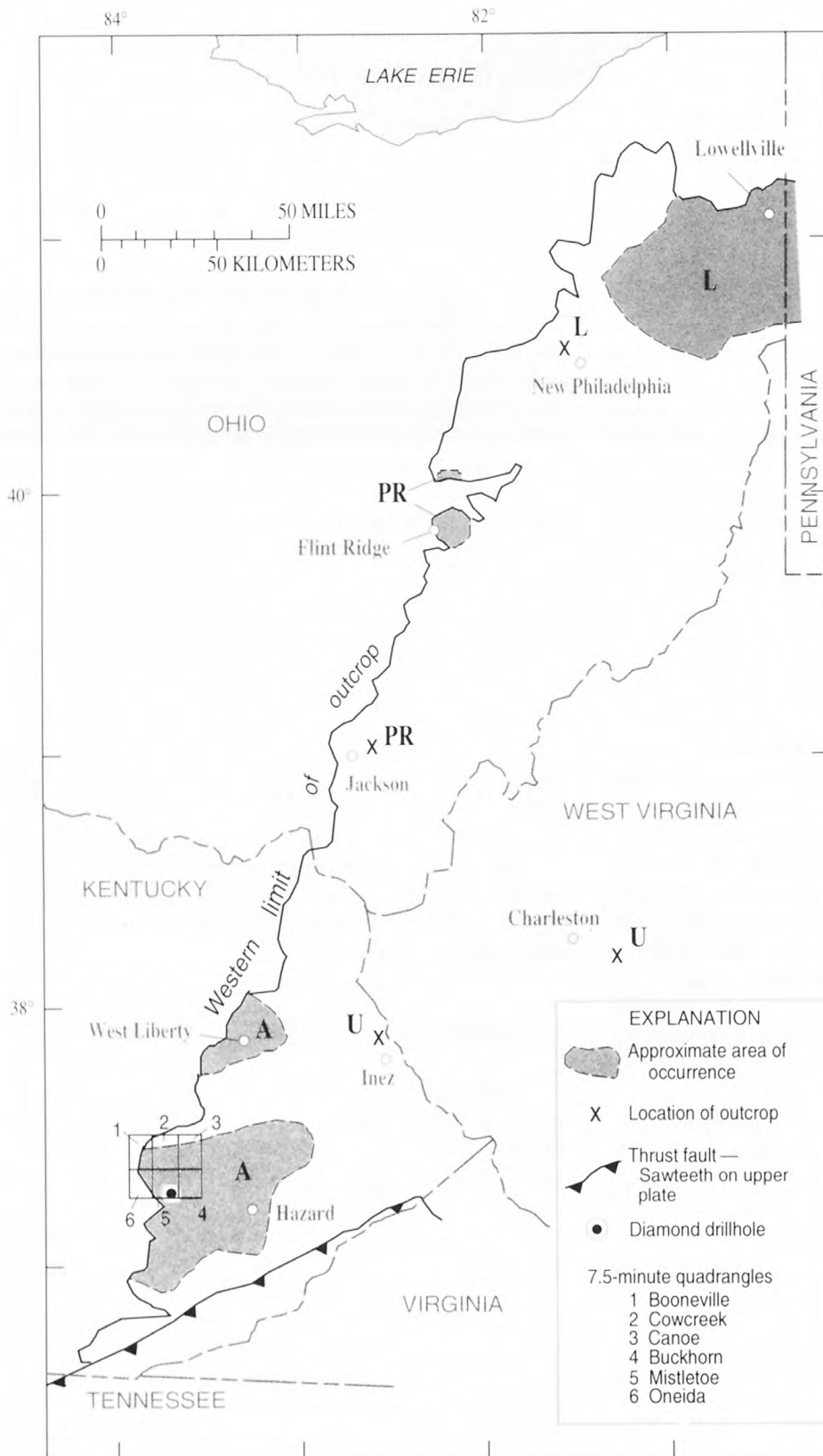
The fossiliferous bed above the Hazard coal zone was also mapped as a resistant marker bed in areas adjacent to the Cowcreek quadrangle, such as the Oneida (Rice and Lee, 1978) and the Booneville (Weir, 1978) 7.5-min quadrangles, and was identified as a discontinuous but persistent unit in the Canoe (Hinrichs, 1978), the Buckhorn (Danilchik and Lewis, 1978), and the Mistletoe (Volckmann and Leo, 1978) 7.5-min quadrangles (fig. 1). Where the bed is a calcareous siltstone or sandstone, it is relatively resistant and tends to crop out on ridges and steep slopes. The marker-bed facies is probably restricted to the area indicated above. In other areas, because of poor exposure, the Arnett Member has been identified as sparsely fossiliferous shale directly overlying the Hazard (5, 5A, 6) coal zone or equivalent coal beds.

### LITHOLOGY AND STRATIGRAPHY

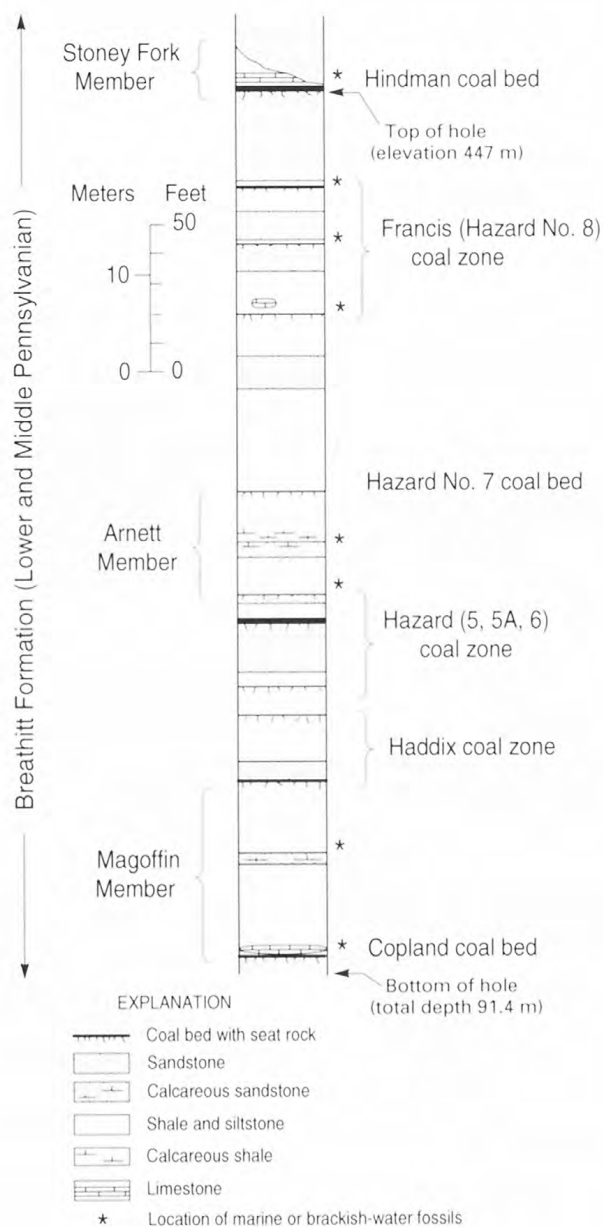
Although the Arnett Member has been identified mostly by its resistant facies (limestone, siltstone, or sandstone) in the area of the quadrangles shown in figure 1, it appears to be mainly a marine shale sequence that may be 10 m or more in thickness. A coal exploratory diamond drillhole in the southeastern part of the Mistletoe 7.5-min quadrangle is here designated the type section; a lithologic log of this core is illustrated in figure 2. The corehole was drilled at an elevation of about 447 m on a ridge between the head of Dusty Fork of Leatherwood Creek and the head of Long Fork of Squabble Creek (lat 37°17'11" N., long 83°31'17" W.). The core description (by an unknown driller) indicates that the Arnett Member, which extends from corehole depth 42 m to corehole depth 52 m, consists mainly of dark-gray shale and siltstone. In this core, marine fossils are

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**Figure 1.** Distribution and extent of outcrop of the Arnett Member of the Breathitt Formation (A) (Lower and Middle Pennsylvanian) in Kentucky and of Middle Pennsylvanian units in Ohio and West Virginia with which it is tentatively correlated in the outcrop belt along the western margin of the Appalachian basin. Some data used in establishing the distribution of the Arnett Member in the area of Hazard, Ky., were provided by Donald R. Chesnut, Jr., and Gerry A. Weisenfluh of the Kentucky Geological Survey. PR, Poverty Run limestone (unranked) of the Pottsville Formation; L, Lowellville limestone (unranked) of the Pottsville Formation; U, unnamed marine or brackish-water unit.



**Figure 2.** Generalized diagram of a coal exploratory drillhole (type section of the Arnett Member of the Breathitt Formation) collared just below the Hindman coal bed on a ridge in the southeastern part of the Mistletoe 7.5-min quadrangle, Perry County, Ky. (lat 37°17'11" N., long 83°31'17" W.). Section above collar is generalized from Volckmann and Leo (1978) and Danilchik and Lewis (1978).

reported in the basal beds of the member, although marine fossils are most abundant in the upper part of the 1.5-m-thick sandstone bed in the middle of the member and in a 1-m-thick shale bed directly overlying the sandstone bed. The fossiliferous sandstone bed of the core log is similar in description to the sandstone facies of the limestone-siltstone marker bed mapped by Outerbridge (1978), Rice and Lee

(1978), and Weir (1978) in areas to the north and northeast and probably is that marker bed. The Arnett Member is exposed in the highwalls of strip mines of the Hazard coal beds that extend generally from the area of the type section to the vicinity of the village of Arnett.

In other areas in eastern Kentucky, strata at the horizon of the Arnett Member generally have been identified as shale sequences above the Hazard coal zone (or equivalent coal beds) (see Rice and Hiatt, 1994). The shale has rare marine or brackish-water fossils in the burrowed basal beds that are the roof shales of the uppermost Hazard coal bed. The Hazard coal zone may consist of at least three coal beds (fig. 2), and these may be difficult to distinguish from beds of the underlying Haddix coal zone. However, the beds of the Hazard coal zone have been extensively mapped in eastern Kentucky with confidence on the basis of the interval between them and the underlying persistent Magoffin Member of the Breathitt Formation.

Chesnut (1991) recorded a variety of calcareous rock types (siltstone, sandstone, and shale) for strata here assigned to the Arnett Member that are described in geologic reports for eastern Kentucky. He also provided lists of tentatively identified fossils in strata assigned to the member that include brachiopods, bryozoans, pelecypods, gastropods, conularids, and foraminifers.

Marine units of the Breathitt Formation (Lower and Middle Pennsylvanian) in eastern Kentucky commonly consist of upward-coarsening sequences where the basal fossiliferous transgressive facies are shale or limestone. Overlying the transgressive strata are generally coarser grained and less fossiliferous shales and siltstones that are terrigenous clastic deposits of advancing deltas. The occurrence of a relatively coarse grained calcareous sandstone associated with abundant marine fossils in the Arnett Member suggests that a local deepening or subsidence of the basin took place during deposition of the middle part of the member, which resulted in a return to more marine conditions. Coincidentally, the Magoffin Member appears to contain a similar unusual fossiliferous sandstone bed near its middle in this area (fig. 2).

## DISTRIBUTION AND REGIONAL CORRELATION

The Arnett Member appears to occur in two distinct areas in eastern Kentucky (fig. 1): near West Liberty and near Hazard. Individual thin marine units generally are not seen where the underlying coal bed either is thin or has not been exposed by mining. In addition, identification of marine units generally depends upon identification of the underlying coal bed. Because coal beds tend to split and form complex zones of coals, overlying thin marine and brackish-water shales (which some workers suggest occur locally over every coal bed) commonly cannot be traced

laterally with any confidence. For example, the three marine or brackish-water horizons in the Francis coal zone probably would not be known except for the exploratory corehole (fig. 2). Experience has shown that correlation of individual marine beds (as well as coal beds) in this zone would be difficult for any great distance even between corehole logs of equivalent detail. Consequently, even though the Arnett Member does thin away from the areas identified in figure 1, the actual boundaries of its extent are not presently known.

The difficulty of identifying the stratigraphic horizons of some isolated marine strata is illustrated by the local occurrence of two unnamed marine units, one north of Inez, Ky. (Jenkins, 1966), and the other southeast of Charleston, W. Va. (Martino, 1991) (fig. 1). These marine units appear to be at the stratigraphic horizon of the Arnett Member because of their positions with respect to the Magoffin Member (and its equivalent in West Virginia, the Winifrede Shale Member of the Kanawha Formation), as well as their relations to overlying and underlying coal beds. In both these occurrences, the marine strata seem to be geographically isolated from any other marine deposits. Whether this isolation is a function of lack of data or postdepositional erosion is undetermined. Chesnut (1991) tentatively assigned the marine unit north of Inez to the informal marine member N that underlies the Arnett Member in eastern Kentucky; this assignment was based on his interpretation of the identity of the overlying and underlying coal beds. Other evidence listed by Chesnut for a marine unit at this lower horizon in eastern Kentucky is mainly the widespread occurrence of calcareous sandstone concretions between the Hazard and Haddix coal zones. Such an assignment, however, would make the occurrence of fossiliferous beds near Inez even more isolated from identified marine strata than its assignment here to the Arnett Member.

The Arnett Member is the best known and most extensive marine unit in the Middle Pennsylvanian stratigraphic section between the Magoffin Member and the Stoney Fork Member of the Breathitt Formation in Kentucky. It appears to be thickest and most fossiliferous along the western margin of the Appalachian basin. Its identification near West Liberty, Ky., is locally difficult because of the thinness of the stratigraphic section in that area and the occurrence of other marine units in relatively close vertical position. Whereas the Arnett is about 38 m above the base of the Magoffin Member in the Mistletoe quadrangle (see figs. 1 and 2), it is only about 22 m above the base of the Magoffin in areas southwest of West Liberty, where it apparently occurs in the middle of the Prater coal zone (Sable, 1978); the Prater is equivalent to the Hazard (see Rice and Hiett, 1994). A report by Englund (1955) also described this section.

The Arnett Member of the Breathitt Formation is here tentatively correlated with the unranked Poverty Run limestone in the Pottsville Formation in central and southern

Ohio and with its correlative in northeastern Ohio, the unranked Lowellville limestone in the Pottsville Formation. These two are the oldest named marine units of the Pottsville Formation in Ohio and generally crop out in that State in the western part of the Pennsylvanian basin (fig. 1). The Lowellville (limestone plus marine shale) is as much as 11 m thick in northeastern Ohio but is discontinuous and has proven to be difficult to trace in Ohio (Slucher and Rice, 1994). For example, an occurrence of the unit just below the Beach City reservoir dam northwest of New Philadelphia, Ohio (fig. 1), was mistakenly assigned to the unranked Boggs limestone in the Pottsville Formation by Lamborn (1956) but was correctly identified as the Lowellville by Gray (1954). The Poverty Run was described in its type area near Flint Ridge (fig. 1) as a 38-cm-thick fossiliferous limestone about 2.2 m above the Vandusen coal bed by Morningstar (1922). An additional occurrence was recognized by Rice and others (1992), just east of Jackson, Ohio (fig. 1), but the unit has not been otherwise identified in southern Ohio.

The Vandusen coal bed that directly underlies the Poverty Run and Lowellville units of the Pottsville Formation in Ohio contains the earliest occurrence of the palynomorph *Radiizonates* sp. (Rice and others, 1992), later identified as *Radiizonates difformis* and *R. rotatus* (Cortland F. Eble, written commun., 1994). This miospore first occurs in the Leatherwood coal bed that is equivalent to one of the coal beds of the Hazard coal zone that underlie the Arnett Member in eastern Kentucky (Robert M. Kosanke, written commun., 1968). Additionally, the first occurrence of this miospore in West Virginia is in the Winifrede coal bed (Kosanke, 1988), which closely overlies the unnamed marine unit near Charleston, W. Va. (Martino, 1991). On the basis of the first occurrence of *Radiizonates* sp. in all three States, the Arnett Member is correlated with the Poverty Run limestone, the Lowellville limestone, and the unnamed marine unit near Charleston.

Analyses of conodonts of the Arnett Member show that these are identical to those of the Poverty Run and Lowellville marine units in Ohio and those of the Lead Creek Limestone Member of the Mansfield Formation in Indiana (Bruce R. Wardlaw, written commun., 1994).

Should further paleontological studies confirm the correlations of these widely separated marine occurrences, this horizon will be the oldest regional stratigraphic marker bed in the Pennsylvanian to link the northern part of the central Appalachian basin in Pennsylvania and Ohio to the deeper parts of the basin in southeastern Kentucky. The Arnett will also be the oldest Pennsylvanian marine horizon to be correlated directly with strata in the Illinois basin. Thus, the Arnett Member and its correlatives may well become a key part of the stratigraphic framework of the Pennsylvanian of the Appalachian basin as well as an important marker for interbasinal correlations. The Arnett Member may also provide the control needed to interpret the geometry of the



Pennsylvanian sedimentary sections as they thin rapidly from the central part of the basin in Kentucky and West Virginia onto the North American craton in Ohio and Pennsylvania.

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### 3. The Coast Mountains Complex of Southeastern Alaska and Adjacent Regions

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#### ABSTRACT

The Cretaceous and Tertiary Coast Mountains Complex is a 1,750-km-long, plutonic-metamorphic entity that extends into Canada both to the northwest and southeast of southeastern Alaska. This entity is part of the discontinuous intrusive-metamorphic system of the western Cordillera that extends from Baja California on the south to the Alaska Peninsula on the northwest.

This note formally names the part of the Coast Mountains Complex in Alaska in accord with accepted procedures and definitions of the North American Commission on Stratigraphic Nomenclature, U.S. Board on Geographic Names, and U.S. Geological Survey. The type area for the lithodemic complex is herein designated as a transect across the Coast Mountains near Juneau, Alaska. Overall, the complex consists of about 70 percent intrusive granitic rocks, most of which are latest Cretaceous to middle Tertiary in age, and most of the remainder consists of metamorphic rocks. A consistent metamorphic-plutonic zonation with four northwest-striking zones characterizes the complex. The protoliths of the metamorphic rocks range from Late Proterozoic to Cretaceous in age and were metamorphosed during several episodes, the most important being Early and Middle Triassic, Early Cretaceous, and latest Cretaceous in age. Most of the intrusive and metamorphic episodes post-date the assembly of the terranes that provide the metamorphic rock protoliths; the accreted lithotectonic terranes are the Nisling, Stikine, and Wrangellia, the Behm Canal structural zone, and the Gravina overlap assemblage. Although the ages of protoliths and intrusive rocks together range from Late Proterozoic to Tertiary, most of the intrusive and metamorphic events occurred in Cretaceous and Tertiary time, and we therefore refer to the complex as Cretaceous and Tertiary in age.

The rocks of the Coast Mountains Complex have been, and currently are being, referred to by several informal names; most are incorrect either geologically or geographically, and the remainder are misleading at best. The formal name Coast Mountains Complex rectifies these problems.

#### INTRODUCTION

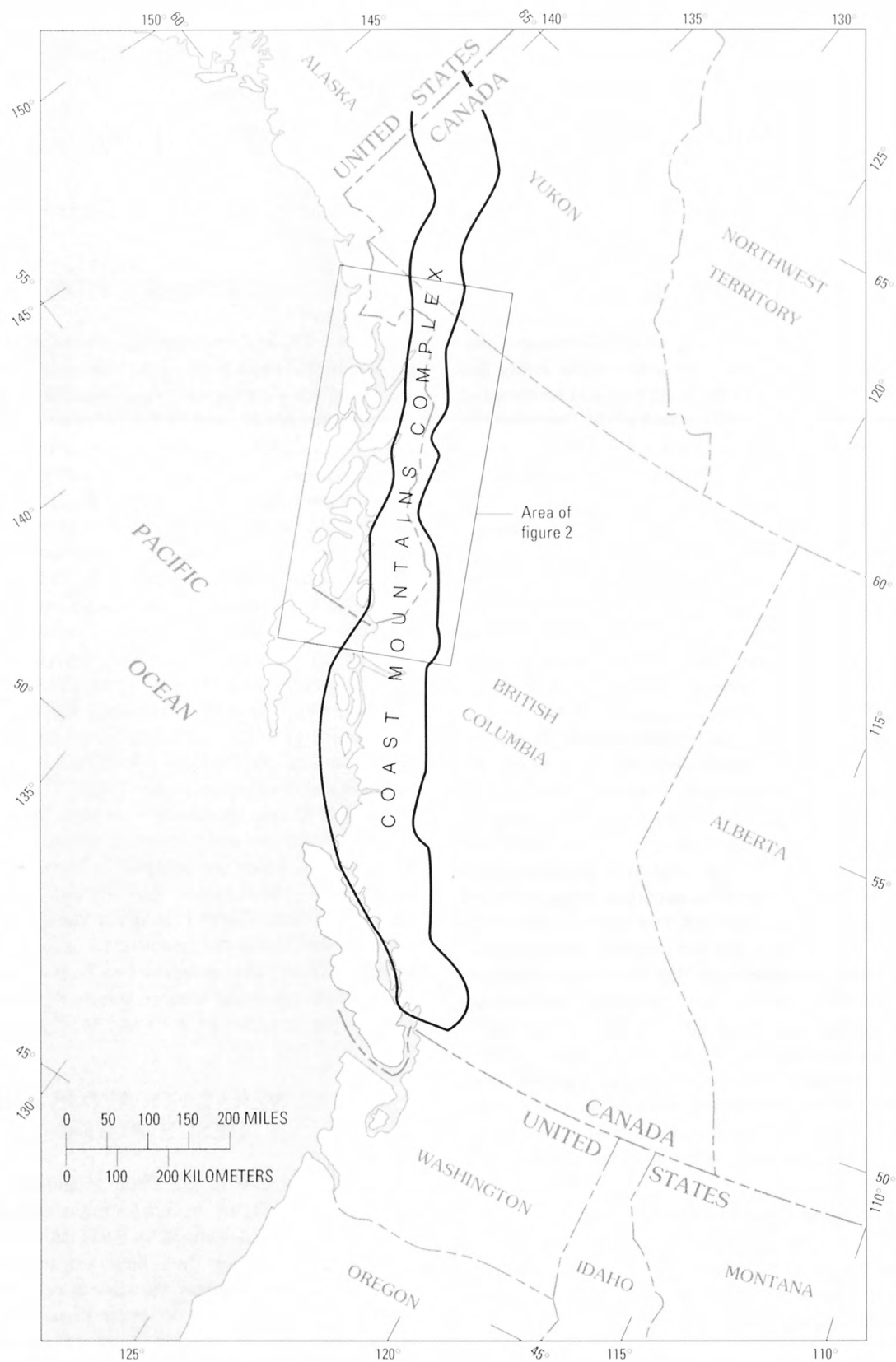
The 1,750-km-long complex of intrusive and metamorphic rocks that extends along the west coast of North America from the latitude of Vancouver, British Columbia, Canada, into Alaska west of the 141st meridian is probably the world's largest single plutonic-metamorphic complex (fig. 1). It is the major segment of a still larger, discontinuous plutonic-metamorphic complex that extends south from the Coast Mountains physiographic province of Alaska, the Yukon, and British Columbia, through the western conterminous United States, and south to the southern tip of Mexico's Baja California for a total length of about 8,000 km. Different names, some of which are (in our opinion) inappropriate, inaccurate, or otherwise misleading, have been applied to the Alaska-British Columbia part of the complex. The purpose of this note is to formally name this complex in accordance with the guidelines provided by the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). The name we have selected is Coast Mountains Complex. In this note, we record the previous and current conflicting terms applied to this complex, locate the complex in relation to other segments of the overall system, give our rationale for selecting the formal name Coast Mountains Complex, and briefly describe the herein-designated type area at and east of Juneau, Alaska. This complex can be described by using several different sets of criteria; herein, we use the plutonic-metamorphic zonation of Brew and Ford (1984).

#### GENERAL LOCATION AND DESCRIPTION

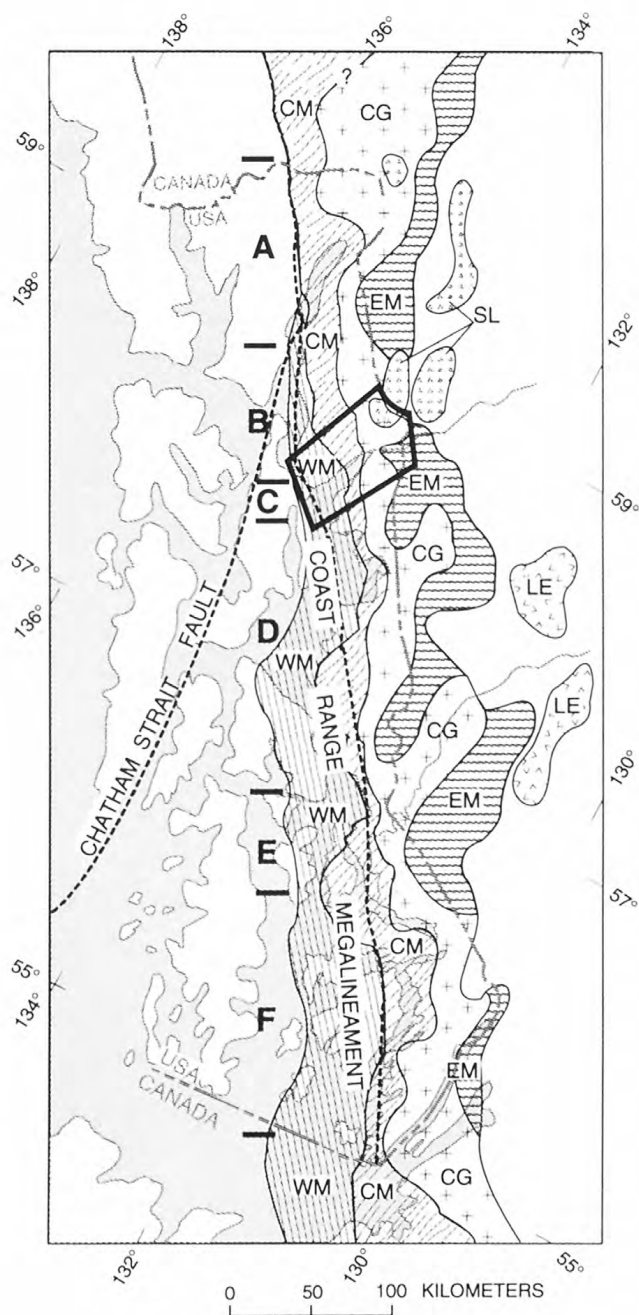
The boundaries of the Coast Mountains Complex as defined here (fig. 2) are, except for minor changes, the same as those defined and outlined by Brew and Ford (1984); the changes are so minor that they are insignificant. The western boundary is either the eastern contact of Gravina overlap assemblage rocks or, where those rocks have been metamorphosed, the western limit of the metamorphic effects. The eastern boundary of the complex is either the eastern limit of the metamorphism associated with the

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**Figure 1.** Location of Coast Mountains Complex in the United States and Canada. The complex may continue west past the limit of the studied area at the intersection of lat 62° N. with the 141st meridian.



EXPLANATION	
	Western metamorphic belt
	Central metamorphic zone
	Central granitic zone
	Eastern metamorphic zone
	Sloko Volcanics (Canadian usage)
	Level Mountain and Mount Edziza volcanic fields

← **Figure 2.** Coast Mountains Complex, southeastern Alaska and adjacent parts of British Columbia, showing approximate boundaries of major belts, zones, and units (from Brew and Ford, 1984). Single capital letters A–F indicate different segments of the complex mentioned in the text. Type area of complex is indicated by heavy outline; Juneau is located under the “M” of “WM” within that outline.

Tertiary plutons or, where Nisling terrane pre-Tertiary metamorphic rocks adjoin the Tertiary intrusions, the eastern contact of those metamorphic rocks.

The Coast Mountains Complex as a whole extends from the latitude of Vancouver, B.C. (about lat 48° N.), to the intersection of lat 62° N. with the 141st meridian, a distance of about 1,750 km. This note focuses on the part of the complex that is in southeastern Alaska, although much of the complex is in Canada. From past discussions with our Canadian colleagues, it appears unlikely to us that they will accept this name for the Canadian portion, however well it may be grounded in the North American Stratigraphic Code. The complex takes its name from the Coast Mountains physiographic province (Holland, 1964), which in southeastern Alaska consists of the Boundary Ranges subprovince (Wahrhaftig, 1965). This province closely follows tidewater on its west to about lat 59°30' N. (fig. 1), where tidewater is left behind and the province is inland of the more prominent Pacific Border Ranges province.

The Coast Mountains Complex can be described in terms of its metamorphic-plutonic zonation (Brew and Ford, 1984), metamorphic belts (Brew and others, 1989, 1992), magmatic belts (Brew and Morrell, 1980, 1983; Brew, 1988, 1994), individual plutons (Drinkwater and others, 1989, 1990, 1992a,b, 1994), and lithotectonic terranes and superterrane (Monger and others, 1982; Brew and Ford, 1994). Rather than reiterate all of these aspects in detail here, we refer the reader to the above papers; the following paragraphs summarize only the overall metamorphic-plutonic zonation and provide some detail as to the occurrence of plutons and batholiths in the complex.

The Coast Mountains Complex in southeastern Alaska and adjacent parts of British Columbia consists of four major belts or zones, shown in figure 2 from west to east: western metamorphic belt, central metamorphic zone, central granitic zone, and eastern metamorphic zone. Figure 2 also shows the distribution of the Sloko Volcanics (Canadian usage) and the Level Mountain and Mount Edziza volcanic fields; these are shown because they are the volcanic expression, in part, of the plutonism recorded in the complex.

One of the main reasons for describing this zonation was to establish the close linkage between the rocks of the western metamorphic belt and the other parts of the complex. Brew and Ford (1978), as well as others previously, excluded those rocks from the rest of the complex, but their

origin and evolution are now known to be inextricably linked to those of the other parts.

The Coast Mountains Complex consists almost entirely of metamorphic and plutonic rocks, although it includes some small outliers of young volcanic rocks (fig. 2) and at least one area of very low grade metamorphic rocks within the central granitic zone (Brew and others, 1985). The extensive snow and ice that mantle it discourage attempts at areal measurements, and there are no rigorous calculations of the proportions of intrusive and metamorphic rocks available. Subjective estimates of the ratio of plutonic rocks to metamorphic rocks for six southeastern Alaska segments (fig. 2), in which orthogneisses are included with the plutonic rather than with metamorphic rocks, are as follows:

Segment labeled on fig. 2	Ratio of plutonic to metamorphic rocks
A (Alaska-British Columbia boundary south to Berners Bay).....	7:3
B (Berners Bay to Taku Inlet).....	6:4
C (Taku Inlet to Whiting River).....	5:5
D (Whiting River to Stikine River).....	8:2
E (Stikine River to Bradfield River).....	6:4
F (Bradfield River to Portland Canal).....	7:3
Average.....	7:3

As described below for the different metamorphic-plutonic zones, the ages of protoliths and intrusive rocks in the Coast Mountains Complex range from Late Proterozoic to Tertiary. However, most of the intrusive and metamorphic events occurred in Cretaceous and Tertiary time, and we therefore refer to the complex as Cretaceous and Tertiary in age.

The western metamorphic belt consists mostly of progressively metamorphosed (higher grade to the northeast) medium- to high-pressure and medium- to high-temperature pelitic and amphibolitic schists. The schists near Juneau have been described in detail by Himmelberg and others (1991, 1994a,b), and the lower grade rocks that are adjacent to the west were described by Himmelberg and others (1995). Overall, the protolith ages for the belt range from Permian and older to Late Cretaceous. Scattered Cretaceous and Tertiary epizonal to mesozonal granitic to ultramafic bodies occur within the western metamorphic belt (Brew and Morrell, 1980, 1983; Brew and Ford, 1984; Brew, 1988, 1994). As noted above, the western boundary of the belt and of the Coast Mountains Complex is either the eastern contact of Gravina overlap assemblage rocks or, where those rocks have been metamorphosed, the western limit of the metamorphic effects.

The central metamorphic zone consists mostly of syn-kinematic to postkinematic mesozonal to epizonal granitic bodies, mixed with intermediate- to high-temperature and

high-pressure schists, gneisses, and some migmatites (Brew and Ford, 1984, 1985; Brew and others, 1984; Karl and Brew, 1984). The ages of the protoliths of the rocks in the zone are uncertain, but most may be Late Proterozoic to Paleozoic (Gehrels and others, 1990; Brew and others, 1994) and belong to the Nisling terrane. The granitic rocks range in age from Paleozoic(?) to Tertiary, with the most conspicuous single map unit being the latest Cretaceous and Paleocene Great tonalite sill (Brew and Ford, 1981; Brew, 1988, 1994; Ingram and Hutton, 1994).

The central granitic zone consists mostly of crosscutting epizonal to mesozonal unfoliated granodioritic to granitic plutons of middle to late Tertiary age (Brew, 1988, 1994), with minor screens and pendants of metamorphic rocks like those in the central metamorphic zone and minor migmatites (Brew and Ford, 1984). The Sloko Volcanics (Souther, 1971) (fig. 2) are roughly coeval with the middle Tertiary plutonic rocks. Field mapping (Brew and others, 1984; Brew and Ford, 1985; Berg and others, 1988) and detailed studies (Drinkwater and others, 1992a,b) indicate that many (and perhaps most) of the individual granitic bodies in this zone are of batholithic dimensions (Bates and Jackson, 1987).

The eastern metamorphic zone consists mostly of low- to high-temperature, low-pressure hornfels with scattered epizonal granitic bodies (Brew and Ford, 1984). This zone is exposed mostly in British Columbia and includes some intermediate- to high-temperature and high-pressure schists, gneisses, and marbles that have the same protoliths as described for the central metamorphic zone and probably belong to the Nisling terrane. Other protoliths include Permian to Upper Triassic rocks like those extending to the east beyond the Coast Mountains Complex. As noted above, the eastern boundary of this zone and of the complex is either the eastern limit of the metamorphism associated with the Tertiary plutons or, where Nisling terrane pre-Tertiary metamorphic rocks adjoin the Tertiary intrusions, the eastern contact of those metamorphic rocks.

## PREVIOUS AND CURRENT INFORMAL NOMENCLATURE

Many different informal terms have been, and are currently being, used to describe the geologic entity that we here formally name the Coast Mountains Complex. In our opinion, some of the terms are inaccurate, some are misleading, and the multitude of terms itself has led to confusion. The informal terms used previously include Coast batholith, Coast batholithic complex, Coast crystalline belt, Coast Mountain belt, Coast Plutonic Complex, Coast plutonic-metamorphic complex, Coast Range batholith, Coast Range batholithic complex, and Coast Range plutonic complex. The shortcomings of most of these terms are discussed in the following section.



In their pioneering study based on fieldwork done about 70 years ago, Buddington and Chapin (1929) used the term "Coast Range batholith" in their text and on their maps to indicate the intrusive granitic rocks (Buddington, 1927), gneisses, and other rocks of what is now called the Great tonalite sill and on to the northeast of it as far as the international boundary. Buddington and Chapin (1929) used the terms "Wrangell-Revillagigedo belt of metamorphic rocks" or "Wrangell-Revillagigedo metamorphic belt" for the "composite belt of sedimentary and intrusive rocks" or "metamorphic complex belt" that bordered their Coast Range batholith on the southwest. Their Coast Range batholith corresponds to the central metamorphic and central granitic zones of the Coast Mountains Complex as defined here, and their Wrangell-Revillagigedo belt of metamorphic rocks corresponds more or less to the western metamorphic belt of the complex.

Douglas and others (1970) may have been the first to use the term "Coast plutonic complex," which they defined as a belt of crystalline rocks or a complex composed dominantly of foliated and unfoliated granitic rocks with a gneiss-migmatite core that contained some large areas of metamorphic rocks. They specifically noted (p. 427) that "An irregular belt of narrow, elongate, steep-walled roof pendants of metasedimentary rocks stretches southeastward from within the Wrangell-Revillagigedo gneiss belt on the west side of the complex in southeastern Alaska, to near the eastern side, near Bella Coola." The sketch map of Douglas and others (1970, p. 422) shows the western limit of their Coast plutonic complex about where Buddington and Chapin (1929) placed the eastern edge of their Wrangell-Revillagigedo belt, but it seems clear that Douglas and others (1970) and Roddick and Hutchison (1974) intended to include the rocks of the Wrangell-Revillagigedo belt in their Coast plutonic complex. This inclusion agrees with our definition of the Coast Mountains Complex. At about the same time, Forbes and Engels (1970) were using the term "Coast Range batholith and related rocks" for the complex.

Brew and Ford (1978) summarized how the U.S. Geological Survey had been handling the terminology for the preceding two decades or so in their footnote on page 1764: "The [informal] term Coast Range batholithic complex is used here to denote the granitic and gneissic rocks of the Coast Range as well as any enclosed schists, marbles, etc. This usage specifically excludes parts of the schist terrane of the Wrangell-Revillagigedo metamorphic belt (Buddington and Chapin, 1929) that adjoins the gneisses and granitic rocks on the southwest."

Brew and Ford (1984) were the first to use the informal term "Coast plutonic-metamorphic complex" for all of the rocks included in both Buddington and Chapin's (1929) Coast Range batholith and their Wrangell-Revillagigedo belt. Brew and others (1991, 1992) continued this informal use during the time that other workers (Barker and Arth, 1984; Arth and others, 1988; Gehrels and others, 1991) con-

tinued to refer to the entire complex informally as a batholith. More recently, Brew and Ford (1993, 1994) realized that the term "Coast," when used alone (as they had used it), was inappropriate, as it was not a valid geographic-physiographic name, and started using the informal term "Coast Mountains plutonic-metamorphic complex" instead.

## RATIONALE FOR SELECTION OF FORMAL NAME

As noted above, the Coast Mountains Complex includes metamorphic rocks and plutonic rocks of different ages and types. Many of the plutons are of batholithic dimensions, and most have been grouped into chronometric and modal-compositional belts (Brew and Morrell, 1980, 1983; Brew, 1988, 1994). After studying the rocks of the complex and dealing with the multitude of informal names for about 30 years, we have decided to here formally name this world-class geologic entity the Coast Mountains Complex. This note informs others of the problems involved and our reasoning in this action.

The North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983, p. 861, article 37) defines the lithodemic unit term "complex" as "An assemblage or mixture of rocks of *two or more genetic classes*, i.e., igneous, sedimentary, or metamorphic ... ." Prior to the 1983 version of the code, the term "complex" had been used for a variety of geologic entities that do not fit the 1983 definition; for example, Stillwater Complex, Shoo Fly Complex, Franciscan Complex, Valdez Complex. The Coast Mountains Complex being named in this note may be the first formal use of the term "complex" in the United States to follow the 1983 definition.

Two of the authors of this note made a serious effort (Brew and Ford, 1989, 1990) to amend the code to exclude the lithodemic term "complex" from formal stratigraphic nomenclature, but that proposed amendment was defeated by a formal vote of the North American Commission on Stratigraphic Nomenclature. Because the geologic entity we study is truly a complex as defined by the 1983 code, we are formally naming it herein as the Coast Mountains Complex.

Other large plutonic-metamorphic complexes in the world are called "batholiths"; for example, the Boulder batholith of Idaho, the Sierra Nevada batholith of California and Nevada, the Peninsular Ranges batholith of southern California and northern Baja California, and the Cordilleran batholith of western South America. The same terms have been applied consistently and without variation to these geologic entities for many years, even though each actually consists of more than one "batholith" as defined by Bates and Jackson (1987, p. 59). Many informal terms, including the word "batholith," have been applied to the rocks that we call the Coast Mountains Complex, but we wish to follow

the 1983 code, which clearly indicates that "complex" is the proper term for the entity we study.

Terms cited in the above section on "Previous and Current Informal Nomenclature" that incorporate the words "batholith," "Coast" [used alone], "Coast Range," and "belt" are inappropriate because these are not approved geographic-physiographic names. Orth (1967, p. 227) specifically pointed out that the name "Coast Range" is "frequently misapplied to the Coast Mountains." Informal terms including the word "belt" are also inappropriate because "belt" is not defined by the 1983 code.

Names using "complex" with the implication that it is solely a plutonic complex violate the definition in the 1983 code. Some of our colleagues consider the term "plutonic" to include medium- to high-grade metamorphic, as well as intrusive, rocks; Bates and Jackson (1987, p. 513) defined the term as "Pertaining to igneous rocks formed at great depth" or "Pertaining to rocks formed by any process at great depth." We use the term "plutonic" here in the sense of being associated with plutons, meaning discrete bodies of intrusive igneous rock.

## LOCATION AND DESCRIPTION OF TYPE AREA

On the basis of our studies along the length of the Coast Mountains Complex in southeastern Alaska, we here designate a broad (about 40 km wide) transect extending for about 80 km from Douglas Island on the south-southwest to the Alaska-British Columbia boundary on the north-northeast as the type area of the Coast Mountains Complex (fig. 2). This transect contains all of the various belts, zones, terranes, and other features that occur anywhere in the complex. It is the site of the greatest amount of detailed mapping in the complex, and the pertinent chronometric and compositional units present here have been described adequately and also have been correlated lithologically and temporally with their lateral equivalents on strike throughout the length of the complex in southeastern Alaska.

The transect is contained within the regional geologic map of Brew and Ford (1985), and a large part is also within the detailed geologic maps of Ford and Brew (1973, 1977b), Brew and Ford (1977), and D.A. Brew and A.B. Ford (unpub. data). From south-southwest to north-northeast, it is made up of these major units and structures, listed with their lithotectonic terrane assignments:

- (1) low-pressure, low-temperature, intermediate-composition metavolcanic and some metapelitic sedimentary rocks of the Douglas Island Volcanics of the Stephens Passage Group of the Gravina overlap assemblage (Lathram and others, 1965; Berg and others, 1972; Ford and Brew, 1988; Himmelberg and others, 1995);
- (2) the Coast Range megalineament as defined by Brew and Ford (1978), which is here the high-angle Gastineau Channel fault (Ford and Brew, 1973);
- (3) low- to medium-pressure, low- to medium-temperature, mafic- to intermediate-composition metavolcanic and some metapelitic and metacarbonate sedimentary rocks belonging to the Wrangellia terrane (Ford and Brew, 1993);
- (4) medium- to high-pressure, medium- to high-temperature pelitic schists together with minor amphibolitic schist and marble that are presently assigned to the Behm Canal structural zone (Brew and Ford, 1993, 1994) and have been described in detail by Himmelberg and others (1991, 1994a,b); the Late Cretaceous sills of the Mount Juneau pluton are within this unit (Ford and Brew, 1977a; Drinkwater and others, 1990);
- (5) the well-foliated and locally lineated, intermediate-composition granitic rocks of the Great tonalite sill composite batholith (Brew and Ford, 1981; Brew, 1988; Gehrels and others, 1991; Ingram and Hutton, 1994), which is dated at 69 to 56 Ma and which was emplaced at or close to the contact between the Behm Canal structural zone to the west and the metamorphic rocks of the Nisling terrane to the east;
- (6) layered biotite-hornblende gneiss, amphibole gneiss, quartz- and feldspar-rich schist, and multicomponent migmatite intruded by a series of broad hornblende-biotite granodiorite sills (Brew and Ford, 1985; Brew, 1988, 1994; Drinkwater and others, 1989, 1990), which are dated at 60 to 55 Ma and which are related to the Great tonalite sill;
- (7) generally unfoliated, massive, and homogeneous sphene-biotite-hornblende granodiorite (50 Ma) of the Turner Lake batholith (Brew and Ford, 1985; Brew, 1988, 1994; Drinkwater and others, 1992a,b, 1994) with its sporadic screens of metamorphic rocks and local migmatite zones; and
- (8) locally hornfelsed, intermediate-composition metavolcanic rocks of the Stikine terrane and pelitic and semi-pelitic schists of the Nisling terrane at and near the international boundary (Brew and Ford, 1985; Brew and others, 1994).

All these units fit into the metamorphic-plutonic zonation scheme given previously for the rocks of the Coast Mountains Complex as a whole (Brew and Ford, 1984). The western metamorphic belt consists of above units 1–4, the central metamorphic zone consists of units 5–6, the central granitic zone is unit 7, and the eastern metamorphic zone is unit 8.

Magmatic and metamorphic belt classifications for these rocks (Brew and Morrell, 1983; Brew, 1988, 1994; Brew and others, 1989, 1992) aggregate some of the units mentioned above into larger entities and partition some units into different parts. The point is that the rocks in the type area of the Coast Mountains Complex and in the other

parts of the complex can be described according to a variety of schemes that correspond to their varied attributes, but definition on the basis of other attributes would not affect the formal naming of the complex.

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