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Scientific notes and summaries of investigations prepared by members of the Conservation, Geologic, and Water Resources Divisions

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GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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FOREWORD

This collection of 62 articles is the second of a series to be released in 1963 as chapters of Professional Paper 475. The articles report on scientific and economic results of current work by members of the Geologic, Water Resources, and Conservation Divisions of the United States Geological Survey. Some of the papers present the results of completed parts of continuing investigations; others announce new discoveries or preliminary results of investigations that will be discussed in greater detail in reports to be published in the future. Still others are scientific notes of limited scope, and short papers on methods and techniques.

Chapter A of this series will be published later in the year, and will present a synopsis of work of the Geological Survey during the present fiscal year.

Thomas B. Nolan

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Director.

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Article 68

REVISED STRATIGRAPHIC NOMENCLATURE AND AGE OF THE TUXEDNI GROUP IN THE COOK INLET REGION, ALASKA

By ROBERT L. DETTERMAN, Menlo Park, Calif.

Abstract.—The Tuxedni Formation is raised to group rank in the Cook Inlet region. Names are given to three formerly unnamed members, and these and three other members are raised to formation rank. In ascending order they are designated the Red Glacier Formation, Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, Twist Creek Siltstone, and Bowser Formation.

The Tuxedni Formation was defined as the Tuxedni Sandstone by Martin and Katz (1912, p. 59–64) to include all the marine sandstone and shale of Middle Jurassic age exposed on the south shore of Tuxedni Bay, Alaska. The formation was subdivided as the result of mapping by oil company and Geological Survey geologists during and immediately after World War II (fig. 68.1).

Recent mapping in the Cook Inlet region and southern Alaska has shown that the formation should be considered a group. Therefore, in this article the Tuxedni Formation is raised to the rank of group and its former members to the rank of formation, except for the former Bowser Member, which is subdivided and raised to two formations. In ascending order, the formations are the Red Glacier Formation, Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, Twist Creek Siltstone, and Bowser Formation. The marine rocks of the Tuxedni Group are abundantly fossiliferous. Ammonites studied and described by R. W. Imlay (1961, 1962a, 1962b, and report in preparation) indicate that the Tuxedni Group is of Middle and Late Jurassic age.

The name Red Glacier Formation is here introduced to replace the term lower member of the former Tuxedni Formation in the older reports. The formation is named after Red Glacier, and the type section is designated as exposures along both sides of the glacier (fig. 68.2). The upper 3,310 feet is exposed along the south side, 4½ miles S. 62° E. of Iliamna Volcano, and the lower 1,230 feet is on the north side of the glacier, 6½ miles N. 86° E. of Iliamna Volcano. The Red Glacier Formation is 1,980 feet thick at Tuxedni Bay, 18 miles northeast of Red Glacier, and about 6,500 feet thick in the subsurface under Iniskin Peninsula, 18 miles southwest of Red Glacier.

The Red Glacier Formation consists mainly of arkosic sandstone and shale with minor amounts of subgraywacke-type sandstone, conglomerate, and limestone in the lower part, and sandy siltstone in the upper part. At the type locality the lower 200 feet is light-brown arkosic sandstone. This is overlain by 200 feet of black silty shale, 200 feet of arkosic sandstone, 1,000+ feet of soft black silty shale in which a small fault cuts out part of the section, 720 feet of light-brown arkosic sandstone, 1,060 feet of interbedded sandstone and siltstone, and at the top by 1,160 feet of sandy siltstone. The base of the formation rests unconformably on the Talkeetna Formation of Early Jurassic age. The upper contact is gradational into the overlying Gaikema Sandstone.

The Gaikema Sandstone Member, named by Kirschner and Minard (1948) after Gaikema Creek on Iniskin Peninsula, is herein designated the Gaikema Sandstone. The type locality is designated as the left bank of the creek, starting 5,000 feet from the mouth and continuing for 1,800 feet upstream. The section at the type locality is 850 feet thick and consists of resistant cliff-forming sandstone, in part conglomeratic. Siltstone, shale, and cobble-boulder conglomerate are subordinate constituents.

Measured sections of the Gaikema Sandstone range in thickness from 500 to 870 feet. At the type locality the lower 180 feet is medium-bedded olive-gray to yellowish-green sandstone containing beds of silty shale, siltstone, and conglomerate. This is overlain by 220

ART. 68 *IN* U.S. GEOL. SURVEY PROF. PAPER 475–C, PAGES C30–C34. 1963.

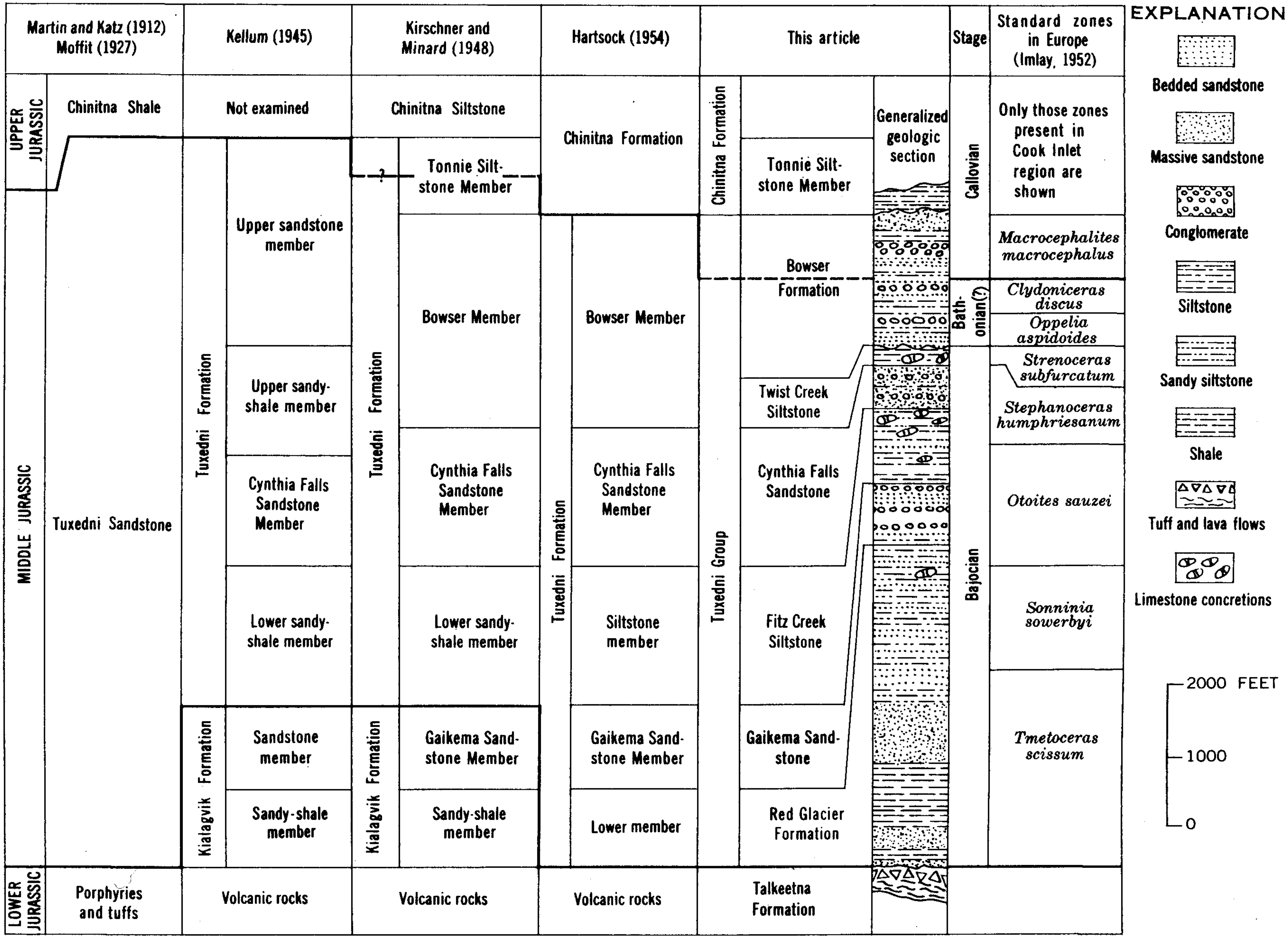

FIGURE 68.1—Revision of stratigraphic nomenclature of the Tuxedni Group in Cook Inlet region, Alaska.

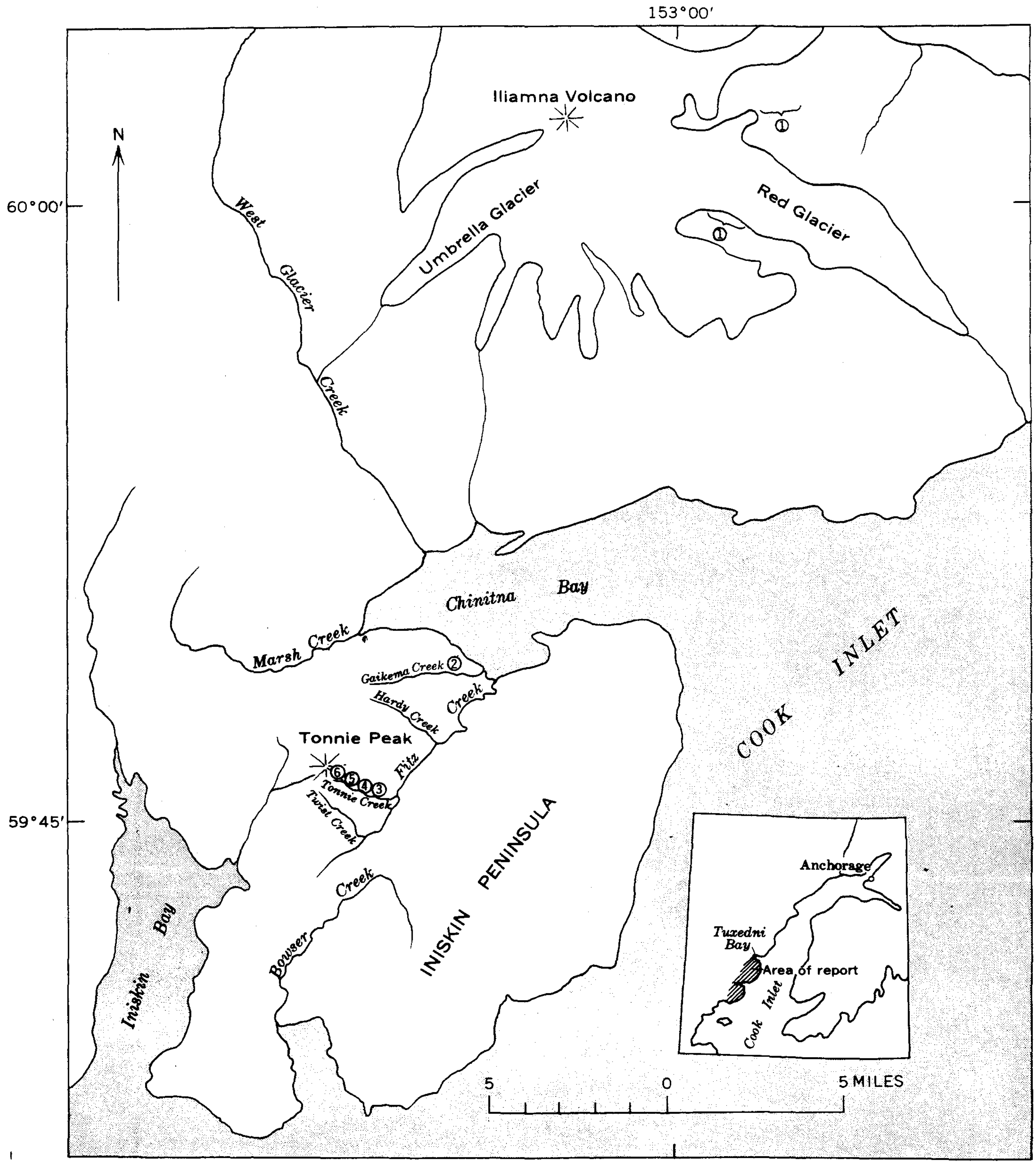

FIGURE 68.2.—Index map showing type localities of formations in the Tuxedni Group, Cook Inlet region, Alaska. *1*, Red Glacier Formation. *2*, Gaikema Sandstone. *3*, Fitz Creek Siltstone. *4*, Cynthia Falls Sandstone. *5*, Twist Creek Siltstone. *6*, Bowser Formation.

feet of medium-bedded greenish-gray sandstone, 110 feet of cobble-boulder conglomerate and coarse-grained arkosic sandstone, 220 feet of thin- to medium-bedded olive-green sandstone, and at the top by 120 feet of medium-bedded medium-grained dark-olive-green sandstone containing a few beds of cobble-boulder conglomerate. The lower contact is gradational into the Red Glacier Formation, and the upper contact with the Fitz Creek Siltstone is conformable and sharp.

The Fitz Creek Siltstone is here named to replace the term siltstone member of the former Tuxedni Formation of older reports. The formation is named after Fitz Creek, the principal stream on Iniskin Peninsula. The type locality is on Tonnie Creek, a tributary of Fitz Creek, starting 7,000 feet S. 55° E. of Tonnie Peak and continuing upstream for 1,400 feet. The formation is 1,090 feet thick at the type locality.

The formation is composed mainly of massive bluish-gray arenaceous siltstone that commonly weathers rusty brown and contains many small ovoid fossiliferous limestone concretions. Interbedded with the siltstone are fine-grained sandstone and, locally, conglomerate. Measured sections range from about 650 to 1,280 feet in thickness. The lower 80 feet of the type section is a massive bluish-gray siltstone, with a 70-foot covered interval above the siltstone. The covered interval is overlain by 340 feet of siltstone, 70 feet of very fine grained silty sandstone, and at the top by 530 feet of massive bluish-gray arenaceous siltstone. The upper and lower contacts are conformable.

Formational status is given the former Cynthia Falls Sandstone Member of Kellum (1945). The formation was named after Cynthia Falls, a prominent waterfall on Hardy Creek, Iniskin Peninsula. The type section is on Tonnie Creek, starting 5,600 feet S. 50° E. of Tonnie Peak and continuing upstream for 600 feet. Massive- to thick-bedded coarse-grained greenish-gray graywacke-type sandstone is the main constituent. Interbedded with the sandstone are thin layers of pebble-cobble conglomerate and arenaceous siltstone. Much of the sandstone is mottled green and white. The white spots are formed by the abundant zeolite minerals in the sandstone.

The Cynthia Falls Sandstone is 600 to 700 feet thick in the Cook Inlet region. The type section is 600 feet thick; it consists of 270 feet of massive coarse-grained greenish-gray-mottled sandstone at the base, overlain by 50 feet of brownish-gray arenaceous siltstone and 280 feet of massive sandstone containing a few layers of pebbles. The contacts with the underlying and overlying formations are conformable.

The Twist Creek Siltstone is herein named for the sequence of rocks included by Imlay (1962b) as the lower part of the former Bowser Member of the Tuxedni Formation. The formation is named after Twist Creek on Iniskin Peninsula, and the type section is on Tonnie Creek, starting 5,000 feet S. 47° E. of Tonnie Peak and continuing upstream for 500 feet. The Twist Creek Siltstone is uniformly soft, poorly consolidated siltstone and shale with a few thin graywacke-type sandstone interbeds. The siltstone is thin bedded to massive, arenaceous, dark gray, and weathers rusty dark brown. Many thin beds of volcanic ash are intercalated with the siltstone, and small discoidal limestone concretions occur abundantly throughout. The formation is 240 feet thick at the type locality and has a maximum thickness of about 410 feet near Red Glacier.

A major unconformity exists between the Twist Creek Siltstone and the overlying Bowser Formation. As a result of this unconformity the Twist Creek is missing in the southwestern part of Iniskin Peninsula.

The Bowser Member of the Tuxedni Formation, named by Kirschner and Minard (1948), is here restricted to the upper part of the member and raised in rank to the Bowser Formation of the Tuxedni Group. The formation is named after Bowser Creek. The formation is exposed at many localities along the creek, but the type locality is on Tonnie Creek, starting 4,500 feet S. 47° E. of Tonnie Peak and continuing upstream for 1,500 feet.

Rocks assigned to the Bowser Formation include massive units of cliff-forming graywacke-type sandstone, pebble-cobble conglomerate, thin-bedded shale, and massive siltstone. Measured sections of the formation range in thickness from about 1,250 feet to as much as 1,850 feet. The type section is 1,830 feet thick and consists of 70 feet of thin-bedded sandstone overlain by 280 feet of massive siltstone, 70 feet of cobble conglomerate, 260 feet of gray siltstone, 250 feet of sandstone with pebble-conglomerate layers, 130 feet of dark-gray siltstone, 170 feet of thin-bedded light-gray sandstone, 170 feet of cobble conglomerate, 250 feet of massive olive-gray siltstone, and at the top by 180 feet of massive coarse-grained dark-gray sandstone. The contact with the overlying Chinitna Formation, of Late Jurassic age, is locally unconformable.

Ammonites from the lower part of the Bowser Formation have been identified by Imlay (1962a) as of Bathonian (Middle Jurassic) or Callovian (Late Jurassic) age, and from the upper part as of definite Callovian age. Therefore the age of the Bowser Formation is herein considered to be Middle(?) and Late Jurassic.

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POSSIBLE PLEISTOCENE–RECENT BOUNDARY IN THE GULF OF ALASKA, BASED ON BENTHONIC FORAMINIFERA

By PATSY B. SMITH, Menlo Park, Calif.

Abstract.—Of 10 cores from sediments in the Gulf of Alaska, 7 contained boreal faunas throughout, similar to those living in the area today, and 3 contained boreal foraminiferal faunas at the top and Arctic faunas in the lower part. It is inferred from the cores that the change in faunas marks a possible Pleistocene-Recent boundary in the sediments.

In the spring of 1961, 10 cores were taken by scientists on the U.S. Coast and Geodetic Survey ship *Pioneer* from sediments in the Gulf of Alaska, west and southwest of Kodiak Island (fig. 79.1). The coring was done under the direction of Lt. Comdr. H. P. Nygren, oceanographer of the *Pioneer*, and the samples were examined by G. W. Moore, U.S. Geological Survey, Menlo Park, Calif. Eight cores were obtained with a Phleger coring tube and two with a modified Ewing piston coring tube. Five of the cores are from the Continental Shelf (at depths of 76 to 240 meters) and five are from the north scarp of the Aleutian Trench (at depths of 810 to 5,540 meters) (table 79.1).

The top centimeter of each core was preserved in ethanol so that living Foraminifera could be recognized by a stain test for protein. Generally, 1-centimeter samples were taken at 10-centimeter intervals from the remainder of each core. From these samples, distribution of successively older faunas was determined and the age and depositional environment of the cored sediments were interpreted.

TABLE 79.1.—*Location and length of cores and description of the top centimeter of sediment*

Core No.	Location: Latitude (north)	Location: Longitude (west)	Depth (m)	Core length (cm)	Sediment	Color [1]
1	57°18′	155°20′	230	56	Clayey silt	Dark greenish gray.
3	54°33′	157°24′	2,070	6	do	Olive gray.
4	55°31′	156°16′	240	122	Medium sand	Grayish olive.
5	55°17′	155°09′	1,950	33	Clayey silt	Do.
6	55°52′	154°25′	810	54	Clayey very fine sand.	Grayish olive green.
7	56°25′	155°36′	76	15	Very fine sand	Dark greenish gray.
8	55°36′	158°23′	146	101	Sandy silt	Olive gray.
9	54°55′	157°59′	117	72	Pebbly medium sand.	Dark greenish gray.
10	54°51′	155°24′	4,170	13	Clayey silt	Do.
11	54°27′	155°23′	5,540	43	do	Olive gray.

[1] Color of the wet sediment follows the convention of Goddard and others (1948)

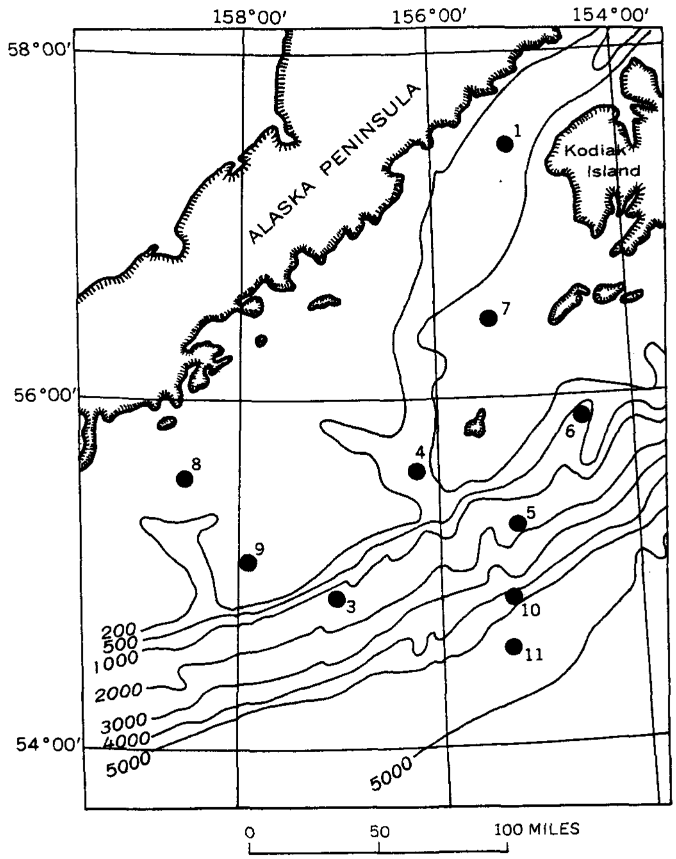

FIGURE 79.1.—Map of part of the Gulf of Alaska, showing station locations. Depth contours in meters.

ART. 78 *IN* U.S. GEOL. SURVEY PROF. PAPER 475–C, PAGES C73–C77. 1963.

Living and dead faunas (table 79.2) from the tops of all the cores are similar to those from the boreal waters of the Continental Shelf and Slope off Washington, Oregon, and California. A few species characteristic of arctic waters are present in the samples from the Continental Shelf and Slope in the Gulf of Alaska, but most forms characteristic of Arctic water are not present (Phleger, 1952; Loeblich and Tappan, 1953; Green, 1960).

The shallow (76–240 meters) benthonic faunas of the shelf samples (cores 9, 8, 7, 4, 1) are similar to those of the Continental Shelf off Washington, Oregon, and northern California (Enbysk[1]; Bandy, 1953). Characteristic species are most of the Nonions and Nonionellas, *Buliminella elegantissima*, *Uvigerina hollicki*, *Virgulina pauciloculata*, and *Epistominella pacifica* (generally a bathyal species off California).

The present bathyal faunas in the Gulf of Alaska (cores 6, 5, 3) (810–2,070 meters) have a wider distribution than the shallow faunas; many of the species occur at similar depths not only off Washington, Oregon, and California, but also off the coast of Central America (Smith, 1963). Included in these faunas are *Bolivina argentea*, *B. spissa*, *Bulimina marginospinata*, *B. subacuminata*, and most commonly, *Uvigerina peregrina*.

The present abyssal faunas (cores 10, 11) (4,170 and 5,540 meters) are composed almost entirely of arenaceous species, very similar to faunas found in deep north Pacific waters from the Aleutian Trench to Hawaii.

[1] Enbysk, B. J., 1960, Distribution of Foraminifera in the northern Pacific: Univ. Washington, Ph. D. thesis.

TABLE 79.2.—*Foraminifera in the top centimeter of each core*

[Abundance given as percentage of dead faunas. Number of living specimens shown in parentheses]

Depth zone	Shelf					Bathyal			Abyssal	
Core No.	7	9[1]	8	1	4	6	5	3	10	11
Species / Depth (m)	76	117	146	230	240	810	1,950	2,070	4,170	5,540
Arenaceous										
Adercotrema glomeratum (Brady)			1	2.5	<1(4)					1
Alveophragmium nitidum (Goes)			4.5	1	<1	1			15	8
A. ringens (Brady)										<1
A. subglobosum (G. O. Sars)									10	1
A. weisneri (Parr)										<1
Ammobaculites agglutinans (d'Orbigny)										9
A. cf. *A. americanus* (d'Orbigny)										3
A. agglutinans filiformis Earland										6.5
Ammoglobigerina globigeriniformis (Parker and Jones)								<1	10	2
Ammomarginulina foliacea (Brady)									5	2
Bigenerina minutissima (Earland)			<1							<1
Cornuspira involvens (Reuss)							2			
Cyclammina cancellata Brady										<1
C. trullissata (Brady)						<1			5	<1
Cystammina galeata (Brady)									5	
Eggerella bradyi (Cushman)							7	10	30	1
Eggerella propinqua (Brady)						1				
E. scabra (Williamson)	1		2(1)	2	7			1.5		
Gaudryina sp					<1					
Glomospira gordialis (Jones and Parker)										2
Haplophragmoides canariensis (d'Orbigny)			1							
Hyperammina and *Astrorhiza* spp										Frag. A
Involutina tenuis (Brady)										2
Jaculella acuta Brady										<1
Karreriella apicularis (Cushman)										<1
Nodellum membranaceum (Brady)										<1
Placopsilina bradyi Cushman and McCulloch										7
Psammosphaera fusca Schulze										6
Reophax bacillaris Brady			1		<1					
R. difflugiformis Brady						<1	2		10	16
R. distans Brady										2
R. nodulosus Brady										2.5
R. scorpiurus Montfort			1							2
R. scotti Chaster							5.5			
Spiroplectammina biformis (Parker and Jones)			1.5	<1	1	1			5	
Textularia torquata Parker			1		<1	<1				
Trochammina grisea Heron-Allen and Earland										<1
T. cf. *I. inflata* (Montagu)					<1	<1				
T. kellettae Thalmann					1	1(1)		2		
T. cf. *T. malovensis* Heron-Allen and Earland										1

See footnote at end of table

TABLE 79.2.—*Foraminifera in the top centimeter of each core*—Continued

[Abundance given as percentage of dead faunas. Number of living specimens shown in parentheses]

Depth zone	Shelf					Bathyal			Abyssal	
Core No.	7	9[1]	8	1	4	6	5	3	10	11
Species / Depth (m)	76	117	146	230	240	810	1,950	2,070	4,170	5,540
Calcareous benthonic										
Angulogerina angulosa (Williamson)		(1)			5(4)	2		5. 5		
Astrononion gallowayi Loeblich and Tappan			1		<1(1)	1	2			
Bolivina argentea Cushman						<1				
B. decussata Brady	10	(3)	2	<1(1)	9(4)	2. 5		<1		
B. pacifica Cushman and McCulloch	1	(3)	1(2)	<1	<1	1		<1(2)		
B. pseudobeyrichi Cushman					<1	<1				
B. spissa Cushman						17(11)		<1		
Buccella frigida (Cushman)		(1)	3. 5	<1	<1					
Bulimina cf. *B. auriculata* Bailey		(1)					2			
B. marginospinata Cushman and Parker						1(2)	5. 5			
B. subacuminata Cushman						13(5)				
Buliminella elegantissima (d'Orbigny)	1		<1(1)		1					
B. subfusiformis Cushman						3(2)		<1		
Cassidulina cushmani R. E. and K. C. Stewart						8(3)				
C. islandica nørvangi Thalmann			2	4(6)	1			21		
C. norcrossi Cushman			1(1)	<1	1		2	<1		
C. cf. *C. subglobosa* Brady									(1)	
Cibicides lobatulus (Walker and Jacob)		(2)			<1(1)	<1				
Ehrenbergina sp						1				
Elphidium cf. *E. incertum* (Williamson)				<1	<1					
E. magellanicum Heron-Allen and Earland	10									
Epistominella exigua (Brady)	37	(1)	17(4)	13(43)	33(15)	<1		32(1)		
E. pacifica (Cushman)				15(9)	4. 5(3)	<1				
Eponides tenera (Brady)							4			
Eponides tumidulus (Brady)			2. 5							
Globobulimina pacifica Cushman					<1(4)	<1				
Lagenid spp	1		<1	<1	1	2. 5	2			
Loxostomum amygdaliformis (Brady)		(1)								
Nonion cf. *N. depressulum* (Walker and Jacob)					2. 5(6)			6		
N. grateloupi (d'Orbigny)	1		<1	4	<1					
N. labradoricum (Dawson)		(8)	5(3)	1	<1(2)		2			
Nonionella auricula Heron-Allen and Earland						1	15(8)	1		
N. bradii Chapman	7		9(6)	6	12					
N. globosa Ishiwada			8(5)	<1	<1	1(2)	2			
N. miocenica stella Cushman				2. 5(20)						
Pullenia bulloides (d'Orbigny)							4			
P. subcarinata (d'Orbigny)		(1)			<1	1	2			
Quinqueloculina spp			1	1	<1					
Robulus sp					1(2)					
Rosalina sp	1									
Uvigerina hollicki Thalmann		(1)	5. 5(4)	17(18)	19(5)					
U. peregrina Cushman						14(15)	4	3. 5		
Valvulineria sp				1		2(1)	2	<1(2)		
Virgulina pauciloculata Brady	10	(1)	25(11)	8	<1(1)			2		
V. seminuda Natland							4			
V. spinosa Heron-Allen and Earland			<1	1. 5	<1			<1		
Planktonic										
Globigerina bulloides d'Orbigny	16			4. 5	<1	4	9	<1		
G. pachyderma Ehrenberg				11	4	11	9	10		
Globigerinita uvula (Ehrenberg)	3			<1	2	<1				
Total dead population	67		196	260	1, 200	190	26	175	20	928

[1] Only living specimens counted, as reworked Pleistocene(?) specimens are present.

Faunas from below the top of the cores were also examined. Cores 1, 5, 6, and 7 contained faunas over the length of the core similar to those at the top. Cores 4, 8, and 9 contained boreal faunas at the top but arctic benthonic faunas in the lower part. In core 4 (table 79.3) the change in faunas occurs between 26 and 29 centimeters; in core 8, between 80 and 90 centimeters; and in core 9, within the first 2 centimeters. All three cores contain similar faunas, and except for the depth of the faunal break the three cores are similar. The upper layer, characterized by a Recent fauna, generally thins toward the edge of the shelf. The bathyal and abyssal faunas in cores 3, 5, 10, and 11 show no significant change from top to bottom.

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TABLE 79.3.—*Distribution of Foraminifera in core 4*

[Abundance given as percentage of dead faunas. Number of living specimens in top 2 cm is shown in parentheses]

Age	Recent			Pleistocene(?)								
Species / Depth in core (cm)	0–2	2–14	14–26	26–29	29–32	41–42	51–52	61–62	71–72	81–82	91–92	101–102
Arenaceous												
Adercotrema glomeratum (Brady)	<1(4)	<1										
Alveophragmium nitidum (Goes)	<1	<1										
A. ringens (Brady)		<1										
Eggerella bradyi (Cushman)		<1										
E. scabra (Williamson)	7(5)	<1										
Gaudryina sp	<1	<1	1	<1	<1							
Haplophragmoides spp		<1										
Karreriella bradyi (Cushman)				2	<1							
Reophax bacillaris Brady	<1											
R. difflugiformis Brady		<1										
Spiroplectammina biformis (Parker and Jones)	<1	<1										
Textularia torquata Parker	<1											
Trochammina cf. *T. inflata* (Montagu)	<1											
T. kellettae Thalmann	1	<1	<1	<1			<1	<1		<1		
Calcareous benthonic												
Angulogerina angulosa (Williamson)	5(4)	23	30	8	5	<1		<1	<1	<1	<1	<1
Astacolus sp								<1				
Astrononion gallowayi Loeblich and Tappan	<1(1)	1	2					<1		<1		
Bolivina decussata Brady	9(4)	4	1.5	6	6	<1	<1	<1		<1	<1	<1
B. pacifica Cushman and McCulloch	<1	<1	<1	<1	<1	<1	<1	<1		<1	<1	
B. pseudobeyrichi Cushman	<1	<1	<1									
B. spissa Cushman		<1	<1									
Buccella frigida (Cushman)	<1			1	2							
B. inusitata Anderson		1.5	1	3	7.5	2	3.5	5	3	5	5	4.5
Buliminella elegantissima (d'Orbigny)	1(1)	<1	<1	<1	<1							
B. subfusiformis Cushman		<1										
Cassidulina islandica Nørvang		1	<1	10	3	3	3	3	2.5	10.5	3.5	2.5
C. islandica nørvangi Thalmann	1	<1	<1	10	9	11	8.5	8	11	17	8.5	11
C. norcrossi Cushman	1	3	6	2	1	<1	1	<1		<1	<1	1
Cibicides lobatulus (Walker and Jacob)	<1(1)	<1	<1	8	7.5	<1	1	2	2.5	5	3	4.5
C. pseudoungerianus (Cushman)		<1	1	<1			<1					
Dentalina spp				<1		1	<1		<1	<1	1	
Dyocibicides biserialis Cushman and Valentine				3	<1							
Elphidium cf. *E. bartletti* Cushman				1.5	5	2	7	6	6	4.5	3	5.5
E. clavatum Cushman			<1	10	12	30	30	26	40	13	32	31
E. cf. *E. incertum* (Williamson)	<1	<1										
Elphidiella groenlandica (Cushman)				5	1.5	2	1.5	2	1	5	15	4
Epistominella exigua (Brady)	33(15)	6	4	11	9	23	16	15	16	17	13	8
E. pacifica (Cushman)	45(3)	12	7	<1	<1	1	1	1				
Globobulimina pacifica Cushman	<1(4)	<1	<1	<1	<1							
Gyroidina broekiana (Karrer)		<1	<1	<1								
Lagenid spp	1	1.5	2	2	1.5	3.5	2.5	4	3.5	3.5	5	3
Nonion cf. *N. depressulum* (Walker and Jacob)	2.5(6)		<1		1.5							
N. grateloupi (d'Orbigny)	<1			1	1.5	2	2		<1	<1	1	<1
N. labradoricum (Dawson)	<1(2)	1	<1	<1		6.5	3.5	4	<1	2	4	2
Nonionella auricula Heron-Allen and Earland					1							
N. bradii (Chapman)	12	2.5	<1						1	1	2	1.5
N. globosa Ishiwada	<1	<1					<1					
Parafrondicularia advena Cushman				<1								
Patellina corrugata Williamson							<1					
Pullenia subcarinata (d'Orbigny)	<1	<1	<1	<1	<1							
Pyrgo spp				4								
Quinqueloculina stalkeri Loeblich and Tappan				<1	<1	1						
Q. spp	<1	<1										
Robertinoides sp				<1								
Rodulus sp	<1(2)	<1	<1		<1							
Triloculina spp							<1	<1	1		<1	1
Uvigerina hollicki Thalmann	19(5)	28	30	1	<1	<1	<1			<1		
Valvulineria sp		<1									1	<1
Virgulina pauciloculata Brady	<1(1)	<1		<1	<1	<1	<1					
V. spinosa Heron-Allen and Earland	<1	<1										

TABLE 79.3.—*Distribution of Foraminifera in core 4*—Continued

[Abundance given as percentage of dead faunas. Number of living specimens in top 2 cm is shown in parenthesis]

Species / Age / Depth in core (cm)	Recent			Pleistocene(?)								
	0–2	2–14	14–26	26–29	28–32	41–42	51–52	61–62	71–72	81–82	91–92	101–102
Planktonic												
Globigerina bulloides d'Orbigny	<1	1	<1	5	9	4	6	6	3	7	11	12
G. pachyderma Ehrenberg	4	7	6. 5	8	9	6	4	6	8	5	3. 5	5. 5
Globigerinita uvula (Ehrenberg)	2			1	<1							
Total population in 10 cc of sediment	1, 200	1, 280	250	900	1, 000	500	350	325	190	700	440	460

The distribution of species in core 4 is tabulated in table 79.3. The faunas of the upper 26 centimeters of this core contain a high percentage of *Angulogerina angulosa*, *Epistominella pacifica*, and *Uvigerina hollicki*. The faunas below 29 centimeters are characterized by *Cassidulina islandica* and subsp. *nørvangi*, *Elphidium* cf. *E. bartletti*, *E. clavatum*, and *Elphidiella groenlandica*. These species are characteristic of Recent faunas of the Point Barrow region (Loeblich and Tappan, 1953) and the Canadian and Greenland Arctic (Phleger, 1952). The species characterizing the upper part of the core, with a few exceptions, form only a very small percentage of the faunas from the lower part.

In core 4, woody material is common below the faunal break and rare above. Chlorite is the predominant clay mineral below and montmorillonite above. G. W. Moore (written communication, 1961) considers the chlorite to have been derived from the erosion of rocks on Kodiak Island by former glaciers. Perhaps the woody material was also delivered to the marine environment by these glaciers.

The evidence suggests that while the sediment sampled by cores 4, 8, and 9 was being deposited, the water temperature and characteristics abruptly changed from Arctic to boreal. The most probable explanation for this change is that the lower sediment containing the abundant Arctic species was deposited when glaciers and pack ice were nearby and that the upper sediment was deposited when conditions resembled those of today. Thus, the faunal break in the cores marks a possible Pleistocene-Recent boundary in the sediments in the Gulf of Alaska.

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GLACIOLACUSTRINE DIAMICTON DEPOSITS IN THE COPPER RIVER BASIN, ALASKA

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Abstract.—The character, stratigraphic relations, and distribution of nonsorted and poorly sorted diamicton deposits, interbedded with stratified lacustrine sediments, indicate that many diamicton units were deposited in a lacustrine environment, and that turbidity currents and subaqueous mudflows were important as agents of deposition. Commonly, the diamicton is till like in character.

Numerous diamicton units interbedded with stratified lacustrine sediments occur within the unconsolidated deposits of Pleistocene age in the Copper River Basin, Alaska. The term "diamicton," proposed by Flint and others (1960a, b) for "nonsorted or poorly sorted terrigenous sediment that consists of sand and/or larger particles in a muddy matrix," is especially applicable to both the nonsorted, till-like units not deposited directly by glaciers, and to poorly sorted units of similar origin.

The Copper River Basin, in south-central Alaska, is approximately 5,500 square miles in areal extent and is surrounded by high mountains with numerous glaciers. The Wrangell Mountains lie to the east, the Chugach Mountains to the south, the Talkeetna Mountains to the west, and the Alaska Range to the north.

The distribution of glacial erratics and till around the margin of the basin and on top of bedrock hills within the basin indicates that the entire basin floor was covered with ice one or more times during early Pleistocene time. In addition, in the northeastern part of the Copper River Basin there is stratigraphic evidence of three younger, major glaciations during which ice did not completely cover the basin floor.

During each major glaciation, glaciers advancing in the mountains surrounding the Copper River Basin dammed the drainage of the basin, thus impounding an extensive proglacial lake (Nichols, 1956, p. 4; Ferrians and Schmoll, 1957; Nichols and Yehle, 1961, p. 1066). The lake that existed during the last major glaciation covered more than 2,000 square miles of the basin floor, and numerous glaciers and sediment-laden glacial streams debouched into it. At Gakona, in the northeastern part of the basin, the age of the sediments that were deposited in this lake is bracketed between a maximum radiocarbon date of greater than 38,000 years B.P. (before present) and a minimum date of 9,400±300 years B.P. (Rubin and Alexander, 1960, p. 170 and 171, samples W–531 and W–714). Therefore, the last major glaciation in the Copper River Basin is comparable in age to the last major glaciation (Wisconsin) of central North America.

The conclusions presented in this article are based primarily on observations of the diamicton and associated materials deposited in the northeastern part of the Copper River Basin during the last major glaciation. The diamicton units were examined in detail at Gakona, where river bluffs 250 feet high provide nearly continuous exposure of these deposits for more than a mile.

The diamicton units range in thickness from less than 1 inch to as much as 150 feet. Some of the nonsorted, till-like diamicton deposits have only a few phenoclasts, some are intermediate in character, and others consist predominantly of phenoclasts. The poorly sorted diamicton deposits are relatively fine grained, with the coarser fraction generally limited to sizes smaller than cobbles. Locally, these poorly sorted deposits show well-developed graded bedding.

TYPES OF DIAMICTON AND ASSOCIATED DEPOSITS

Nonsorted diamicton

Numerous units of nonsorted, till-like diamicton alternate vertically with bedded lacustrine sediments and with poorly sorted diamicton (fig. 91.1). Locally these alternations may repeat several times within a

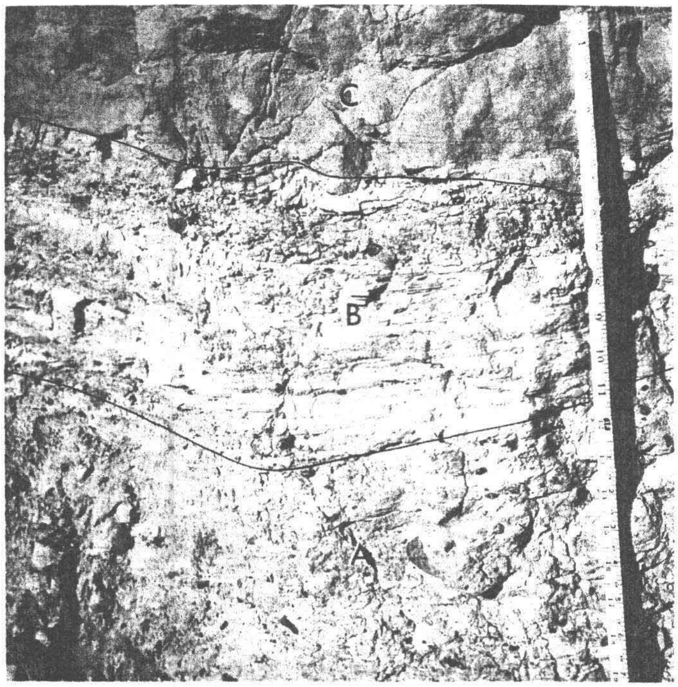

FIGURE 91.1.—Section of lacustrine deposits near Gakona consisting of (*A*) nonsorted till-like diamicton, (*B*) interbedded poorly sorted diamicton and well-stratified sediment, and (*C*) poorly sorted diamicton (sand and granules in a clayey-silt matrix).

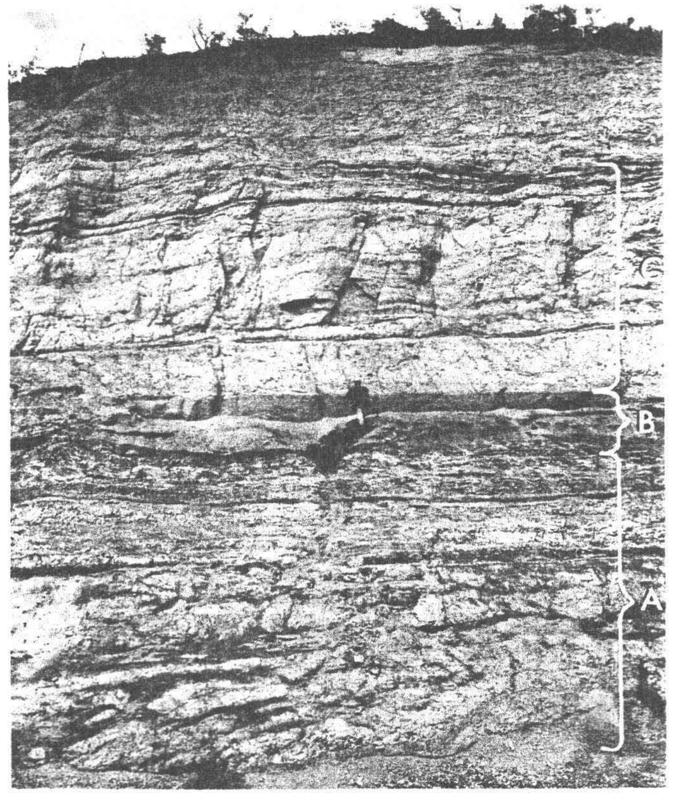

FIGURE 91.2.—Section of lacustrine deposits near Gakona consisting of (*A*) well-stratified sediment interbedded with poorly sorted diamicton units at base—lower part deformed, (*B*) gravel unit which has the form of a channel filling (man standing on unit), and (*C*) thick unit of nonsorted diamicton with numerous thin zones of bedded silt, sand, and gravel, which give an overall bedded appearance to the unit.

stratigraphic thickness of a few feet. Generally, the contacts between these units are extremely sharp; the beds immediately underlying the diamicton units generally are not deformed, even though deformation is common within the rest of the lacustrine sequence. Many nonsorted diamicton deposits of this type occur as thick units consisting of a series of superimposed diamicton beds. The character of these beds makes them difficult to differentiate. These thick units generally include numerous thin, discontinuous deposits of horizontally bedded silt, sand, and gravel, which give them an overall bedded appearance (fig. 91.2). The variety of rock types, from various source areas, occurring in these diamicton deposits indicates that considerable mixing has occurred.

The stratigraphie relations, character, and distribution of these deposits indicate that they were deposited mainly by dense turbidity currents and (or) subaqueous mudflows. The intimate stratigraphic relation between the diamicton deposits and the bedded lacustrine sediments, plus the general lack of deformation of beds immediately underlying the deposits, precludes the possibility that they were deposited directly by glaciers. Kuenen and Migliorini (1950, p. 105) have shown experimentally that very dense turbidity currents could deposit materials that do not show graded bedding, and Menard and Ludwick (1951, p. 12) suggest that several superimposed currents depositing simultaneously also could cause deposition of material that would not show graded bedding.

Some nonsorted diamicton units occurring within the lacustrine sequence contain rock types from a single source area and have phenoclasts that are angular to subangular, whereas stratigraphic units immediately below contain mixed rock types and have phenoclasts that are subrounded to rounded. The character of this type of diamicton is similar to that of a subaerial volcanic mudflow deposit that occurs in the Copper River Basin (Ferrians and others, 1958). A subaqueous mudflow is the most logical agent that could have transported these angular to subangular rock fragments several miles out onto the lake floor without abrading them, and without eroding the underlying sediments. Because large accumulations of glacial and fluvial phenoclastic material with mixed rock types could have been the source of other subaqueous mudflows, it seems likely that some nonsorted diamicton units not having distinct mudflow characteristics also were deposited by subaqueous mudflows.

Other nonsorted diamicton units grade almost imperceptibly, both horizontally and vertically, into well-stratified fine-grained sediment. Many of these units occur as large lenses within bedded sediment and, consequently, are isolated from potential ice sources. Deposits of this type typically have a fine-grained matrix and relatively few pebble- and cobble-sized phenoclasts. The character of the pebbles and cobbles is quite similar to that of the ice-rafted pebbles and cobbles found in the associated laminated sediment. The isolation of these units from potential ice sources, the gradational contacts with laminated sediment, and the character of these deposits indicate that this type of nonsorted diamicton was formed by rapid, uniform deposition of fine-grained sediment, with the concurrent deposition of ice-rafted stones, and that it was not deposited directly by glaciers. The stratigraphic data suggest that the fine-grained fraction of this type of diamicton was transported to deep parts of the lake by turbidity currents generated by sediment-laden glacier-fed streams entering the lake.

Other, less important, depositional agents of nonsorted diamicton were glaciers and icebergs, which locally dumped phenoclastic material into the lake. Deposits of material dumped by glaciers characteristically have a chaotic stratigraphic relation with associated bedded sediment, because of subaqueous slumping and sliding. Material forming small pods of nonsorted diamicton is present locally within the bedded lacustrine sediments and probably was dumped into the lake by overturning icebergs which held large quantities of ablation debris in depressions on their upper surfaces.

Poorly sorted diamicton

Poorly sorted diamicton units occur interbedded with nonsorted diamicton and bedded lacustrine sediments (fig. 91.1). Generally, contacts are sharp between these units and dissimilar materials lying below and above them; bedded materials immediately underlying the diamicton units are not deformed. The variety of rock types occurring in these diamicton units indicates that considerable mixing has occurred. Some of these units display well-developed graded bedding (figs. 91.3 and 91.4) and, consequently, provide good evidence of deposition by turbidity currents. Many of these units that do not display well-developed graded bedding have stratigraphic relations and a lithologic composition similar to those that do; therefore, they also are considered to have been deposited by turbidity currents.

The end members of the continuum represented by typical deposits of subaqueous mudflows and turbidity

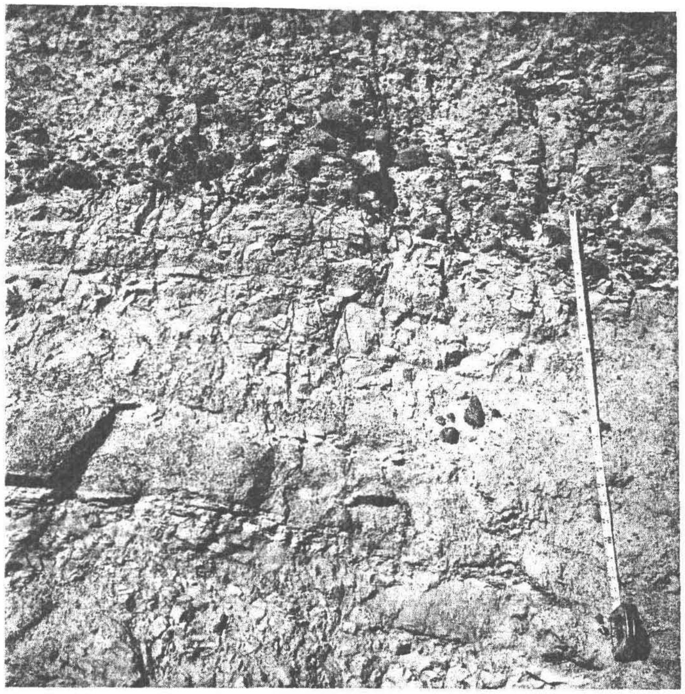

FIGURE 91.3.—Several fine-grained diamicton units, each of which grades upward from sand and granules in a clayey-silt matrix to massive fine sand, silt, and clay. The fine-grained diamicton units are overlain by a coarse-grained till-like diamicton unit which is graded also, to the extent that the cobble-sized phenoclasts are concentrated at the base. Slopewash occurs in the lower right corner. See figure 91.4 for closeup view of one of the fine-grained diamicton units.

currents can be distinguished by the presence or absence of well-developed graded bedding, by the character of the included phenoclasts, and by the degree of mixing. However, it is very difficult to distinguish between the two types of deposits in the intermediate range.

Bedded sand and gravel

Numerous relatively thin discontinuous deposits of bedded sand and gravel, ranging in thickness from less than 1 inch to several feet, are interbedded with the diamicton, especially within many of the thick units (fig. 91.2). Generally these deposits are relatively uniform in thickness, but locally they occur as what appear to be channel fillings (fig. 91.2). Commonly the included phenoclasts are not so well rounded as normal stream-deposited phenoclasts, indicating that the material was not transported far by water currents. The character of these bedded sand and gravel deposits and their association with lacustrine diamicton units, plus the lack of any evidence suggesting that deposition in the lake was interrupted by subaerial conditions, indicate that these deposits were laid down by turbidity currents with a velocity high enough, in relation to

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density, to remove the fine-grained material and to deposit sand-, pebble-, and cobble-sized material.

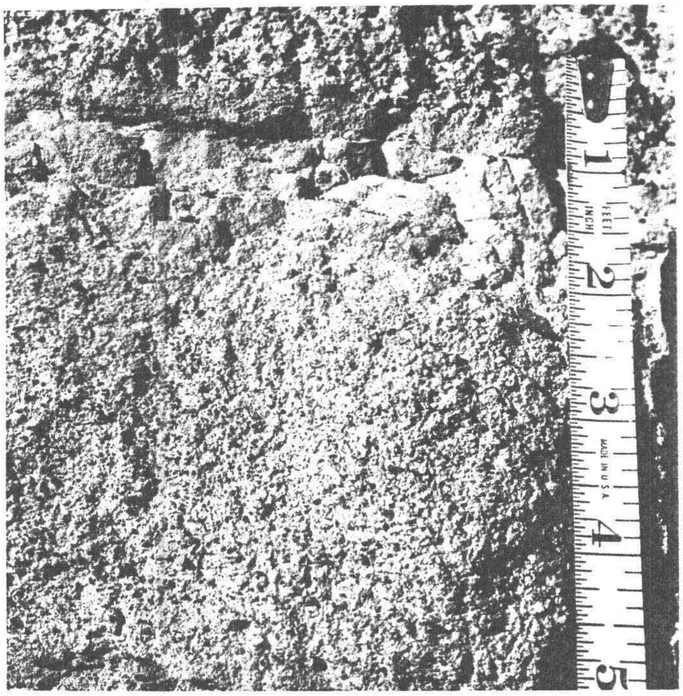

FIGURE 91.4.—Closeup view of a fine-grained, poorly sorted diamicton unit which grades upward from sand and granules in a clayey-silt matrix to massive fine sand, silt, and clay. Base of overlying diamicton unit is at top of picture. This unit is one of several shown in figure 91.3.

DEFORMATION OF LACUSTRINE BEDS

Deformation of beds is common within the stratified lacustrine deposits; however, the bedded sediments that underlie the diamicton units deposited by turbidity currents and subaqueous mudflows generally are not deformed. Most of the deformation probably was caused by subaqueous slumping and sliding. Nichols (1960) has described two types of deformation of lacustrine beds in the southeastern part of the Copper River Basin, and has postulated that the deformation was caused by slumping, triggered by earthquakes.

CONCLUSIONS

Gould (1951) discusses turbidity currents formed by the sediment-laden Colorado and Virgin Rivers entering Lake Mead in the western United States. The glacier-fed sediment-laden streams debouching into the proglacial lake that existed in the Copper River Basin also must have created turbidity currents because of the heavy load of suspended sediment. Even today, the glacier-fed streams in the basin are heavily laden with suspended sediment. For example, the Copper River near Chitina, in the southeastern part of the basin, discharged 71,395,000 tons of suspended sediment during the period June 17 to September 6, 1957 (U.S. Geological Survey, 1960, p. 40), an average of 870,670 tons a day.

Stratigraphic analysis of the lacustrine sediments indicates that much of the fine-grained bedded sediment, as well as the relatively fine-grained diamicton, was transported by turbidity currents generated by sediment-laden glacial streams entering the lake. Numerous thin sand beds interbedded with the varve-like clayey silt attest to the presence of currents, even in the relatively quiescent lacustrine environment. An apparent secondary preferred orientation of the *A*-axis of ice-rafted phenoclasts in these varve-like sediments may have been caused by currents, according to Schmoll (1961, p. C195). Kuenen (1951a, b) has postulated that even "glacial varves" can be deposited by turbidity currents formed by sediment-laden melt water entering lakes.

The rapid accumulation of deltaic material where major streams entered the lake, and of ice-deposited material where glaciers bordered the lake, created unstable slope conditions which resulted in slumping. Slumping of this type probably generated the subaqueous mudflows and dense turbidity currents that deposited many of the coarse-grained diamicton units.

In summary, the character, distribution, and stratigraphic relations of the various types of lacustrine diamicton conspicuous in the Copper River Basin indicate four agents of deposition, the first two of which were most important: (1) Turbidity currents; (2) subaqueous mudflows; (3) glaciers, which dumped phenoclastic material into the lake; and (4) icebergs, which dumped phenoclastic material into the lake.

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