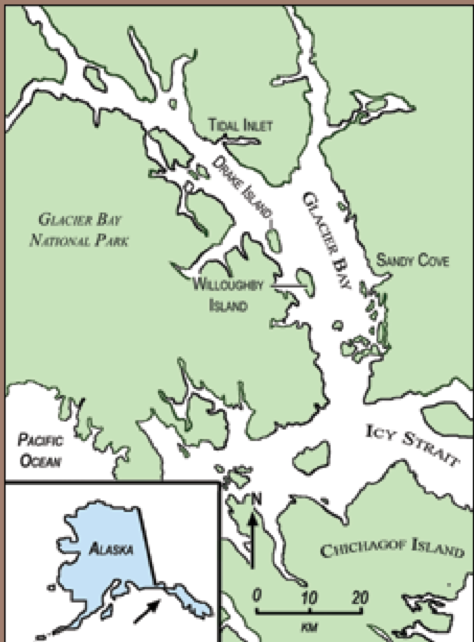
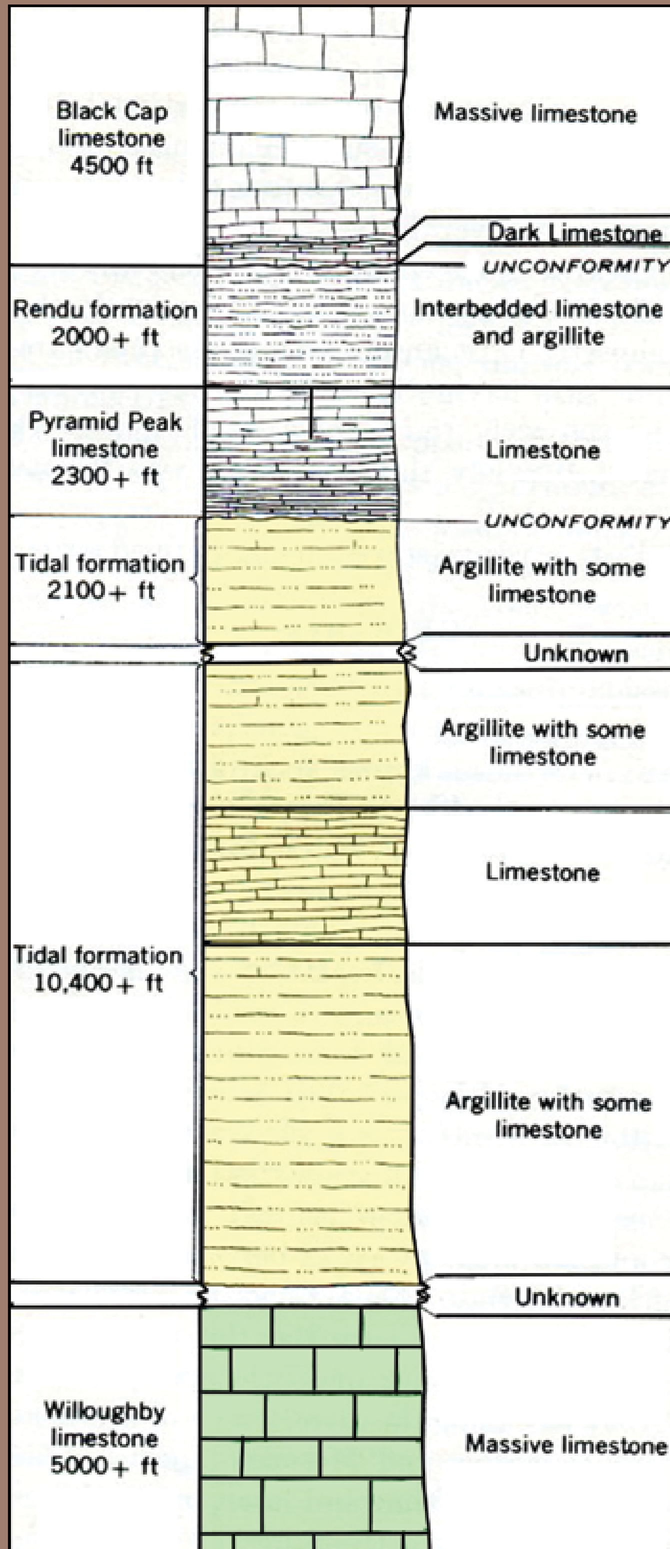

Tidal Inlet
Drake Island
Glacier Bay
Glacier Bay National Park
Sandy Cove
Willoughby Island
Icy Strait
Pacific Ocean
Alaska
N
Chichagof Island
0 10 20
km

1


Black Cap limestone 4500 ft
Massive limestone
Dark Limestone
UNCONFORMITY
Rendu formation 2000+ ft
Interbedded limestone and argillite
Pyramid Peak limestone 2300+ ft
Limestone
UNCONFORMITY
Tidal formation 2100+ ft
Argillite with some limestone
Unknown
Argillite with some limestone
Limestone
Tidal formation 10,400+ ft
Argillite with some limestone
Unknown
Willoughby limestone 5000+ ft
Massive limestone

2


CM.

3

4

Shallow and Deep Water Origins of Silurian Rocks at Glacier Bay, Alaska

By David M. Rohr, Robert B. Blodgett, Vincent Santucci, and Ladislav Slavik

Glacier Bay in the northern part of Southeast Alaska (*Figure 1*) contains a remarkably thick succession of middle Paleozoic (*Silurian and Devonian*) age strata, which were geologically mapped in detail by Seitz (*1959*) and Rossman (*1963*). The stratigraphic framework (*Figure 2*) for the Paleozoic succession of the Glacier Bay area was established by Rossman, who formally named the Paleozoic formations present in the region. These included from presumed stratigraphic bottom to the top: Willoughby Limestone (late Silurian, about 425 million years old); Tidal Formation (late Silurian); Pyramid Peak Limestone (unfossiliferous, age unknown); Rendu Formation (unfossiliferous, age unknown); and Black Cap Limestone (Middle Devonian according to Rossman, but now known to contain Early Devonian fauna as well). These rocks are all part of the accreted Alexander terrane. In the Alexander terrane, thick Silurian carbonate shelf facies have been mapped from Prince of Wales Island in the south to Glacier Bay in the north. The limestone lithosome was named the Heceta Limestone (*Eberlein and Churkin 1970*) on Prince of Wales Island, the Kennnel Creek Limestone (*Loney et al. 1963*) on Chichagof Island and the Willoughby Limestone (*Rossman 1963*) in Glacier Bay. The north-south trend is offset by the Chatham Strait Fault.

Figure 1. (Map) Silurian strata are exposed on Willoughby and Drake Islands, Marble Mountain, Sandy Cove, and Tidal Inlet in Glacier Bay. Similar Silurian formations are also found to the south on Chichagof Island.

Figure 2. Rossman formally named the Paleozoic formations in Glacier Bay, including the very thick Silurian Willoughby and Tidal formations.

From Rossman (*1963*)

Figure 3. The large, upper *Silurian lagoonal bivalve Pycinodesma* is locally abundant in the Willoughby Limestone on northern Willoughby Island.

Photograph courtesy of R. Blodgett

Figure 4. Nearly horizontal bedding in the Willoughby Limestone is present on parts of the eastern side of Marble Mountain.

Photograph courtesy of D. Rohr

Willoughby Limestone

The Willoughby Limestone was formally established by Rossman (*1963*) who estimated it to be at least 5,000 ft (1,524 m) thick and to consist of bedded limestones, with the exposures on Willoughby Island representing the most typical section. The name Willoughby Limestone was earlier used by Seitz (*1959*) without formal definition for Silurian limestone exposures in a small area of Geikie Inlet where he was mapping. He did not establish it as a formal stratigraphic name, obviously deferring to Rossman to name it, as the Willoughby formed a greater portion of his adjacent map area.

The Willoughby contains nearly all illustrated or formally described fossils from the Glacier Bay area. Previous faunal studies on the formation include work on the large, upper Silurian lagoonal bivalve *Pycinodesma* (*Figure 3*) (*Kirk 1927a, 1927b, Kříž* et al. *in preparation*) and associated large gastropods belonging to the genera *Bathmopterus*, *Kirkospira*, and *Coelocaulus* (*Kirk 1928, Rohr and Blodgett 2003, Rohr et al. 2003*). All of the preceding molluscan papers were based on collections made from restricted lagoonal limestones exposed on a small satellite island lying off the northeast coast (Johnson Cove area) of Willoughby Island. Two samples from the Johnson Cove area were processed for condonts, but they were barren. Soja et al. (*2000*) reported on stromatolite reefs and associated lithofacies found in the Willoughby Limestone on the southwest and east sides of Drake Island. Locally abundant brachiopods from western Drake Island collected by us in 2011 are described in Blodgett et al. (*2013*). The upper contact of the Willoughby Limestone was reported by Rossman to not be recognized.

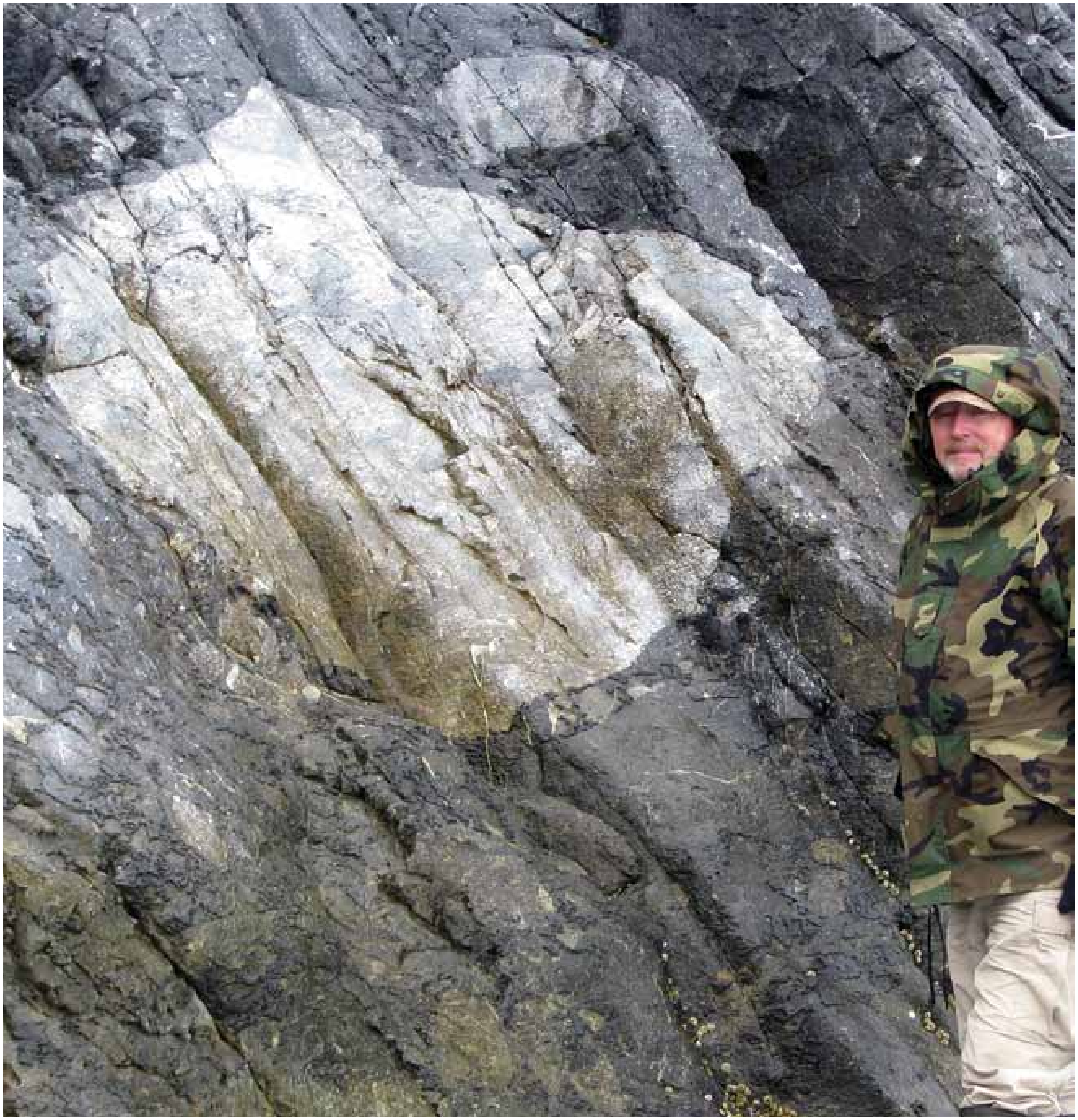
Not all of Marble Mountain is marble. Marble Mountain was mapped by Rossman as Willoughby Limestone. Totally recrystallized carbonates do occur on the eastern shore of Marble Mountain, North and South Marble Islands, and southern Drake Island. Marble Mountain itself consists in part of noticeably bedded nearly horizontal limestone, about 3,300 ft (1,000 m) thick, without any major structural features (*Figure 4*). An unpublished USGS collection (66AOv181) made by A.T. Ovenshine from the northern shoreline of Marble Mountain contained recrystallized, indeterminate rugose coral, possibly *Tryplasma* sp., and we observed recognizable textures and fossils in talus on the western shoreline of Marble Mountain in Shag Cove. Rossman observed "…the large flat-lying body of the Willoughby Limestone that caps White Cap Mountain" (*Rossman 1963*).

Tidal Formation

The Tidal Formation was named by Rossman for a widespread argillaceous unit, which he mapped at Tidal Inlet and around Pyramid Peak and Mount Wright. He reported the formation to be at least 10,400 feet (3,200 m) with an unknown base and an angular unconformable relation with the overlying Pyramid Peak limestone. The typical lithology reported by Rossman is laminated sandy

Photograph courtesy of D. Rohr

Figure 5. The typical lithology of the Tidal Formation reported by Rossman is laminated sandy siltstone with abundant shale. Our examination of the shale beds during 2011 at Tidal Inlet did not yield any graptolites or other fossils.

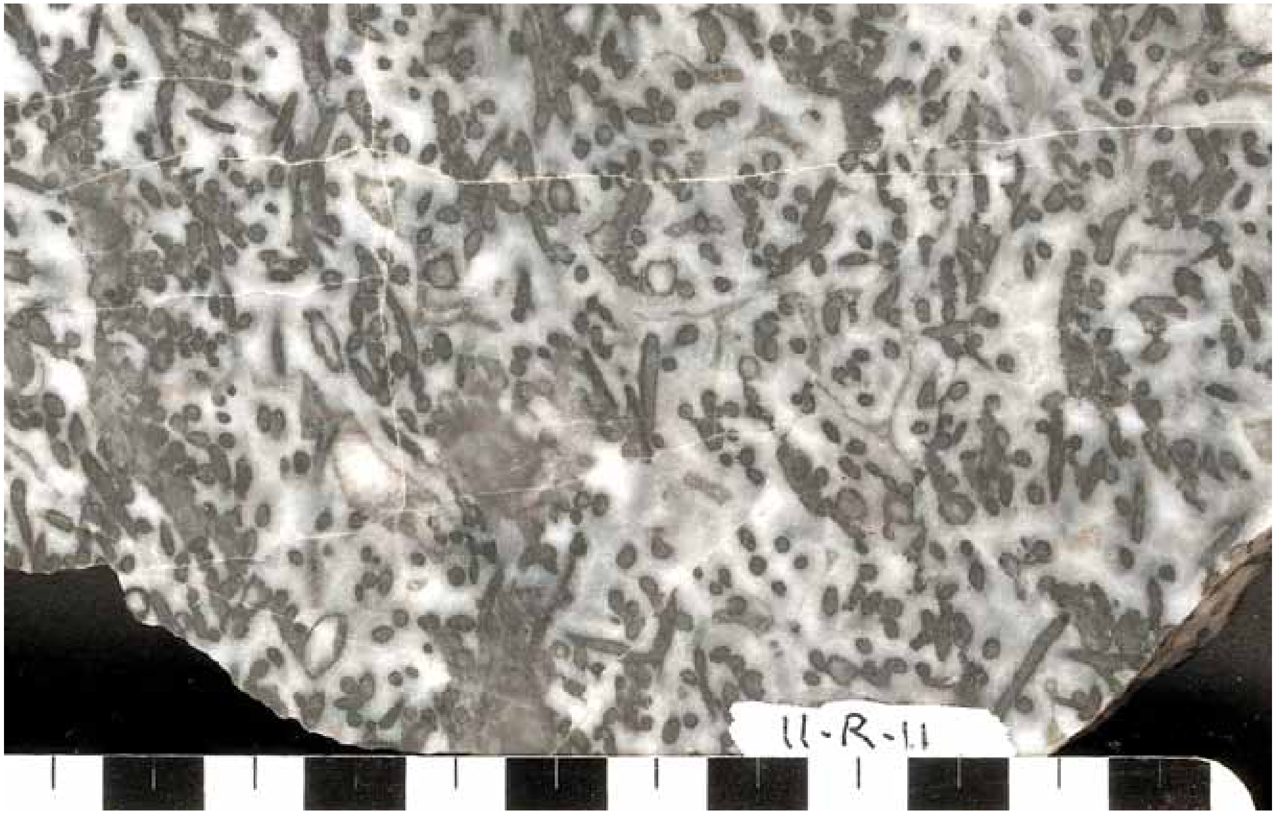


Photograph courtesy of R. Blodgett

Figure 6. Limestone conglomerate and breccia occur in the Tidal Formation along Tidal Inlet. Clasts are similar to the Willoughby Limestone.

siltstone with abundant shale (*Figure 5*). Our examination of the shale beds during 2011 at the illustrated locality did not yield any graptolites or other fossils. Fossil collections made by Rossman and colleagues were identified by USGS paleontologists Edwin Kirk, Arthur Boucot, and Jean Berdan. Based on these identifications, Rossman assigned an age of late Silurian to the Tidal Formation.

A lithology not reported by Rossman, but possibly included in his middle limestone member of the Tidal Formation, is limestone conglomerate and breccia. These limestones are found along Tidal Inlet (*Figure 6*) and appear to be of similar lithologies as the Willoughby Limestone. One smaller clast (*Figure 7*) contained abundant amphiporoid stromatoporoids characteristic of shelfal or reefal facies. A large olistolith within the Tidal Formation on the southern side of Tidal Inlet (*Figure 8*) is crystalline carbonate. We conclude this enigmatic lithology to represent altered Willoughby Limestone because of its generally massive appearance and its similarity to that found on North Marble Island, southern Drake Island, and the eastern shore of Marble Mountain. Thin-bedded gray limestone (*Figure 9*) at Puffin Island in Sandy Cove may be the equivalent of Rossman's limestone member of the Tidal Formation, which he mapped south



Photograph courtesy of D. Rohr

Figure 7. A smaller clast in the Tidal Formation at Tidal inlet contains abundant amphiporoid stromatoporoids characteristic of shelfal or reefal facies. The slightly metamorphosed tubular fossils are surrounded by calcite spar cement. National Park Service collection, GLBA-00634.

of Tidal Inlet and on Mount Wright. The limestone in Figure 9 was processed for conodonts, but it was barren.

Talus of large blocks of siltstone along the shore at North Sandy Cove appears to be turbidite beds from the Tidal Formation. We found a single bed with brachiopods. Our limited collection of megafauna from the Tidal Formation in the Sandy Cove area is similar in general aspect to previous USGS collections. Graptolites have been earlier collected from Tidal Formation outcrops during the 1960s. Unfortunately the graptolite collections were noted as being misplaced at the U.S. Geological Survey Western Regional Office in Menlo Park, and never reported upon.

Our Reinterpretation

Rossman reported the total thickness of the Silurian Willoughby Limestone and Tidal Formation to be at least 17,500 ft. (5,330 m). Our reconnaissance field study during the summer of 2011 indicates the Tidal Formation, instead of overlying the Willoughby, represents a coeval deeper-water facies equivalent of the carbonate platform succession of the Willoughby. The Willoughby is the carbonate shelf to the west and the Tidal filled the basin to the east (*Figure 10*). This interpretation is also accordant with the spatial distribution of outcrop belts of the Willoughby Limestone and Tidal Formation. The Willoughby is primarily restricted to the west side of Glacier Bay and Gloomy Knob on the east side, with outcroppings of the Tidal Formation restricted further to the east side of Glacier Bay.

Comparison to Chichagof Island

The geology of northeastern Chichagof Island is similar to Glacier Bay. Although biostratigraphic control for many outcrops is still lacking, we have speculated that the rocks exposed in the Hoonah area represent a Silurian shelf-to-basin transition (*Rohr et al. 2011*). The rock types in the Tidal Formation are similar to that observed in an equivalent unnamed upper Silurian mixed siliclastic and limestone succession on northeast Chichagof Island (*Figure 1*) in the vicinity of Hoonah (*Kříž et al. 2011, Rohr et al. 2011, Boucot et al. 2012*). The latter rocks appear to represent slightly deeper-water, basinal equivalents of shallow platform carbonates of the Kennel Creek Limestone (also containing abundant remains of the bivalve *Pycinodesma* and amphiporoids). The Kennel Creek Formation at its type area is composed of *Amphipora* and *Pycinodesma*, and was deposited in a shallow, shelf environment. Other exposures on northern Chichagof interpreted as slope deposits contain varying amounts of limestone. Quarries near Hoonah contain tabular limestone breccias, sedimentary folds and large, and channel-like lenses. The dominance of limestone suggest a proximal slope facies, close to the carbonate shelf.

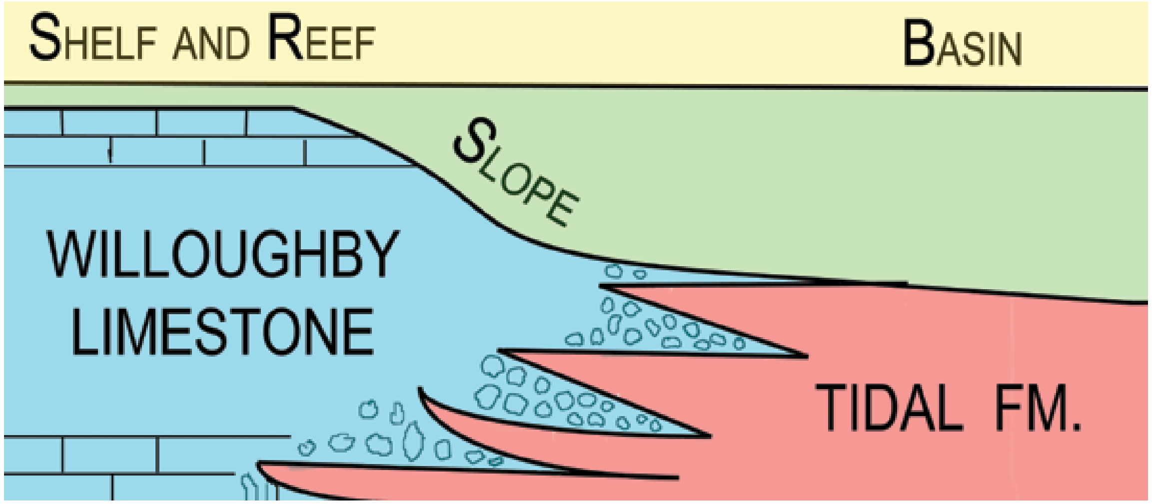
Massive metamorphosed limestone with sparry calcite stromatactis structures is very unusual, and appears identical to unaltered parts of the Willoughby Limestone at Glacier Bay as well as the Silurian reefal rocks of southwest Alaska (*Clough and Blodgett 1988*). Karl and Giffen (*1992*) and Karl (*1996*) concluded the Point Augusta Formation represents a basinal, clastic turbidite fan deposit that grades into the Kennel Creek Formation. The Point Augusta Formation is similar to the Tidal Formation in Glacier Bay and consists of conglomerate, massive to medium bedded calcareous graywacke turbidites with associated debris flow deposits, and interbedded limestone.

Photograph courtesy of D. Rohr

Figure 8. A large olistolith (arrow) within the Tidal Formation on the southern side of Tidal Inlet is crystalline carbonate, probably representing altered Willoughby Limestone.

Photograph courtesy of D. Rohr

Figure 9. Thin-bedded gray limestone at Puffin Island in Sandy Cove may be the equivalent of Rossman's limestone member of the Tidal Formation.



Photograph courtesy of Douglas Deur

Figure 10. Generalized cross section of our interpretation of the facies relationship between the Willoughby Limestone and the Tidal Formation.

Conclusions

The great thickness of Silurian strata in Glacier Bay may be explained in part if the Willoughby Limestone and the Tidal Formation are coeval lateral facies representing a carbonate shelf-to-basin transition. This model fits the other Silurian formations seen elsewhere in the Alexander Terrance of Southeast Alaska. Even this interpretation leaves an impressive thickness (5,000-10,000 ft, 1,500 - 3,000 m) of Silurian for further biostratigraphic studies.

Acknowledgments

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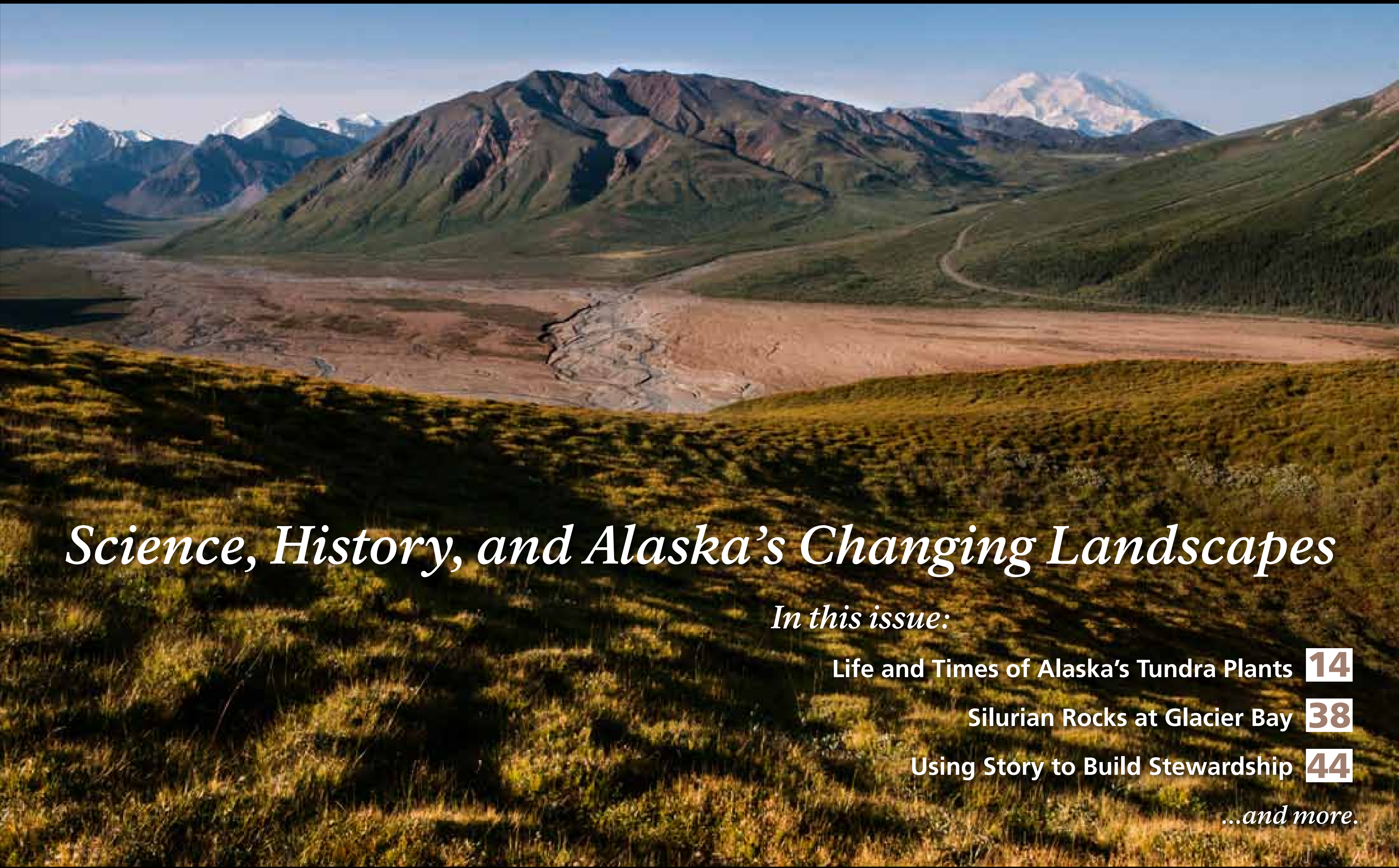

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Volume 12, Issue 1

Table of Contents

Cover Photo: Sheep Hill, Denali National Park and Preserve.
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Backcover Photo: Collecting data in the Savage River basin in Denali National Park and Preserve.
Article on page 18.
Photograph courtesy of John Blong

Teklanika River Valley Denali National Park and Preserve
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