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PLEISTOCENE ICE FLOW DIRECTION INDICATED BY *TERATASPIS GRANDIS* (TRILOBITE)-BEARING ERRATICS FROM THE RICKARD HILL FACIES OF THE SAUGERTIES MEMBER OF THE SCHOHARIE FORMATION (LOWER DEVONIAN)

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ABSTRACT: Glacial erratics belonging to the Rickard Hill Facies of the Saugerties Member of the Schoharie Formation occur scattered throughout the Piedmont of New Jersey and Lower Hudson Valley of New York. Analysis of these erratics identified four specimens belonging to the historically significant trilobite, *Terataspis grandis* (Hall, 1861). Reconstructions of Wisconsinan glacial ice advance and retreat identify the likely source of the Rickard Hill erratics containing the *T. grandis* specimens to be a narrow outcrop belt within the Schoharie Valley and Helderberg Mountains. This outcrop belt is a maximum distance of 200 kilometers from where the southern-most *T. grandis* specimen was recovered. Palynology, lake varves, cosmogenic-nuclide exposure studies and recessional moraines indicate that the final deposition of the Rickard Hill erratics occurred after 18,500 bp.

INTRODUCTION

Over a century ago, Whitefield and Parsons (1897) identified the occurrence of the iconic and spectacularly-ornamented trilobite *Terataspis grandis* (Hall, 1861) from the Piedmont of New Jersey. The *T. grandis* specimens described by Whitefield and Parsons (1897) included hypostomes and other disarticulated skeletal elements discovered in glacial erratics of the "Schoharie Grit" approximately one mile north of the city of Paterson. Since this time, the occurrence of *T. grandis* in the Piedmont has remained unreported although the region was extensively glaciated during the Pleistocene and erratics are common.

Recently, an assemblage of glacial erratics belonging to the Schoharie Formation was discovered scattered across High Mountain in Wayne, Passaic County, New Jersey (Becker and Bartholomew, 2013). The distinctive lithology and associated fossils allowed the source of these erratics to be identified as the Rickard Hill Facies of the Saugerties Member of the Schoharie Formation occurring in a narrow outcrop belt extending just west of Albany, New York and within the Schoharie Valley Region (Figure 1). Although *Paciphacops bombifrons* (Hall and Clarke, 1888), *Trypaulites calypso* (Hall, 1861) and an indeterminate species of phacopid were described, *T. grandis* was not identified in these Rickard Hill erratics (Becker and Bartholomew, 2013).

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This report describes the occurrence of four specimens of *Terataspis grandis* (Hall, 1861) collected since completion of the original account by Becker and Bartholomew (2013). The specimens were also recovered from glacial erratics belonging to the Rickard Hill Facies and include sections of cephalon, glabella, and pygidia that contain diagnostic spinose and tubercled ornamentation (Figure 2). The occurrence of *T. grandis* fossils supports earlier surficial geologic maps by Stone et al. (2002) and Stanford (2003) that determined the direction of Laurentide Ice Sheet advance and retreat. Additionally, erratics with distinct lithologies and fossil assemblages such as the Rickard Hill Facies provide important evidence for reconstructing glacial plucking, transport and the occurrence of historically studied fossils relocated from original source regions.

RECOVERY LOCATIONS & FIELD METHODS

The Rickard Hill Facies glacial erratics containing the *T. grandis* described in this report were collected from the following locations: 1) a ground moraine lying above the Preakness Formation (Lower Jurassic) on High Mountain, in Wayne, Passaic County, New Jersey; 2) a ground moraine scattered across the Feltville Formation (Lower Jurassic) in Franklin Lakes, Bergen County, New Jersey; and 3) a ground moraine scattered across the Normanskill Shale (Middle Ordovician) New Windsor, Orange County, New York (Figure 1, localities 4, 7, and 8). The two New Jersey specimens were deposited within the Piedmont physiographic province and along the eastern slopes of the second Watchung Mountain. Bedrock of the second Watchung Mountain and Preakness Formation is comprised of basalt and gabbroid that forms the topographically highest area in the region. To the east, the Feltville Formation forms a valley between the first and second Watchung

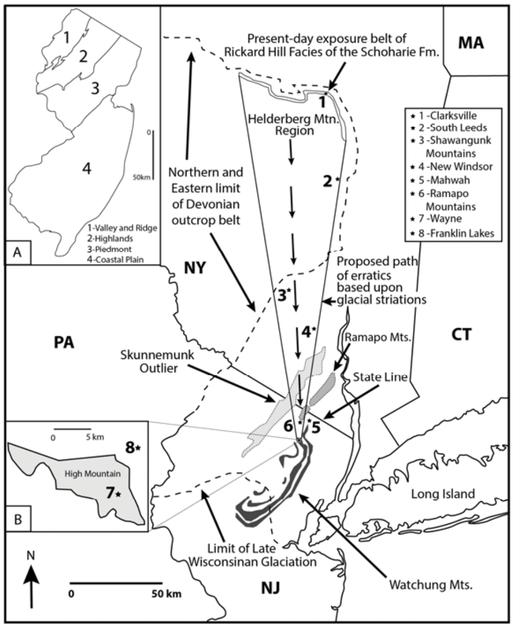

Figure 1: Locality map within the Piedmont and Lower Hudson Valley with interpreted path of glacial transport from the Rickard Hill Facies of the Schoharie Formation, Helderberg Mountains Region, New York. (1) Rickard Hill Facies exposure belt; (2–8) fossiliferous erratics described in Becker and Bartholomew (2013) and this report. *Terataspis grandis* (Hall, 1861) has been identified in Rickard Hill erratics from (*4) New Windsor, (*7) Wayne, and (*8) Franklin Lakes. Inset maps: (A) physiographic provinces of New Jersey; and, (B) High Mountain region. **Note**: limit of Wisconsin Glaciation, Skunnemunk Mountains, Ramapo Mountains.

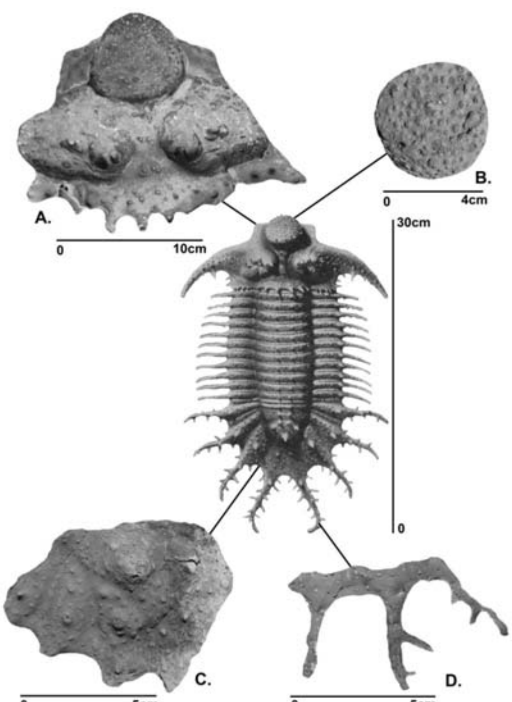

Figure 2: *Terataspis grandis* (Hall, 1861). (A) Cephalon (mold): Wayne, Passaic County, New Jersey; (B) Glabella (cast): Franklin Lakes, Bergen County, New Jersey; (C–D) Pygidia skeletal elements and spines (casts): New Windsor, Orange County, New York. Elements from glacial erratics of the Rickard Hill Facies of the Schoharie Formation discussed in text. Reconstruction of *T. grandis* modified from Reimann (1945).

Mountains and consists of hematitic-cemented sandstone with interbedded siltstone and calcareous mudstone (Volkert, 2006). The two New York specimens were deposited within the Lower Hudson Valley along a gradual slope of the Normanskill Shale. Bedrock of the Normanskill Shale consists of interbedded shale, argillite and siltstone that comprise an area of low topographic relief between the Shawangunk Mountains to the northwest and Schunemunck Mountain to the southeast (Fisher et al., 1970). Additional details regarding the bedrock and surficial geology in the study areas are available in Becker and Bartholomew (2013).

Rickard Hill erratics containing the *T. grandis* specimens were collected by hiking a series of transects through the study areas identified in Figure 1 with specific focus on larger boulders concentrated in ground moraines. The *T. grandis* cephalon, glabella, and pygidia were discovered while splitting larger Rickard Hill erratics along fossiliferous bedding planes and exposing less-weathered, interior surfaces. A repository for the *T. grandis* specimens has been established in the paleontological collections of the Department of Geology at SUNY New Paltz.

SYSTEMATIC PALEONTOLOGY

Phylum: ARTHROPODA von Siebol, 1848
Class: TRILOBITA Walch, 1771
Order: LICHIDA Moore, 1959
Family: LICHIDAE Hawle et Corda, 1847
Genus: TERATASPIS Hall, 1863
Terataspis grandis (Hall, 1861)
-*Lichas grandis* Hall 1861, p. 82.
-*Lichas grandis* Hall 1862, p. 110.
-*Lichas superbus* Billings, 1875, pp. 239–240.
-*Acidaspis* (*Terataspis*) *grandis* Hall 1876, Pls. XVII, XVIII.
Terataspis grandis Hall and Clark, 1888, pp. 73–77, Pl. XVII, Figs. 1–6; Pl. XVIII, Figs. 1–2; Pl. XIX, Figs. 1–7.
Terataspis sp. Reimann, 1941, pp. 39–46, Figs. 1–2, and 1945, pp. 70–71, Figs. 1–2.

Materials Examined: Partial cephalon, glabella, partial pygidium, three pygidial spines

Descriptions: Mold of an incomplete cephalon preserving cranidium, glabella, fixigena, librigena, eyes, partial left genial spine, and spinose posterior border. Cast of a near circular glabella with diagnostic spinose and tubercled ornamentation. Cast of an incomeplete pygidium preserving a partial section of the left pleural lobe, terminal ridge of the axial lobe, and basal-most sections of four pygidial spines. Three incomplete pygidial spines with diagnostic spinose and tubercled ornamentation.

Discussion: The earliest description and classification of *Lichas* (*Terataspis*) *grandis* are attributed to James Hall in (1861) and examples are featured in numerous publications of New York State paleontology across the middle and late eighteenth century (see Whiteley et al., 2002). An interesting account of this trilobite is included in the work of Clarke (1890, p. 90), who stated: "With his extravagant armor of defense and aggression, *Terataspis grandis* must have been easy lord of his invertebrate domain and no very palatable morsel for the heavily plated fishes of his day." Based on multiple incomplete specimens, Reimann (1941; 1945) reconstructed an entire *T. grandis*, which at total lengths ranging up to 600 mm, was considered the largest trilobite that ever lived (see Rabano, 1989; Rudkin et al., 2003). According to Whiteley et al. (2002), *T. grandis* remains among the most ornamented and spinose trilobites that existed and specimens are considered uncommon.

Currently, *T. grandis* has a limited geographic range and is restricted to central and western New York, eastern Ontario, and the northern Michigan Basin (Whiteley et al., 2002). *T. grandis* is known to occur only in the early and middle Devonian from these locations and within the Schoharie, Onondaga, and Bois Blanc Formations (Whiteley et al., 2002). In particular to this study, the Rickard Hill Facies of the Saugerties Member of the Schoharie Formation (New York State: Early Devonian, Emsian-Tristates Group) is well-known for producing exceptional casts and molds of brachiopods, corals, cephalopods, and trilobites including *T. grandis* (Grabau, 1906; Goldring, 1943; Whiteley et al., 2002). The *T. grandis* pygidium and pygidial spines discussed in this report were found adjacent to one another and on the same erratic, although they were not articulated. Based on this occurrence, we interpret the pygidium and pygidial spines as belonging to the same individual. This viewpoint is further supported by the fact that the Rickard Hill Facies represents a series of storm beds where fossils are typically disarticulated and hydrodynamically sorted (e.g., Speyer and Brett, 1986; Ver Straeten and Brett, 2006).

DISCUSSION

Reconstructing the Transport of *Terataspis grandis*

In the study area, advance of the Laurentide Ice Sheet formed the Hudson-Champlain Lobe that thickened within the Hudson-Mohawk Lowlands (Connally and Sirkin, 1986; Cadwell and Muller, 2004). The Hudson-Champlain Lobe was topographically constrained between the Taconic Mountains, Hudson Highlands, and Manhattan Prong to the east, and Catskill Mountains to the west (Sirkin and Bokuniewicz, 2006). As the advancing ice reached New Jersey, a similar north-to-south travel path existed and the thickest ice that formed the Hackensack Lobe was confined between topographically higher elevations of the Highlands to the west and the Watchung Mountains within the Piedmont to the east (Stone et al., 2002; Harper, 2013). The terminal moraine of the Hackensack Lobe extended eastward through central New Jersey, Staten Island, and Long Island having reached its southerly boundary by approximately 24,000 bp (Sirkin and Bokuniewicz, 2006; Harper, 2013; Rayburn et al., 2015).

We interpret the Rickard Hill erratics and *T. grandis* trilobites to have been plucked and transported along a similar path due south from the Clarksville exposure belt, and based on recovery locations, in the topographically lower areas covered by the western margin of the Hudson-Champlain and Hackensack Lobes. This interpretation is reinforced by: 1) numerous moraines and glacially striated outcrops between Clarksville, New York and Wayne, New Jersey (Stone et al., 2002; Stanford, 2003; Sirkin and Bokuniewicz, 2006; Harper, 2013); and, 2) the recovery of Rickard Hill erratics in seven localities as reported in Becker and Bartholomew (2013) and this study (Fig. 1). These seven localities are south of the exposure belt and indicate a maximum distance of transport for the erratics containing *T. grandis* trilobites between Clarksville, New York and Wayne, New Jersey of 200 kilometers.

While the field occurrence is not in question, the Rickard Hill erratics containing the *T. grandis* trilobites may have been moved multiple times during seasonal advance and retreat of the Laurentide Ice Sheet and associated lobes. Moreover, enormous amounts of meltwater during the final retreat of this ice sheet would have been capable of additional erosion, transportation, and deposition of the Rickard Hill erratics (See: Uchupi et al., 2001; Donnelly et al., 2005 and Rayburn et al., 2005). Considering that the terminal moraine of the Hackensack Lobe is located 35 km south of Wayne, New Jersey additional Rickard Hill erratics containing *T. grandis* trilobites may occur in this area. However, none were recovered during an extensive search south of Wayne, New Jersey for this project or were reported in Becker and Bartholomew (2013).

Recently, Rayburn et al. (2015) calculated the rate of ice advance through southern New York and New Jersey at about 40 m/yr based on luminescence age dating of varved glacial-lacustrine units. At this rate of ice advance, it would have taken approximately 5,000 years for the Rickard Hill erratics with their *T. grandis* trilobites to be transported 200 km from the outcrop belt near Clarksville, New York to Wayne, New Jersey. Cosmogenic-nuclide exposure studies on boulders and outcrops adjacent to Wayne, New Jersey indicated the area had become deglaciated by approximately 18,500 bp (Clark et al., 1995; Kelly et al., 2008). The Middleburgh, New York recessional moraine, just north of the Clarksville outcrop belt, has been dated at approximately 15,500 bp (Sirkin and Bokuniewicz, 2006). This would indicate deglaciation of the study area containing the Rickard Hill erratics and *T. grandis* trilobites occurred within 3,000 years.

Our ongoing investigation indicates that fossiliferous erratics representing most physiographic provinces in southeastern New York can also be recovered throughout the lower Hudson Valley as well as the northern and central Piedmont of New Jersey. This includes erratics of well-known fossiliferous Ordovician, Silurian, and Devonian sections that have been transported from as far north as the Allegheny Plateau and areas northwest of Albany. The distinctive lithologies and fossil assemblages, from these groups have been well-documented for nearly two hundred years (Mather, 1843; Linsley, 1994). Study of these fossilifierous erratics is currently underway as a means to broaden interpretations presented in this report and further reconstruct the complex glacial history and surficial geology between the Helderberg Mountains Region and New Jersey Piedmont.

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