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A REVISED STRATIGRAPHY OF THE MARTINSBURG FORMATION OF EASTERN PENNSYLVANIA AND PALEOGEOGRAPHIC CONSEQUENCES

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ABSTRACT. Recent investigation of the Martinsburg Formation has led to a reevaluation of Taconic events as recorded in eastern Pennsylvania. Faunal evidence from over 100 new localities resolves stratigraphic relationships between the allochthonous rocks of the Hamburg klippe, the Shochary Ridge sequence (Wright and Stephens, 1978), and the autochthonous Martinsburg Formation to the east of Shochary Ridge. Faunal and lithologic evidence demonstrates that the lower shaley part of the Shochary Ridge sequence correlates with the Bushkill Member of the Martinsburg Formation, and that the upper sandy part is correlative with the Ramseyburg Member. Two stratigraphic positions are possible for the Pen Argyl Member: (1) it is younger than both the Bushkill and Ramseyburg Members, that is, the Martinsburg contains three members in eastern Pennsylvania (Drake and Epstein, 1967), or (2) it is older than the Ramseyburg Member and is correlative with the upper part of the Bushkill Member, that is, the Martinsburg contains only two members (Wright, Wright, and Stephens, 1978). The evidence presented favors the second interpretation. Faunal ages and environmental analysis of the sedimentary rocks place additional constraints on interpreted historical events, including the arrival of the allochthonous Hamburg klippe. The following sequence of Taconic events satisfy these new data: (1) deposition of Middle Ordovician carbonates on the craton and deposition of Hamburg klippe rocks in deeper water to the southeast up to and during *Nemagraptus gracilis* Zone time; (2) depression of the Martinsburg basin by rapid downwarping of the carbonate platform between *Nemagraptus gracilis* and *Diplograptus multidens* Zone time; (3) emplacement of the allochthonous rocks during early *Diplograptus multidens* Zone time; (4) basin filling by northward flowing currents from *Diplograptus multidens* through *Climacograptus spiniferus* Zone time; and (5) folding, uplift, and erosion, followed by latest Ordovician or early Silurian transgression.

INTRODUCTION

The reinterpretation of the Middle and Late Ordovician Taconic orogeny in plate tectonic terms has progressed rapidly during the past decade (for example, Bird and Dewey, 1970; Williams, 1977). Much work, primarily focused on the northern Appalachians, has produced a rich and detailed set of paleogeographic reconstructions for this time interval. This has been accomplished despite considerable complexity and later tectonic overprinting. Effects of the Taconic orogeny also occur to the south; large allochthons are now recognized in the Martinsburg Formation as far south as eastern Pennsylvania (Root and MacLachlan, 1978). Yet the stratigraphic and structural details of these rocks needed for accurate reconstructions are less well known.

Shales and sandstones of the Martinsburg Formation crop out across the southeastern part of Pennsylvania (fig. 1). They occupy a stratigraphic position above the Cambrian-Ordovician carbonate sequence and below coarse clastic rocks of late Ordovician and early Silurian age. In the southern part of the state, the Bald Eagle Conglomerate (gray, sandy, marine conglomerate) and the Juniata Formation (red fluvial sandstone

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and red alluvial-plain shale) record a continuous shallowing of the sea and subsequent emergence after Martinsburg deposition. These formations are absent in eastern Pennsylvania, however, where the Silurian Shawangunk Conglomerate rests unconformably on the Martinsburg Formation.

The Martinsburg outcrop belt in Pennsylvania includes the southernmost "Taconic klippe-type" allochthons in the Appalachians. These allochthons, coupled with the eastward increase in the stratigraphic gap recorded in the Ordovician–Silurian unconformity, suggest that the Martinsburg here contains the transition between a northern region characterized by strong tectonism, large allochthons, and strongly developed unconformities and a southern region of relatively milder events.

In the southwestern part of the outcrop belt within Pennsylvania, the reported stratigraphic relationships are similar to those farther south in Virginia, West Virginia, and Maryland — a lower gradational contact between the carbonates and the shales and an upper gradational contact with the Bald Eagle Conglomerate. The Martinsburg contains a shale that coarsens upward and grades into the overlying Bald Eagle Conglomerate without abrupt change in grain size, lithology, or age. Workers in the southern part of Pennsylvania have mapped a two-membered Martinsburg — a lower shale and an upper sandy member (Stose, 1946).

In the eastern part of the state, the internal stratigraphy has historically been interpreted in two fundamentally different ways. One group (Stose, 1930, 1946; Willard and Cleaves, 1939; Willard, 1943; Loring, ms) concluded that the Martinsburg contains two members — a lower shale (or slate) member and an upper sandstone member, similar to the sequence farther south. The other group (Behre, 1933; Drake and Epstein, 1967) argues that a younger slate is present above the lower shale and sandstone members. Mapping near the Delaware River by the United States Geological Survey (Davis, Drake, and Epstein, 1967; Drake, 1967a,b; Drake, Epstein, and Aaron, 1969) followed the three-membered model, and the three units (Bushkill, Ramseyburg, and Pen Argyl) have been projected along strike into New York by some workers (Berry, 1970; Fisher, 1977). Yet a two-membered sequence is also a viable interpretation. One of the reasons for this ambiguity is that the rocks do not readily

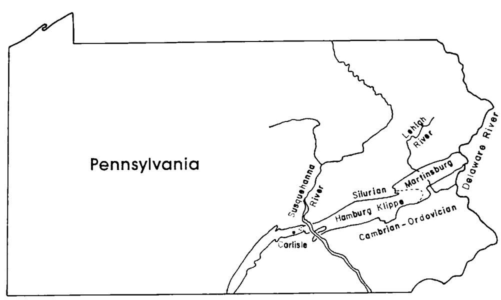

Fig. 1. Outcrop area of the Martinsburg Formation in Pennsylvania.

produce fossils, and the stratigraphy in large part has been based upon lithologic and structural evidence. Unfortunately, the poor exposure, complex structure, and probable facies changes within units make such evidence ambiguous without adequate faunal control. Another reason for this problem is the presence of the Hamburg klippe between Carlisle and the Lehigh River. Although various interpretations for the "klippe" have been proposed (Platt and others, 1972; Stose, 1946, 1950; Alterman, ms; Root and MacLachlan, 1978), the presence of these allochthonous rocks, whatever their configuration, prevents direct correlation of the two areas of autochthonous rocks across the state.

The purposes of this paper are to present new evidence that redefines the stratigraphy of the Martinsburg Formation of eastern Pennsylvania, to separate allochthonous from autochthonous rocks in this area, to resolve the position of Shochary Ridge, and to use this and other new evidence to reinterpret the paleogeographic history of this area.

STRATIGRAPHY

Our stratigraphic interpretation for the Martinsburg Formation in eastern Pennsylvania is based on detailed mapping of the area shown in figure 2. Of the 350 outcrops investigated, 120 are new graptolite localities. In addition, a shelly fauna, collected from 50 localities, is typically present only in the coarse-grained, ridge-forming sandstone. Age assignments of the new graptolite collections were made by Dr. John Riva of Laval University and follow his graptolite zonation developed for Ordovician rocks in the northern Appalachians (Riva, 1974).

Ages of the Ordovician clastic rocks within this area range from the *Nemagraptus gracilis* Zone to the *Climacograptus spiniferus* Zone. The distribution of these zones is shown on figure 2 and the species are listed in table 1. The shelly fauna of late Barneveldian age previously reported from Shochary Ridge (Wright and Stephens, 1978) is also present in the sandstone ridge 5 km to the north. This ridge is informally referred to as the "Ramseyburg Ridge" in this paper, because it is underlain by the Ramseyburg Member of Drake and Epstein (1967).

The oldest fossils found in the area, graptolites of the *Nemagraptus gracilis* Zone, occur only within the Hamburg klippe (fig. 2) and come from a variety of klippe lithologies including dark olive shales, metabentonites, and graywackes. No fossils younger than the *Nemagraptus gracilis* Zone have been found within the limits of the klippe as shown on figure 2, nor have any isolated blocks of klippe lithologies and/or *Nemagraptus gracilis* Zone fossils been found beyond this boundary. Thus the Hamburg klippe in this area is a single coherent block, and no melange or olistostromes of klippe rocks have been recognized within the autochthonous terrain.

Sedimentological and structural evidence demonstrate that the Hamburg klippe underlies the Shochary Ridge sequence and was emplaced during pre-*Corynoides americanus* time. This evidence is best seen along the Appalachian Trail, 2 km southwest of Eckville, where vertical *Nema-*

graptus gracilis-bearing allochthonous shales are overlain by vertically-dipping autochthonous *Diplograptus multidens*-age beds. The contact represents a minor disconformity, as the lower half of the *Diplograptus multidens* Zone is apparently missing. These beds strike east and face north, and they show that the Hamburg klippe underlies the Shochary Ridge sequence. The Shawangunk Conglomerate lies in angular unconformity over both the klippe and autochthonous Martinsburg and is unbroken by faults in the immediate area except for a single reverse fault with minor displacement (50 m or less). Evidence for faults within the shales is also absent at or near the klippe-autochthon contact. We conclude that the allochthon arrived during the early part of *Diplograptus multidens* Zone time, probably by gravity sliding, was covered by sediments of the Shochary Ridge sequence, and has not moved relative to these overlying rocks during later deformations.

These new faunal (table 1) and lithologic data also resolve the relationship between the Shochary Ridge sequence (Wright and Stephens, 1978) and the autochthonous Martinsburg to the east. Shochary Ridge is a doubly-plunging syncline that is cored by rocks of *Climacograptus*

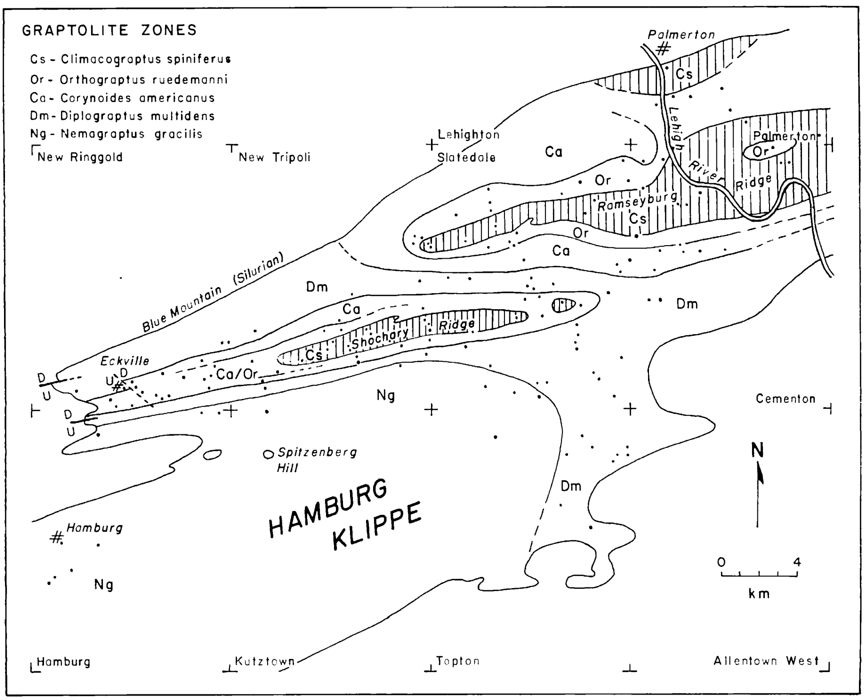

Fig. 2. Geology of the Martinsburg Formation between Hamburg, Penn. and the Lehigh River. Vertical lines denote sandstone, unlined areas denote shale. Dots indicate fossil localities: Ng = *Nemagraptus gracilis* Zone, Dm = *Diplograptus multidens* Zone, Ca = *Corynoides americanus* Zone, Or = *Orthograptus ruedemanni* Zone, Cs = *Climacograptus spiniferus* Zone.

Table 1

Faunal list of the area shown in figure 2

Fossil	Hamburg klippe	South of Ramseyburg Ridge (shale)	North of Ramseyburg Ridge (shale)	East and southeast of Shochary Ridge (shale)	North and south flanks of Shochary Ridge (shale)	Shochary Ridge (sandstone)	Ramseyburg Ridge (sandstone)
Autochthonous rocks							
Shelly Fauna							
Cryptolithus cf. *lorettensis*						4	
Hebertella sinuata						5	
Sowerbyella sp.							3
Sowerbyella rugosa					2	11	
Sowerbyella sericea					16	10	
Resserella sp.							2
Resserella multisecta					1	10	
Resserella rogata					10		
Plectorthis plicatella		1	1		6	11	
Rafinesquina trentonensis					6	8	2?
Plaesiomys ulrichi					3	10	
pentagonal pelmatozoan columnals					5+	10+	3
circular pelmatozoan columnals					5+	10+	5
Graptolites							
Climacograptus brevis		1			1		
Climacograptus praetypicalis			1			2	2
Climacograptus putilis		4	4		1		
Climacograptus spiniferus			1				
Corynoides calicularis		3	1		1		
Corynoides americanus		1	1		2		
Dicranograptus parvangulus			1				
Diplograptus multidens		1		5	3		
Glyptograptus sp.		4	3	4	2		1
Glyptograptus euglyphus		1			2		
Neurograptus sp.		1		1			
Neurograptus margaritatus		1					
Orthograptus amplexicaulis		4	5	5	4		3
O. amplexicaulis/D. multidens		2	1	1	5		
Orthograptus calcaratus				1			
O. calcaratus basilicus		1	1				
Orthograptus quadrimucronatus			3			3	1
Orthograptus ruedemanni			6		1		
Allochthonous rocks							
Shelly Fauna							
stelleroid	1						
radiolaria	4						
Graptolites							
Climacograptus brevis	2						
Climacograptus bicornis	3						
Dicellograptus cf. *intortus*	3						
Dicellograptus sextans	1						
Dicranograptus contortus	1						
Didymograptus serratulus	1						
Glyptograptus euglyphus	2						
Leptograptus trentonensis	2						
Pseudoclimacograptus cf. *modestus*	3						
Pseudoclimacograptus scharenbergi	6						

The number of localities where the form was found is tabulated for each subarea discussed in the text.

spiniferus Zone age. Older faunas of *Diplograptus multidens* and *Corynoides americanus* Zone age surround this core. *Diplograptus multidens*-bearing shales of both limbs of the Shochary Ridge syncline can be traced from outcrop to outcrop eastward into the Bushkill Member of Drake and Epstein (1967) with no change in either lithology or faunal age. Thus we conclude that the Shochary Ridge sequence is part of the autochthonous Martinsburg Formation and that the lower part of Shochary Ridge is continuous with the Bushkill Member of Drake and Epstein (1967). In addition, the presence of *Diplograptus multidens* Zone fossils in the Bushkill Member east of the Hamburg klippe immediately above the Jackson-Martinsburg gradational contact confirms that the *Nemagraptus gracilis* and older Hamburg klippe rocks are allochthonous as stated by many previous workers.

The sandstones of the Ramseyburg Ridge contain graptolites of the *Climacograptus spiniferus* Zone and shelly debris of late Barnveldian age similar to those of Shochary Ridge. The fossils of the Ramseyburg Ridge are, however, sparse and deformed. Sedimentary features observed in the sandstones of the Ramseyburg Ridge are likewise similar to those in the sandstones of Shochary Ridge. Graded beds, cross-bedding, convolute laminations, load casts, flame structures, and other features indicative of deposition by turbidity currents are present in the sandstones of both areas. Current directions obtained from cross-beds indicate that the transport direction in turbidites of the Ramseyburg Ridge was to the north, as it was at Shochary Ridge. Major differences between the sandstones are: the shelly debris is more abundant in the Shochary Ridge rocks; pelmatozoan columnals and, to a lesser extent, brachiopods show less disarticulation in the Shochary Ridge rocks; and the relative thickness of the shale interbeds is less in the Shochary Ridge rocks. Only the uppermost beds of the Shochary Ridge sequence indicate shallow water deposition (Wright and Stephens, 1978). The Ramseyburg Ridge sandstones are of slightly deeper water origin either because the higher units have been lost to erosion or because the water never shallowed here. Burrowing is absent in turbidites of both areas. Evidence of soft-sediment deformation (slumps, oversteepened cross-beds, and soft-sediment faults) indicate a northward-dipping paleoslope for both areas. Although the pelmatozoan debris found within the sandstones of the Ramseyburg Ridge is much more disarticulated than at Shochary Ridge, the same morphological forms in the same proportions are found in both areas (McStraw, ms). Sandstones in both sequences have poorly rounded and poorly sorted clasts of polycrystalline quartz, detrital mica, and feldspars within an argillaceous calcareous matrix. Petrologic data (fig. 3) indicate that the clasts of the Shochary and the Ramseyburg sandstones are similar, both in types and percentages of clasts.

The distribution of faunal ages of the autochthonous rocks shown on figure 2 is consistent with a series of east-west plunging folds. The valley to the north of Shochary Ridge is interpreted as an anticline cored with *Diplograptus multidens-Orthograptus ruedemanni* Zone shales. Fossils of the *Orthograptus ruedemanni* and basal *Climacograptus spiniferus* Zones are found in the valley north of the Ramseyburg Ridge. An increase in structural complexity to the northeast, including pronounced minor folding and stronger cleavage development, produces ambiguous stratigraphic relationships if based solely on lithology, attitude of bedding, and tectonic fabric. At the western end of the Ramseyburg Ridge, however, several lines of evidence strongly suggest that the rocks plunge eastward along a synclinal axis. Sandstone is not present in either outcrop or float on the outside of the fold nose, and the outcrop width of the sandstone increases eastward (fig. 2). Although slightly different in faunal composition (table 1), the shales immediately north and south of the Ramseyburg Ridge contain fossils assigned to the *Orthograptus ruedemanni* Zone. Definitive evidence is lacking for a fault of large displacement that would truncate the sandstone and juxtapose a younger shale to the north with an older shale to the south. Detailed structural mapping by Sarewitz (ms) along the northern side of the ridge in the Slatedale 7-½ min quadrangle indicates that the shale dips under the sandstone except at one locality where sandstone is thrust over the shale and stratigraphic relationships are reversed. Minor high-angle faults do occur within the Martinsburg, but displacements seem to be minimal— a few hundreds of meters at most. The clearest faults within the area are two high-angle reverse faults that cut the Silurian Shawangunk Conglomerate (fig. 2) and trend eastward into the shale. The maximum displacements are 300 m on the northern fault and 50 m on the southern one (Stephens, ms). Identifiable faults within the shale are rare and have only minor displacements. Thus, since major faunal and lithologic discontinuities are absent, we infer that no significant east-west trending faults are present parallel to the Ramseyburg Ridge.

The Pen Argyl Member of Drake and Epstein (1967) occupies the valley north of the Ramseyburg Ridge. Fossils of the *Orthograptus*

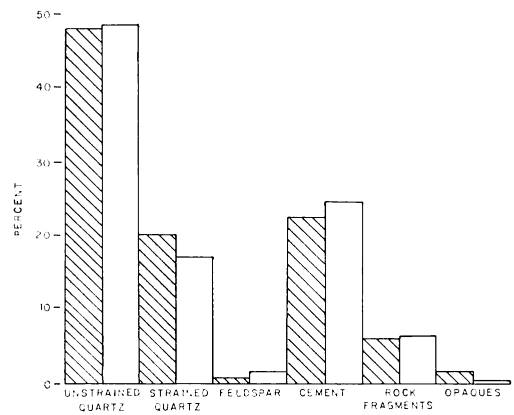

Fig. 3. Petrographic comparison of sandstones from Shochary Ridge (open bars) with sandstones collected 5 km south of Palmerton (lined bars), within the Ramseyburg Member of Drake and Epstein (1967).

ruedemanni Zone have been found near the Ramseyburg Member on the south side of the valley, while fossils of the *Climacograptus spiniferus* Zone have been found near the contact with the Silurian Shawangunk Conglomerate. The *Climacograptus spiniferus*-bearing rocks of these localities contain thicker and coarser turbidite layers than the *Orthograptus ruedemanni* Zone shales. Thus the fossil ages and lithologic patterns argue that the Pen Argyl Member of the Martinsburg is equivalent to the upper portion of the Bushkill Member, a possibility consistent with the east-plunging synclinal interpretation for the Ramseyburg Ridge.

It has been argued repeatedly that the Pen Argyl Member overlies the Ramseyburg Member (Drake and Epstein, 1967; Lash, ms; Lyttle and Drake, 1979). For this interpretation to be valid, the fossils from the Ramseyburg Ridge must be intermediate in age between the shales of the upper Bushkill and the lower Pen Argyl. This would require adjustment in the age range of several forms of graptolites including *Orthograptus ruedemanni*, *Climacograptus putilis,* and *Orthograptus quadrimucronatus* and also would require the presence of a fault to cut out the Ramseyburg Member at the western end of the Ramseyburg Ridge. Alternatively, we believe that the simplest explanation at present is that the Pen Argyl underlies and is older than the Ramseyburg Member.

On the basis of the information presented, we conclude that only the Hamburg klippe is allochthonous, and that the sandstones and shales of Shochary Ridge are directly correlative with the sandstones and shales of the Martinsburg Formation. They contain similar fossils and represent slightly different facies of a single depositional regime — a northward prograding submarine fan/deltaic complex. The lower part of the Shochary Ridge sequence is identical to the Bushkill Member of the Martinsburg Formation of Drake and Epstein (1967), and the upper sandy portion of Shochary Ridge is equivalent to the Ramseyburg Member of Drake and Epstein (1967). The age relations as presently understood indicate that the Pen Argyl Member is in reality the upper part of the Bushkill Member repeated across a syncline as Stose proposed in 1946, although slight faunal differences exist between the shales north of the Ramseyburg Ridge (Pen Argyl Member of Drake and Epstein, 1967) and the Bushkill Member south of the ridge (table 1).

PALEOGEOGRAPHIC RECONSTRUCTIONS

These revised stratigraphic relationships provide a detailed framework for accurate paleogeographic reconstructions of the Middle to Late Ordovician of eastern Pennsylvania. The graptolite succession found in this area can be used to date events unusually precisely. The following sequence of events is consistent with all known paleontologic and lithologic aspects of these rocks.

The platform carbonates of the Great Valley accumulated in a shallow epeiric sea from Cambrian to Middle Ordovician time. The shales, cherts, carbonates, and other lithologies of the Hamburg klippe were apparently deposited in deeper water southeast of the carbonate shelf edge. The presence in the Hamburg klippe carbonates of Lower Ordovician conodonts of a faunal province different from those of the carbonate platform of the same age (Bergstrom, Epstein, and Epstein, 1972) implies a considerably different depositional environment. The presence of pelagic forms, radiolaria (in cherts), and graptolites, as well as the absence of shallow benthonic forms, argues for considerable water depth during deposition of the Hamburg klippe rocks.

Next, the Martinsburg basin in Pennsylvania was formed by rapid depression of the carbonate shelf during parts of the *Nemagraptus gracilis* and mid-*Diplograptus multidens* Zone, because the deep-water Hamburg klippe allochthon contains sediment of *Nemagraptus gracilis* age, and the youngest autochthonous limestone beneath the klippe is also of approximately this age. The basin must have been formed before allochthon emplacement but after deposition of the last platform carbonate layers. Furthermore, on the southern edge of the Hamburg klippe, where the contact between allochthon and platform carbonates can be mapped, *Diplograptus multidens*-bearing shale is absent, indicating that emplacement of the klippe allochthon was nearly penecontemporaneous with basin formation.

The Martinsburg basin was then filled by a northward-prograding submarine fan/deltaic complex which buried the allochthon and accumulated shale conformably over the carbonates elsewhere. This began in *Diplograptus multidens* Zone time in eastern Pennsylvania and continued at least through *Climacograptus spiniferus* Zone time. A continuous sequence of this age span is present at Shochary Ridge (Wright and Stephens, 1978). Farther south and in central Pennsylvania (Thompson, 1970; Zerrahn, 1978), overlying shore and fluvial deposits (Bald Eagle and Juniata Formations) attest to even later Ordovician sedimentation.

The pronounced angular unconformity at the base of the Shawangunk, shown on figure 2, requires folding after *Climacograptus spiniferus* Zone time and before the Shawangunk was deposited. Similarly, because the Shawangunk Conglomerate is in contact with all stratigraphic units of the Martinsburg Formation and in places with the Hamburg klippe rocks, uplift and considerable erosion are required to bring these rocks to the surface before the Shawangunk transgression. Finally, burial and refolding (nearly coaxial with the earlier deformation) during later Paleozoic time are required, because the Silurian clastics are the base for a thick sequence that is itself folded.

The paleogeography outlined here is neither complete nor the only one possible. The internal stratigraphy of the Hamburg klippe, incompletely understood at present, is of particular importance in providing additional refinements.

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