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Cover: *Oblique aerial view northeast of Valdez Creek Mine and glaciated lower Valdez Creek valley. Photograph courtesy of Valdez Creek Mining Company.*

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CONTENTS

FIGURES

TABLES

SHEET

[In pocket]

MULTIPLE GLACIATION AND GOLD-PLACER FORMATION, VALDEZ CREEK VALLEY, WESTERN CLEARWATER MOUNTAINS, ALASKA

By
Richard D. Reger[1] and Thomas K. Bundtzen[1]

ABSTRACT

Stratigraphic observations and a photointerpretive study of the Valdez Creek area provide evidence for pre-Illinoian, Illinoian, Wisconsin, and Holocene glaciations in the western Clearwater Mountains. Only a dissected remnant of the pre-Illinoian glacial trough is preserved on the upper north wall of Valdez Creek valley. The inset lower valley of Valdez Creek was scoured during the Illinoian glaciation. At that time, most of the placer gold in the lower valley was probably liberated from lodes in the Gold Hill-Lucky Hill area and deposited initially in till. Early Wisconsin glaciation in the Valdez Creek drainage was less extensive than the late Wisconsin advance, whether ice was locally derived or came south from the central Alaska Range. During late Wisconsin time, ice of the Susitna River glacier blocked Valdez Creek valley, producing an extensive ice-marginal lake that eventually filled with varved sediments, fan-delta deposits, outwash gravel, and till.

Drilling by Valdez Creek Mining Company geologists indicates that at least three principal paleochannel systems--A, B, and Tammany--and several subsidiary paleochannel systems were incised into bedrock in lower Valdez Creek valley. These paleochannels were filled by auriferous alluvial gravel and slightly retransported, auriferous till during former ice-free periods. Cumulative evidence indicates that paleochannel A is Sangamon in age and that Tammany paleochannel is mid-Wisconsin (Boutellier) in age. Paleochannel B was probably cut during a late Illinoian interstade. Recognition that early Wisconsin glacial advances were less extensive than late Wisconsin advances in this part of the western Clearwater Mountains raises the possibility that buried pre-Wisconsin placers in other glaciated areas of Alaska are preserved within the limits of late Wisconsin glaciation.

Exploration targets for gold placers in the Valdez Creek area include (1) upchannel extensions of known buried paleochannels, (2) buried fans that compose downchannel extensions of known buried paleochannels, (3) other unexploited buried paleochannels, (4) medial-moraine deposits downvalley from the Gold Hill-Lucky Hill upland, (5) former courses of ice-marginal meltwater streams that reworked gold-bearing valley-side colluvium and till, and (6) zones where gold-bearing moraines were breached and reworked by late-glacial and postglacial axial and tributary streams.

INTRODUCTION AND MINING HISTORY

Valdez Creek mining district is located in the western Clearwater Mountains of the southcentral Alaska Range (fig. 1). Placer gold was discovered on the alluvial fan downstream of the canyon of lower Valdez Creek (sheet 1) by a party of prospectors from Valdez on August 15, 1903 (Moffit, 1912; Tuck, 1938; Dessauer and Harvey, 1980). Further exploration upstream resulted in the discovery of rich bench gravels in the fall of 1904 in the lower north wall of the canyon. Subsequent exploitation of the north-bench gravels revealed that they were part of a deeply buried paleochannel cut into bedrock (fig. 2). This paleochannel, which became known as Tammany channel, was mined by opencut, hydraulic, and underground-drift methods; it contributed most of the gold recovered from Valdez Creek mining district through the end of World War II (Smith, 1981).

For nearly 30 yr following World War II, gold mining in Valdez Creek district was confined to small placer-mining ventures--including a hydraulic operation on Dry Creek (sheet 1)--and reconnaissance exploration drilling. Paleochannel A was discovered in 1981 by consulting geologist Don Stevens. WGM, Inc., operator for Camindex Mines, Inc., subsequently started a large-scale churn-drilling program on the upland bench in the vicinity of the former settlement of Denali (Bundtzen and others, 1984; sheet 1). In 1983 WGM announced discovery of several rich, superimposed paleochannels incised into bedrock of the upland beneath 30 to 100 m of glacial and glaciofluvial sediments. Large-scale mining began in 1984 and Valdez Creek Mining Company (VCMC), operator of the project, has produced 202,421 oz (6,295 kg) of refined

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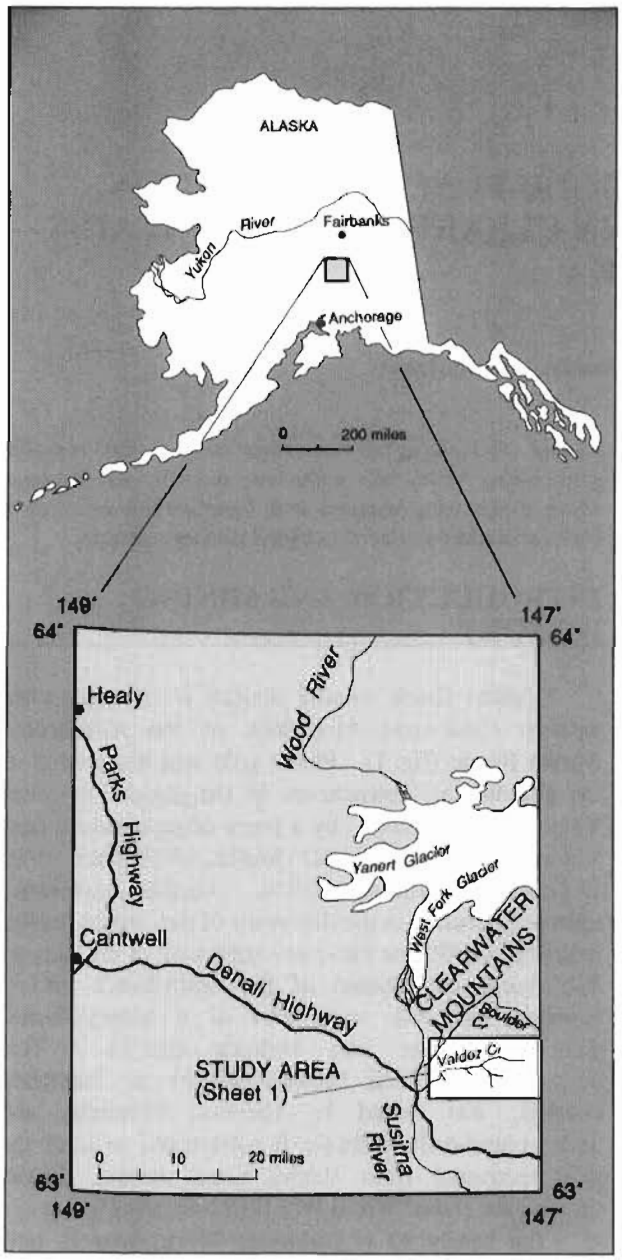

Figure 1. *Index map of central Alaska Range, showing location of study area.*

gold, making Valdez Creek Mine (VCM) Alaska's largest gold producer in 5 of the last 6 yr. Eventually, VCMC became fully owned by a joint-venture partnership that includes three Canadian firms: Camindex Mines Ltd. of Toronto, owning 51 percent; Cambior Inc. of Montreal, owning 25.9 percent; and American Barrick Resources, Ltd., of Toronto, owning 23.1 percent. In 1988 the joint venture arranged a committee management system, in which Cambior Inc. provides the lead role (Hughes, 1989). In October 1989 the joint venture closed the mine until gold prices improve and issues concerning an expensive stream-diversion project are resolved. Placer-gold reserves in VCMC's paleochannels now stand at 627,000 oz (19,499 kg), including 316,000 oz (9,827 kg) classified as proven or probable, which most likely will insure future production from the property. Total production from the Valdez Creek district from 1904 through 1989 is estimated at 243,908 oz (7,585 kg) of gold and 36,201 oz (1,122 kg) of byproduct silver--virtually all of which was recovered from placers in the Valdez Creek drainage (table 1).

ACKNOWLEDGMENTS

Although Bundtzen has studied sediments in VCM since 1984, most of this study was accomplished during August 1988 while we were mapping cooperatively with the U.S. Bureau of Mines in the southcentral Alaska Range. Our work would not have been possible without the encouragement and cooperation of the VCMC staff; we particularly acknowledge the assistance of Richard Hughes (Mine Manager), Pete Oslund (former Mine Manager), Paul Martin (Chief Engineer), Jerry O'Connor (Senior Geologist), Jim Wachter (Geologist), Robert 'Grog' Petersen (Geologist), and Mary MacDonald (Goldroom Supervisor). Concepts presented in this report benefited from discussions with several colleagues: Mike Balen (U.S. Bureau of Mines), Jason Bressler (WGM, Inc.), Laurel Burns (DGGS), John Cook (U.S. Bureau of Land Management), Steve Fechner (U.S. Bureau of Mines), Jerry Harris (University of Alaska Fairbanks), Dave Hopkins (University of Alaska Fairbanks), Tom Smith (DGGS), Steve Teller (University of Alaska Fairbanks), and Milt Wiltse (DGGS). We appreciate reviews of this report by Jerry O'Connor, Tom Smith, and Milt Wiltse, and especially the thoughtful comments by Steve Teller, which considerably improved this paper. We gratefully acknowledge the editorial assistance of Karen Adams (DGGS).

GENERAL GEOLOGY OF DENALI PALEOCHANNEL SYSTEMS

In the vicinity of the former town of Denali, mining-company geologists identified at least three principal, superimposed, gold-bearing paleochannels cut into bedrock subparallel to the modern canyon of lower Valdez Creek and slightly offset to the northwest upstream of the sharp bend in the modern canyon (Bressler and others, 1985; Teller and Bressler, in press). Principal gold-bearing paleochannels have been designated (from youngest to oldest) Tammany paleochannel, discovered in 1904; A paleochannel, discovered by drilling

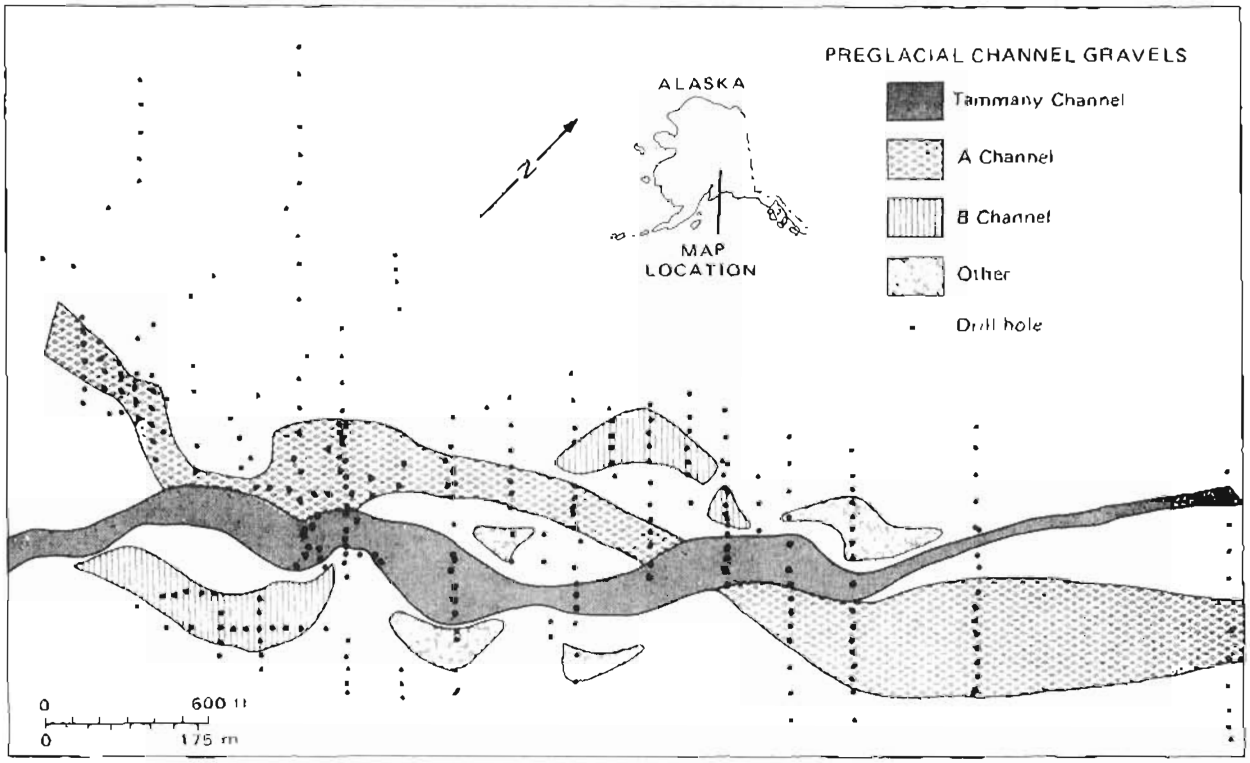

Figure 2. *Plan view of paleochannel systems in Valdez Creek Mine. From Eakins and others (1985, fig. 16) after Bressler and others (1985).*

in 1981; and B paleochannel, discovered by drilling in 1984. Other, less well defined, paleochannels were also discovered by drilling (fig. 2). Each paleochannel follows a unique course at a distinct elevation, whereby younger channels cut older channels (Teller and Bressler, in press). According to Moffit (1912), the bedrock floor of Tammany channel is 60 ft (18 m) above Valdez Creek where the modern canyon transects the paleochannel system. In plan view, paleochannel patterns are straight to meandering, simple, and distributary (fig. 2).

The paleochannels are fairly narrow, V-shaped in cross section, and as deep as 10 m. Steep bedrock walls are primarily argillite-phyllite but locally consist of hornfels and quartz monzodiorite porphyry. Paleochannel walls and floors possess a thin, slightly decomposed near-surface rind that probably formed by contact with ground water. The floors are typically slightly fluted by the passage of water-borne particles and bear no evidence of polishing or striating by glacial ice (Ross, 1933).

Previous observers indicated that alluvial pay gravels filling the narrow bedrock channels vary considerably. Lower gravels exhibit numerous cut-and-fill structures, and upper gravels have planar bedding (Smith, 1970a, 1981); coarse clasts up to cobble size show obvious imbrication (Bressler and others, 1985). Locally, gravels are poorly sorted (Tuck, 1938), and some sections contain thin silt or clay layers that provide barriers upon which perched gold-placers accumulated (Moffit, 1912; Bressler and others, 1985). Ross (1933) noted that boulders up to 3 m diam are locally numerous at the base of the channel fill and are unevenly distributed in the rest of the fill. Smith (1981) pointed out the presence of numerous, discontinuous layers of rounded and subrounded cobbles. Detritus in the pay gravel represents rock types mapped in the drainage of Valdez Creek (Smith, 1970a, 1981); most abundant lithologies are argillite, schist, quartz diorite, and a distinctive alkali gabbro. Thickness of the paleochannel gravel fill averages about 3 to 4 m.

Placer gold is present throughout pay gravel filling the paleochannels but is concentrated in the lowest 1.6 to 3 m within a lag of large, subrounded, granitic boulders and in underlying fractured bedrock (Moffit, 1912; Ross, 1933; Tuck, 1938; Smith, 1981). Two suites of placer nuggets are recognized: most pieces are 'oatmeal-sized,' bright, smooth with round edges, and flat (Yeend, 1984; Cox and others, 1989); other pieces are rough with small fragments of attached gangue material. In general, gold nuggets are modest in weight, averaging about 0.1 oz (3.1 g) (Moffit, 1912). VCMC

Table 1. *Summary of placer-gold and -silver production in Valdez Creek mining district, 1904-89*
[Data from unpublished U.S. Mint records, 1904-68; Territorial Department of Mines semiannual reports, 1912-58; Smith, 1933; unpublished State of Alaska questionnaires, 1978-89]

Year	Number of mines	Employment	Volume of gold (oz)	Volume of silver (oz)	Total bullion value (dollars)
1904-6	4	275	7,862	1,164	165,102
1907	3	--	1,007	131	21,147
1908	4	175	4,837	677	101,577
1909	3	100	2,418	314	50,778
1910	--	--	1,451	195	31,000
1911	--	--	1,451	195	31,000
1912	1	--	387	50	8,127
1913	1	25	290	24	6,050
1914	1	50	193	39	4,100
1915	4	--	1,186	155	24,906
1916	3	--	1,468	190	30,828
1917	5	20	1,601	208	33,621
1918	4	--	286	38	6,006
1919	--	--	94	9	2,000
1920	--	--	475	62	10,000
1921	3	--	958	124	20,100
1922	5	--	1,376	178	28,896
1923	4	--	970	128	20,370
1924	5	--	352	46	7,392
1925	5	--	261	34	5,481
1926	3	--	396	51	8,316
1927	2	--	357	47	7,497
1928	4	--	693	89	14,553
1929	3	--	1,168	157	24,528
1930	5	12	1,879	244	39,459
1931	5	--	1,597	207	33,537
1932	4	--	1,148	149	24,108
1933	2	20	195[a]	26	4,095
1934	3	--	674	89	23,594
1935	3	--	1,323	172	46,305
1936	1	--	984	128	34,440
1937	3	--	1,031	138	36,085
1938-40	--	15	--	--	--
1941	1	15	44	6	1,540
1942	3	10	520	68	18,200
1943-46	--	--	--	--	--
1947	2	4	143	19	5,005
1948	2	2	24	2	840
1949	2	2	26	3	900
1950	--	--	--	--	--
1951	1	1	18	2	630
1952-56	--	--	--	--	--
1957	1	1	19	2	675
1958	3	6	69	10	2,415
1959	1	1	3	--	105
1960-61	--	--	--	--	--
1962	1	--	3	--	105
1963-76	--	--	--	--	--
1977	2	--	250	35	39,000
1978-83	--	--	--	--	--
1984	1	70	19,627	2,551	6,967,585
1985	1	105	29,833	3,937	9,606,226
1986	1	136	24,996	3,250	9,498,480
1987	1	150	21,068	2,823	9,585,940
1988	1	155	44,494	8,467	18,909,950
1989[b]	2	175	62,403	9,568	22,980,500
TOTAL			243,908	36,201	78,523,094

[a]Placer-gold production was greater than indicated on table, according to Territorial Department of Mines records, but no specific figures are available.

[b]Data inclusive through October 15, 1989.

-- = Mine records not available. Some minor placer gold was produced during periods 1938-40, 1963-76, and 1978-83; modest amounts of lode gold have also been intermittently produced but are not included in table.

data indicate that 72.6 percent of the recovered gold is between 0.97 and 5.14 mm diam, 22.8 percent is smaller than 0.97 mm, and 4.7 percent is larger than 5.14 mm (Hughes, 1989). Gold recovered from placers in the Valdez Creek drainage has a remarkably consistent fineness of 852 (Smith, 1941; Eakins and others, 1985; Bundtzen and others, 1986, 1987), although two exceptions to this consistency are placer gold recovered from Lucky Gulch (fineness = 828) and from Tammany channel near Timberline Creek (fineness = 844) (Jerry O'Connor, written commun., 1989; sheet 1). In addition to gold, placer concentrates typically contain abundant pink garnet, green and brown hornblendes, magnetite, and pyrite; minor zircon, apatite, staurolite, sillimanite, kyanite, and biotite; and rare yellow garnet, epidote, hypersthene, rutile, and probably monazite (Moffit, 1912; Ross, 1933). Concentrates collected by Wimmler (1925, p. 70-71) from White Creek (sheet 1) contained hessite (a silver telluride), native bismuth, arsenic, and base-metal sulfides; goldfieldite has been identified on Timberline Creek (Smith, 1981). So far, these minerals from White and Timberline Creeks have not been identified in A paleochannel gravels currently mined by VCMC.

In the thick section above the pay-gravel fill of the bedrock paleochannels, sediments are related to stream activity or directly and indirectly to glaciation (Moffit, 1912; Ross, 1933). Although Smith (1970a, 1981) observed that the top of the section includes outwash gravels overlain by till containing numerous erratic boulders, no detailed descriptions of the upper section are published.

OBSERVATIONS IN VCM PIT A5

Our studies in VCM have been brief, and limited to deposits in and overlying paleochannel A. Bundtzen studied sediments in pit A3 on November 21, 1986, and both of us sampled organic deposits at the bottom of pit A5 on August 5, 1988, shortly after a fragmented proboscidean tusk was removed from pay gravel. We both made later tours of pit A6 in the spring and summer of 1989. Our observations of the stratigraphy in the southeastern wall of pit A5 are supplemented by results of subsequent radiocarbon dating and pollen analysis of sediment samples we collected and by an unpublished radiocarbon date (fig. 3, sample QL-4278) kindly provided by John Cook (oral commun., 1989).

Figure 3 summarizes, in a general way, the section exposed in the southeastern wall of pit A5 on August 5, 1988. Subrounded to rounded granitic boulders of paleochannel A were concentrated on argillite-phyllite bedrock (fig. 3, unit 1) and scattered throughout the 4.5-m-thick pay gravel (fig. 3, unit 2; fig. 4). A radiocarbon date of greater than 32,310 yr B.P. (fig. 3, sample BETA-18870) was determined for shrub twigs and branch fragments collected on November 21, 1986, from a correlative lower pay gravel in pit A3. A 1.2-m length of an 18-cm-diam, broken tusk, probably of a mammoth (*Mammuthus*), was collected 3 m below the top of pay gravel in pit A5 on August 3, 1988; its in-situ location was shown to us by the worker who found it. A small amount of collagen extracted from part of this tusk, which is archived in a deep freeze at the University of Alaska Fairbanks Museum, was dated by standard methodology at 39,900 +2,800 -2,100 yr B.P. (fig. 3, sample QL-4278) at the University of Washington (Minze Stuiver, written commun., 1989).

Discussions with VCMC geologists indicate that they have not seen nor recognized evidence of significant soil development within the pay gravel. However, at the top of pay gravel there was, at least locally, a discontinuous lag of cobbles and boulders (fig. 3, unit 3), which, although the lag did not exhibit evidence of significant associated soil development, represents an unconformity. A 0.3-m-thick, felted and highly compressed peat (fig. 3, unit 4) covered the cobble-boulder lag at the locality we visited, but discussions with VCMC geologists indicate that it is present only rarely elsewhere. This peat was subsequently dated at greater than 40,000 yr B.P. (fig. 3, sample GX-14432).

Overlying the compressed peat was about 6 m of cross-bedded fine sand (fig. 3, unit 5), which we attribute to fan-delta deposition in a former lake. This sand was overlain by about 9 m of medium- to thick-bedded cobbly pebble gravel (fig. 3, unit 6) that contained granitic clasts.

The center of the section was dominated by two thick layers of thin-bedded (varved) silty fine sand (fig. 3, units 8 and 10; fig. 5) that were separated by a discontinuous tongue of iron-oxide-stained cobbly pebble gravel (fig. 3, unit 9). The lowest 5 cm of the 8.5-m-thick lower sand was composed of a single layer of silty, organic fine sand (fig. 3, unit 7; fig. 6) that was dated at 25,900 +3,600 -1,900 yr B.P. (fig. 3, sample GX-14433). A 4.5-kg sample of varved lacustrine silty fine sand was previously collected for pollen analysis (table 2) from pit A3 at a location 20 m stratigraphically above a radiocarbon sample (BETA-18870) in pay gravel of paleochannel A; we consider this sample location to be equivalent to the lower part of the middle thick sand in pit A5 (fig. 3, unit 8).

Discussions with VCMC geologists and brief inspection of their unpublished geologic information indicate that the thin interformational gravel tongue (fig. 3, unit 9) separating the thick fine-sand units is present elsewhere in VCM but is discontinuous. Above the gravel tongue, the upper thin-bedded silty fine sand

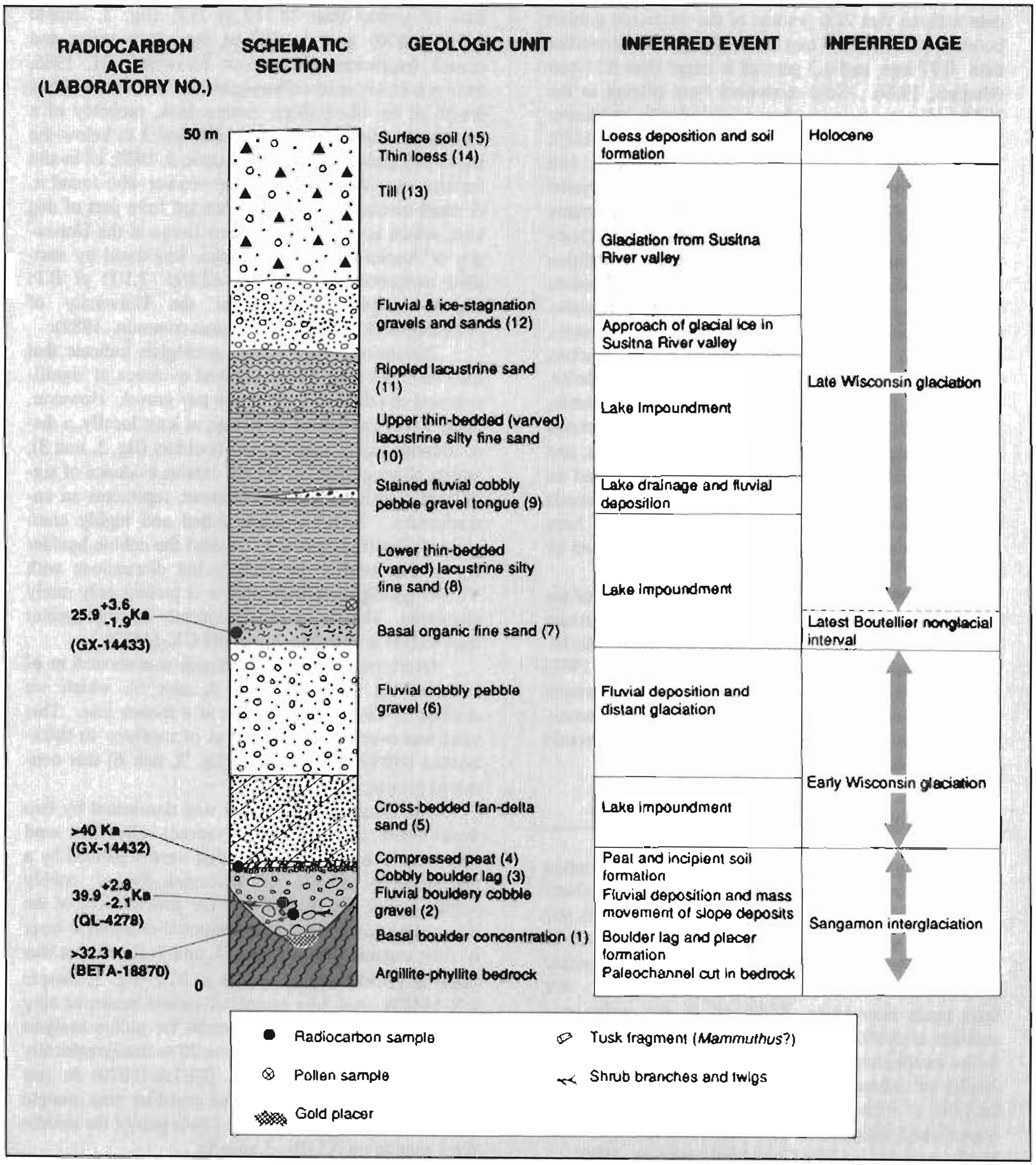

Figure 3. *Generalized stratigraphic section exposed August 5, 1988, in pit A5, Valdez Creek Mine, related to late Pleistocene events. Pollen sample in unit 8 and radiocarbon sample BETA-18870 were collected in pit A3 on November 21, 1986, from geologic units equivalent to those shown in this section. Numbers in parentheses in geologic-unit column are used in text for ready reference.*

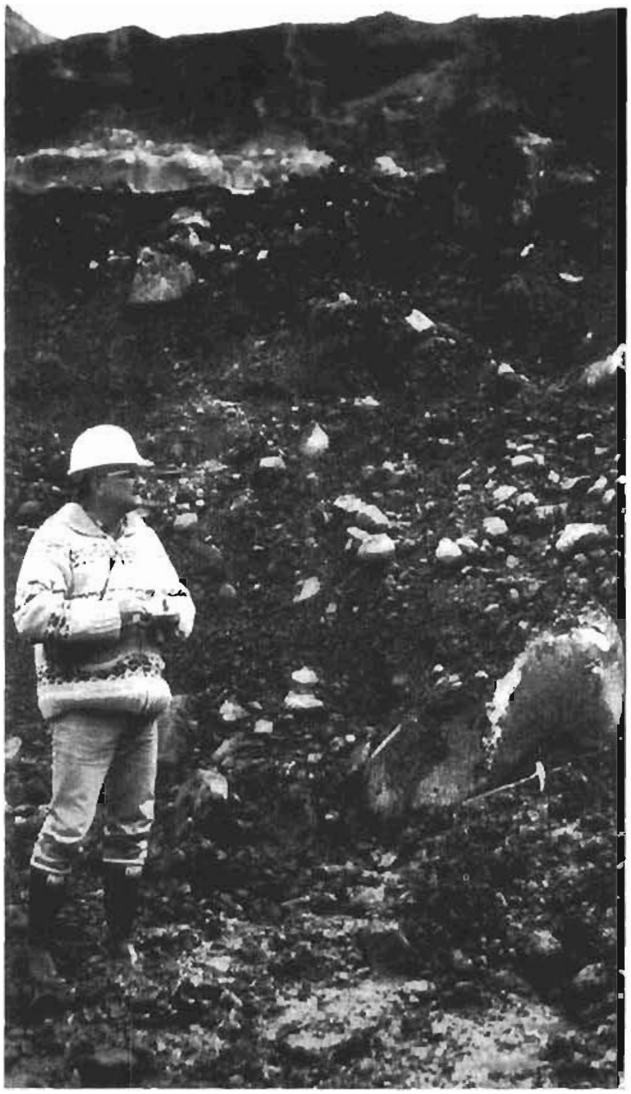

Figure 4. *Large granitic erratics in pay gravel at bottom of pit A5, Valdez Creek Mine. Note rock hammer for scale. Photograph taken August 5, 1988.*

(fig. 3, unit 10) was about 8 m thick. The upper 3.6 m of this sand in pit A5 (fig. 3, unit 11) were distinctly rippled and exhibited no obvious evidence for postdepositional deformation by ice shoving or glacier thrusting.

Disconformably overlying the thick sand section was a 4.5-m-thick complex unit of fluvial and ice-contact deposits composed of planar and cross-bedded cobbly pebble gravels interlayered and interfingered with sand layers and tongues (fig. 3, unit 12). Capping the whole section was an 8-m-thick till complex bearing a 30- to 40-cm-thick cover of loess (fig. 3, units 13 and 14). A moderately developed soil profile (fig. 3, unit 15) had formed in both the loess and the upper part of the till.

SUMMARY OF EVENTS DOCUMENTED IN PIT A5

The stratigraphic section in VCM pit A5 (fig. 3) provides evidence for the ages of paleochannel A and associated gold placers and for at least three glaciations.

FORMATION OF PALEOCHANNEL A AND ASSOCIATED DEPOSITS

The first Quaternary event directly documented in the section we observed in pit A5 is the cutting of paleochannel A to a local depth of about 4 m into the argillite-phyllite bedrock. The steep-walled, V-shaped channel cross section and the concentration of large boulders in the channel bottom are evidence for vigorous streamflow during channel incision and placer formation. Numerous meanders, anabranches, and straight reaches in the paleochannel patterns indicate that Valdez Creek had a variable morphology prior to lowering of local base level. Incision cycles of ancestral Valdez Creek were probably triggered by deglaciation (Smith, 1981). Most likely, local cycles of erosion and placer formation began at the mouth of Valdez Creek simultaneously with incision of the ancestral Susitna River into its alluvial fill during nonglacial intervals. Once initiated, the wave of downcutting and concentration of large boulders and heavy minerals probably progressed rapidly up Valdez Creek, following existing channels, whether straight, meandering, or braided.

We attribute development of the thin surface layer of decomposed bedrock in the channel walls and floor to contact with chemically active ground water after burial of bedrock and not to pedological processes active at the channel surface prior to formation of the basal boulder lag (fig. 3, unit 1) and simultaneous deposition of rich bedrock placers. Experimental studies undertaken by Schumm (1977) and his associates (Schumm and others, 1987) demonstrated that bedrock lags and bedrock placers typically form together by reworking of previous deposits that contain placer minerals. Cheney and Patton (1967) concluded that placers on bedrock beneath thick alluvial fill develop during infrequent floods of very large (unusual) magnitude when most of the channel fill is scoured out and all that is left are the largest clasts and heavy-mineral concentrates.

Lack of recognized evidence for weathering profiles in pay gravel burying the basal boulder lag and bedrock placers and filling paleochannel A (fig. 3, unit 2) implies that paleochannel A filled with gravel soon after it was cut. The presence of discontinuous layers of cobbles, scattered nests of boulders, and zones

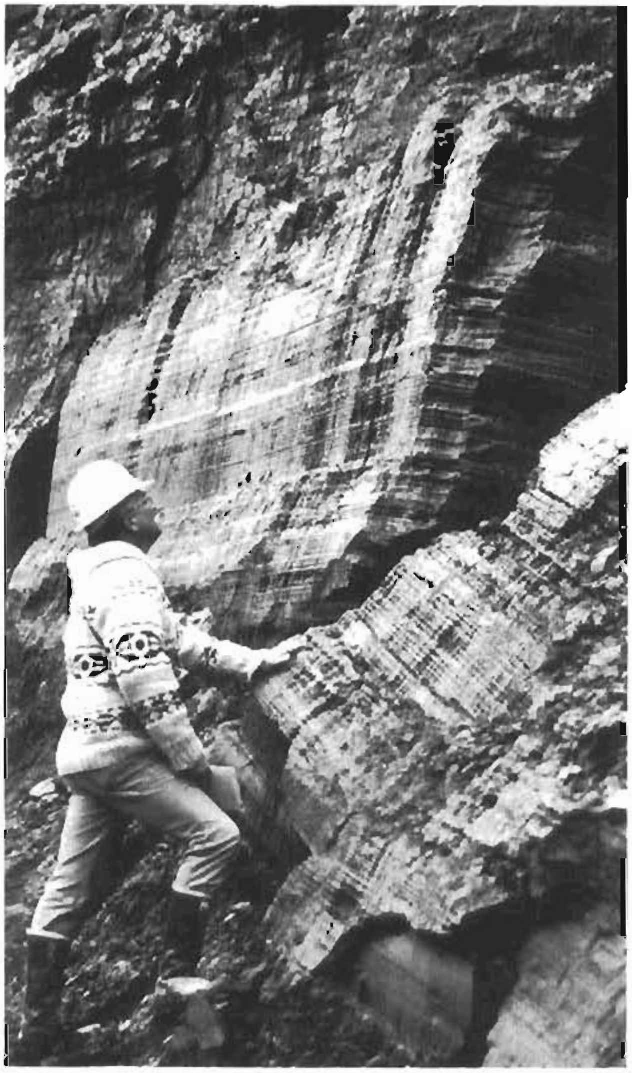

Figure 5. *Thin-bedded (varved) silty fine sand in lower part of thick lacustrine section, pit A5, Valdez Creek Mine. Note light-toned tephra layer. Photograph taken August 5, 1988.*

of poorly sorted sediment (fig. 4) in pay gravel records episodic floods and mass movement of slope deposits into the channel during gravel deposition. We agree with Smith (1970a, 1981) that clast lithologies represent outcrops in the Valdez Creek drainage basin and indicate that the basal boulder lag and overlying pay gravel probably came from the Valdez Creek basin.

The boulder lag at the top of pay gravel (fig. 3, unit 3) clearly documents a period of nondeposition and winnowing late in the gravel-deposition phase, but this lag probably does not have much time significance because it is not widespread in VCM and there is no soil profile associated with it. The well-compressed peat (fig. 3, unit 4) capping unit 3 records a period of high water level (shallow water table) and at least local thick accumulation of paludal vegetation on the gravel channel fill.

On the basis of several lines of evidence, none of which are conclusive, we propose a Sangamon[2] age for cutting of paleochannel A and formation of its associated bedrock placers. First, the large granitic boulders in the basal lag of paleochannel A and the boulders scattered throughout pay gravel were probably derived from the drainage of Valdez Creek. Their compositions, sizes, and shapes are consistent with glacial erratics brought in by ice that originated in the upper Valdez Creek drainage. We propose that these boulders were carried into the channel by mass movements--including debris flows and solifluction--that retransported till deposited in lower Valdez Creek valley during Illinoian time. Cutting of paleochannel A and simultaneous formation of the basal boulder lag with its associated bedrock placers postdate the Illinoian glaciation.

Second, there is evidence provided by the amount and type of woody material found in the gravelly fill of paleochannel A. Elsewhere in interior Alaska, Sangamon-age deposits contain considerable wood, including well-preserved remains of large trees (Péwé and others, 1989). However, the absence of tree remains in pay gravel of paleochannel A and the presence of only shrub remains do not rule out a Sangamon age for paleochannel A because current VCMC operations at 2,800 ft (850 m) elevation are just above modern treeline, where the locality was probably situated in Sangamon time. Further, the vigorous depositional environment of the gravels was probably not conducive to preservation of wood. The infinite radiocarbon age for shrub twigs and branches from pay gravel (fig. 3, sample BETA-18870) is inconclusive in that it sets only a minimum limit of 32,310 yr B.P. for the age of pay gravel.

Third, there is evidence provided by the broken proboscidean tusk found 3 m below the top of pay gravel (fig. 3). We believe that the finite average age of 39,900 yr B.P. (fig. 3, sample GL-4278) for this tusk is spuriously young for several reasons. First, it does not agree with the two infinite dates for wood and peat that are stratigraphically close to the tusk. Second, the amount of collagen dated was very small and the resultant readings upon which the 39,900-yr average is based are highly variable, as documented by the large sigma

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[2]Provisional ages are assigned to informal Quaternary time terms as follows: Holocene = younger than 9,500 yr ago; late Wisconsin glaciation = 9,500 to 25,000 yr ago; Boutellier interstadial = 25,000 to 65,000 yr ago; early Wisconsin glaciation = 65,000 to 122,000 yr ago; Sangamon interglaciation = 122,000 to 132,000 yr ago; Illinoian glaciation = 132,000 to 302,000 yr ago; pre-Illinoian time = 302,000 to 1,650,000 yr ago (modified from Ten Brink, 1983; Richmond and Fullerton, 1986).

Figure 6. *Medium-gray-brown organic fine sand at base of lower thick, lacustrine silty fine sand, pit A5, Valdez Creek Mine. Note knife handle (10 cm long) for scale. Photograph taken August 5, 1988.*

Table 2. *Spore and pollen from silty fine sand of lower part of varved lacustrine section, pit A3, Valdez Creek Mine*

[Plants identified by T.A. Ager, U.S. Geological Survey, Reston, Virginia]

Type of plant remains	Plant represented	Comment
Spores	Club moss (*Lycopodium*)	Most abundant spores, three species identified
	Sphagnum moss (*Sphagnum*)	
	Unidentified ferns	Few spores present
Pollen	Unidentified grasses	
	Unidentified sedges	
	Wormwood (*Artemisia*)	
	Aster (*Aster*) type	
	Fireweed (*Epilobium*)	
	Blueberry/Crowberry (*Vaccinium/Empetrum*) type	
	Valerian (*Valeriana*)	
	Bistort (*Polygonum bistorta*)	
	Jacob's ladder (*Polemonium*)	
	Crowfoot family (Ranunculaceae)	
	Pink family (Caryophyllaceae)	
	Willow (*Salix*)	Small amount of pollen
	Birch (*Betula*)	Very small amount of pollen; may be dwarf or resin birch
	Spruce (Picea)	Some well-preserved pollen

values of +2,800 and -2,100 yr (Minze Stuiver, written commun., 1989). Third, the chalky and permineralized appearance of the tusk indicates that it is considerably altered from its original character and that significant contamination exists. A radiocarbon date of 39,900 yr B.P. indicates that only 0.7 percent active carbon is present in the sample (Minze Stuiver, written commun., 1989). Hence, introduction of even small amounts of radioactive (younger) carbon could change an infinite radiocarbon age to an anomalously young finite age.

Fourth, the 0.3-m-thick, compressed peat at the top of pay gravel (fig. 3, unit 4) records at least local accumulation of hydrophilic vegetation on the paleochannel fill, probably during a relatively warm, moist, nonglacial climate. If 0.3 m of peat remains after glacial overriding, dewatering, and severe compaction, several meters of vegetal matter probably accumulated locally before subsequent burial. The peat found in the channel section could represent several millenia of geologic time. A similarly compressed peat of like thickness that crops out in the sea bluff at the mouth of Goose Bay in upper Cook Inlet is almost certainly of Sangamon age and pollen in that peat documents progressive development of a spruce-hardwood woodland much like the modern woodland in the Goose Bay area (Reger, unpublished data). Unfortunately, at this time we have no pollen data from the compressed peat in VCM to verify similar forest development.

Fifth, there is direct and indirect stratigraphic evidence preserved in pit A5 for at least two glaciations of Wisconsin age in the VCM area.

An alternative age for paleochannel A and its associated deposits is early middle Wisconsin interstadial (that part older than 40,000 yr). In our opinion, the presence of the thick compressed peat and the unconformity (local cobble-boulder lag) at the top of pay gravel and evidence for at least two glaciations of Wisconsin age in the overlying deposits argue against this possibility.

POST-PLACER EVENTS IN PIT A5 AREA

INITIAL LAKE FORMATION AND OUTWASH DEPOSITION

After formation of the cobble-boulder lag and deposition of peat at the top of pay gravel (fig. 3, units 3 and 4) during the Sangamon interglaciation, about 6 m of cross-bedded fine sand (fig. 3, unit 5) was deposited in the area of our pit A5 section during early Wisconsin time. We propose that this sand was deposited as a fan delta in a body of standing water (probably of lake size) that was impounded in lower Valdez Creek valley. This impoundment occurred probably because sedimentation by Valdez Creek could not keep pace with an abrupt rise in local base level that was a direct or indirect consequence of glaciation in Susitna River valley (fig. 1; sheet 1). The abrupt rise in base level could have been caused by physical blocking of lower Valdez Creek by a glacier advancing down Susitna River valley or by very rapid aggradation of the Susitna River flood plain to which Valdez Creek was graded.

Although we have not observed evidence of a former glacier dam in Susitna River valley during our brief inspections of the VCM deposit, other workers observed stratigraphic changes close to the mouth of Valdez Creek that could have resulted from the presence of a glacier (of post-pay-gravel age) in nearby Susitna River valley (Steve Teller, oral commun., 1989). If ice in Susitna River valley dammed lower Valdez Creek valley during early Wisconsin time, the glacier was not thick enough to reach a modern elevation of about 2,800 ft (850 m), the approximate elevation of the base of our section, because it left no evidence of deposition or erosion in pit A5; it was certainly much thinner and less extensive than the late Wisconsin glacier in Susitna River valley that extended 33 km downvalley from the site of VCM to the Hatchet Lake moraine (Smith, 1981, fig. 29; Williams and Galloway, 1986; Williams, 1989).

Less likely would be damming of lower Valdez Creek by rapid aggradation of the Susitna River flood plain, an indirect response to glaciation in the headwaters of Susitna River. Numerous flood-plain-marginal lakes of the rapidly aggrading, proglacial middle Tanana River (Péwé and Reger, 1983a), such as Harding, Quartz, and Birch Lakes, are modern analogs to this possible condition.

Following deposition of the fan-delta sand, about 9 m of cobbly pebble gravel (fig. 3, unit 6) was deposited in the pit A5 area. This gravel represents outwash deposition downstream from alpine glaciers somewhere in Valdez Creek valley.

Our evidence for an early Wisconsin age for the fan-delta sand (unit 5) and outwash gravel (unit 6) is the suspected Sangamon age of the underlying deposits and the date of 25,900 +3,600 -1,900 yr B.P. (fig. 3, sample GX-14433) for the organic fine sand on top of the gravel.

SUBSEQUENT LAKE IMPOUNDMENTS

The next major episode documented in pit A5 is an extended time of lake impoundment of lower Valdez Creek valley, recorded by units 7 through 11 (fig. 3). Evidence for initial ponding of a clear-water stream is the presence of the 5-cm-thick organic fine sand (fig. 3, unit 7) on top of the valley-train gravel (fig. 3, unit 6).

Soon after its formation, this clear-water pond or lake was apparently inundated by silty lake waters in which silty fine sand (fig. 3, unit 8) was deposited.

A qualitative survey for plant microfossils in the sediment sample collected near the bottom of the lacustrine section in pit A3 (fig. 3) revealed a surprising abundance of pollen and spores (table 2) that are indicative of the local vegetation during the early history of the lake. These microscopic plant remains are characteristic of an herb-dominated tundra with interspersed low willow and birch shrubs (Tom Ager, written commun., 1987). The presence of small amounts of well-preserved spruce pollen probably indicates that spruce was present in the region.

After deposition of at least 8.5 m of silty fine sand in the lake, drainage occurred (probably suddenly), as recorded by the gravel tongue (fig. 3, unit 9), possibly representing distal outwash, in the middle of the lacustrine section in pit A5. The thin, discontinuous nature of the gravel and the apparent immediate resumption of lacustrine-sand deposition at the site are evidence that lake drainage was very brief and that the blocking body was soon replaced. We speculate that rapid lake drainage could have resulted from catastrophic failure of an ice dam (Post and Mayo, 1971).

Following redamming of lower Valdez Creek and deposition of at least 4.4 m of silty fine sand (fig. 3, unit 10), lake depth became sufficiently shallow that oscillating surface waves began imposing a rippled character to the upper 3.6 m of bottom sand (fig. 3, unit 11) as the final lake fill was deposited.

Evidence for a latest Boutellier or late Wisconsin age, or both, for the middle (thick lacustrine) section in pit A5 (fig. 3, units 7 through 11) includes the date of 25,900 +3,600 -1,900 yr B.P. for the basal part of the section (fig. 3, sample GX-14433), the pollen record, and the inferred damming of lower Valdez Creek by a glacier advancing down Susitna River valley. The large sigma values for sample GX-14433 are due to the small amount of datable organic matter recovered from the fine sand (fig. 3, unit 7). These values make the average date of 25,900 yr B.P. slightly suspect in our opinion, but this date and the inferred history documented by the upper part of the pit A5 section complement results elsewhere in eastern Beringia (Hopkins, 1967; Hopkins and others, 1982; Kontrimavichus, 1984; Ritchie, 1984; Carter and others, 1989). Nonetheless, because the sigma values are large, others may consider this sample to actually be older than the limit of standard radiocarbon dating (Dave Hopkins, oral commun., 1989).

Although sediments between dated or inferred early and late Wisconsin deposits in Beringia have been dated between about 25,000 yr B.P. and the maximum range of radiocarbon dating by standard (not enriched) techniques (as much as 49,000 yr B.P.) (table 3), many of these results undoubtedly date deposits of waxing and waning glacial phases and not just the mid-Wisconsin interstadial complex. Most radiocarbon dates for the Boutellier nonglacial interval cluster from about 25,000 to 35,000 yr B.P. during the last half of the mid-Wisconsin interstade (Schweger and Janssens, 1980; Hamilton and Robinson, 1988). A local exception, based on radiocarbon and amino-acid (wood) dates, is suggested by Connor (1983), who estimated that the Boutellier nonglacial interval began as early as 65,000 yr ago southeast of the Valdez Creek area in the Copper River basin. Thus, the radiocarbon evidence in pit A5 supports an age of latest Boutellier or early late Wisconsin for the initiation of lake impoundment.

We assert that well-preserved spruce pollen in the lower lacustrine section of pit A3 (table 2) indicates the presence of spruce in the region and also implies a latest Boutellier or early late Wisconsin age for the base of the lacustrine section. Palynologists have similarly documented the widespread presence of spruce in mid-Wisconsin Beringian sediments (Rampton, 1971; Matthews, 1974; Schweger and Janssens, 1980; Connor, 1983, 1984; Heusser, 1983; Ager and Brubaker, 1985). In contrast, deposits that are clearly late Wisconsin in age typically contain little or no spruce pollen throughout interior Beringia, except for a spruce refugium in northwestern Canada; significant spruce pollen begins to reappear in spectra across this broad region only after about 9,500 yr ago (Ager, 1982, 1983, 1989; Matthews, 1982; Ritchie and Cwynar, 1982; Schweger, 1982; Ritchie, 1984; Ager and Brubaker, 1985). A possible exception is pollen evidence for an open, low-growing spruce forest with patches of shrubs and tundra that persisted into late Wisconsin time southeast of Valdez Creek in the eastern Copper River basin (Connor, 1983).

Our strongest evidence for a late Wisconsin age for most of the thick lacustrine section in pit A5 is physiographic and deductive in nature. Clearly, lower Valdez Creek was dammed for a significant time by a blocking body that occupied the adjoining Susitna River valley. Evidence for sudden drainage of the impounded lake, quickly followed by refilling, implies that the blocking body was a glacier that originated in the central Alaska Range to the north. To block lower Valdez Creek valley, this glacier must have flowed southward from its source area to a terminal position at least 25 km beyond the present terminus of the nearest large valley glacier in the Alaska Range (West Fork Glacier; fig. 1). Conditions causing glacial expansion of this magnitude existed during late Wisconsin time in the central Alaska Range (Péwé, 1975; Woodward-Clyde Consultants,

Table 3. *Published radiocarbon dates of middle Wisconsin sediments from Alaska and Yukon Territory*

Area	Radiocarbon date, in yr B.P. (Laboratory no.)	Material dated	Comment	Reference
South Fork Kuskokwim River, Farewell area	34,340 ± 940 (BETA-4222)	Organic layer at base of late Wisconsin loess	--	Kline and Bundtzen (1986, p. 131)
Big River, Farewell area	38,500 ± 980 (BETA-4221)	Forest bed in loess	Dates early loess rain in Farewell area	Do.
Sanford River, northeastern Copper River basin	28,300 ± 1,000 (W-1343)	Organic material in bluff	Dates interval when proglacial lake in Copper River basin was at low level (about 655 m)	Ferrians and Nichols (1965, p. 100)
	31,300 ± 1,000 (W-843)	do.	do.	Do.
Tyone River bluff, northwestern Copper River basin	29,450 ± 610 (DIC-1819)	Collagen from proboscidean bone in nonglacial fluvial gravel (unit 3)	--	Thorson and others (1981)
	$31,070^{+860}_{-960}$ (DIC-1862)	Small twigs from channel fill in fluvial sand of reworked nearshore lacustrine or deltaic deposits (upper unit 2)	--	Do.
Lower Nelchina River	>38,000 (W-842)	Organic material from locality D beneath drift of last major glaciation and above advance outwash	--	Williams and Galloway (1986)
	>38,000 (W-295)	Peat and woody debris from locality E in upper lacustrine deposits beneath advance outwash and drift of last major glaciation	--	Do.
Northern Talkeetna Mountains	$30,700^{+260}_{-1,230}$ (DIC-1859)	Interstadial sediments beneath late Wisconsin drift	--	Thorson and others (1981)
Upper Brushkana Creek, southcentral Alaska Range	>37,000 (GX-8057)	Wood chips in lacustrine fine sand 5.5 m above till	--	Woodward-Clyde Consultants (1982, table 3-2)
Little Delta River, northcentral Alaska Range	24,900 ± 200 (QL-1367)	Paleosol beneath outwash	--	Ten Brink (1983, table 1)
Delta Creek, northcentral Alaska Range	>40,000 (I-10679)	Organic material above Healy outwash	--	Do.
Toklat River, northcentral Alaska Range	28,750 ± 400 (I-10,534)	Organic material above Healy outwash	--	Ten Brink (1983, table 1)
Sushana River, northcentral Alaska Range	43,600 ± 700 (QL-1370)	do.	--	Do.
Gerstle River, northeastern Alaska Range	25,300 ± 950 (GX-2179)	Detrital wood fragments in sandy alluvium beneath unoxidized till and above oxidized till	--	Hamilton (1982, fig. 13 and tables 3 and 4)

Upper Tanana River valley	25,800 ± 800 (W-1174)	Organic zone at base of eolian sand beneath gravelly outwash	--	Hamilton (1982, fig. 13)
Harding Lake, middle Tanana River valley	26,500 ± 400 (W-4817)	Shallow-lake sediments in core	Top of interstadial unit	Ager and Brabaker (1985)
Isabella Creek basin, Fairbanks area	34,900 ± 2,950 (I-3083)	Shreds of organics, including twigs	Pollen zone Aa	Matthews (1974)
	>31,900 (I-4775)	Small amount of fine-grained organic residue from frozen organic silt	Pollen zone Ab	Do.
Fox permafrost tunnel, Fairbanks area	32,790 ± 560 (USGS-2553)	Silty peat with abundant roots over truncated ice wedge	Thaw-pond sediments	Hamilton and others (1988, fig. 12 and table 1)
	35,500 ± 2,400 (I-12,658)	Peat and sod mat over truncated, foliated ice wedge	do.	Do.
Antifreeze pond, Snag-Klutlan area, southwestern Yukon Territory	27,100 ± 390 (GSC-1198)	Organic material in pollen zone 2	Inverted dates for zones 1 and 2 may indicate age >31,000 yr for both zones (Schweger and Janssens, 1980, p. 315)	Rampton (1971, fig. 6)
	31,500 ± 700 (GSC-1048)	do.	do.	Do.
Northern St. Elias Mountains	29,600 ± 460 (GSC-769)	Woody organic material in silt beneath Icefield outwash II	Split of sample Y-1385	Denton (1974, table 1)
	30,100 ± 600 (Y-1385)	do.	--	Do.
	33,400 ± 800 (Y-1488)	do.	--	Do.
	$37,700^{+1,500}_{-1,300}$ (Y-1356)	do.	Oldest finite date	Do.
	>35,000 (GSC-734)	do.	Split of sample Y-1356	Do.
	>49,000 (Y-1486)	Peat stringer in base of Icefield till	Initiation of Boutellier nonglacial interval	Do.
Middle Fork Koyukuk River, central Brooks Range	28,450 ± 950 (I-10,816)	Wood beneath periglacial fan	--	Hamilton (1986, table 5)
Noatak River valley	30,070 ± 470 (USGS-1835)	In-situ roots in alluvium below Itkillik II end moraine	--	Do.
	34,840 ± 950 (USGS-1836)	do.	--	Do.
Epiguruk bluff, central Kobuk River valley	33,690 ± 960 (USGS-1659)	Wood and peat in peat bed	--	Do.
	34,900 ± 320 (USGS-1444)	Willow wood in peat bed	--	Do.

Do. = Ditto.
-- = No comment.

Table 4. *Radiocarbon dates indicating timing of last recession of late Pleistocene ice in general area of Valdez Creek Mine*

Area	Radiocarbon date, in yr B.P. (Laboratory no.)	Material dated	Comment	Reference
Upper Watana Creek valley, Talkeetna Mountains D-2 Quadrangle	9,395 ± 200 (GX-8035)	Wood in frozen lacustrine silt and clay	Last retreat of extensive ice from Watana Creek valley	Woodward-Clyde Consultants (1982, table 3-2)
Upper Deadman Creek valley, Healy A-3 Quadrangle	9,920 ± 265 (GX-8062)	Peat in fine-grained ice-disintegration deposits	Last retreat of extensive ice from upper Deadman Creek valley	Do.
Denali Highway near Maclaren River bridge, Mt. Hayes A-5 Quadrangle	10,565 ± 225 (GX-2049)	Lowest exposed frozen peat in palsa	Minimum age for extensive deglaciation in upper Maclaren River valley	Péwé and Reger (1983b, p. 129)
Upper Boulder Creek, Healy B-1 Quadrangle	9,035 ± 335 (GX-14437)	Frozen basal peat overlying fluvial sand in palsa	Minimum age for retreat of extensive ice in upper Boulder Creek valley	Reger (unpublished data, 1988)
Small lake north of Snodgrass Lake, Healy A-2 Quadrangle	9,195 ± 150 (GX-14438)	Frozen basal peaty organic silt overlying ice-disintegration deposits in palsa	Minimum age for deglaciation of Susitna River valley near Denali Highway bridge	Do.
Cantwell Creek valley near Cantwell, Healy B-4 Quadrangle	9,260 ± 150 (GX-14446)	Frozen basal woody organic silt overlying till in palsa	Minimum age for deglaciation of upper Broad Pass and upper Nenana River valley	Do.

Do. = Ditto.

1982; Hamilton and Thorson, 1983; Kline, 1983; Péwé and Reger, 1983b; Porter and others, 1983; Ten Brink, 1983; Ten Brink and Waythomas, 1984).

INUNDATION BY GLACIAL ICE

Following deposition of the rippled fine sand at the top of the thick lacustrine section (fig. 3, unit 11), outwash (fig. 3, unit 12) invaded the area of pit A5 and was followed by the arrival and passage of glacial ice. During this glaciation, the upper till in pit A5 (fig. 3, unit 13) was deposited along with ice-stagnation gravels (fig. 3, unit 12). Eventually, glacial ice in lower Valdez Creek valley thinned and retreated from the VCM area. During postglacial time, a surface loess (fig. 3, unit 14) was deposited and pedogenic processes produced a moderate soil profile (fig. 3, unit 15).

We contend that the last major glaciation of Valdez Creek valley probably took place in late Wisconsin time. Evidence for this argument is the late Wisconsin age for most of the thick lacustrine section (fig. 3, units 7 through 11) beneath the outwash and ice-contact units (fig. 3, units 12 and 13); soil development in the surface loess and in the upper part of the till (fig. 3, unit 15) documents significant Holocene weathering after glacial ice left the area. Further, physiographic evidence indicates that lower Valdez Creek valley was glaciated during the Hatchet Lake advance of the Susitna River lobe, which fronted in waters of a late Wisconsin ice-dammed lake that had a surface elevation between 3,016 and 3,218 ft (914 and 975 m) in the northwestern Copper River basin (Williams and Galloway, 1986).

The timing of late Wisconsin glaciation in the central Alaska Range is well documented by numerous published radiocarbon dates (Hamilton, 1982; Woodward-Clyde Consultants, 1982; Hamilton and Thorson, 1983; Péwé and Reger, 1983b; and especially Ten Brink, 1983; and Ten Brink and Waythomas, 1984). Regionally, ice expansions began close to 25,000 yr ago, and late Wisconsin ice generally left mountain valleys as late as 9,500 yr ago (Ten Brink, 1983; Ten Brink and Waythomas, 1984). Several radiocarbon dates demonstrate that Pleistocene ice last retreated from mountain valleys in the general area of VCM before 9,000 to 10,600 yr ago (table 4).

AGE IMPLICATIONS

Speculations on the formation and ages of paleochannel systems other than paleochannel A are relevant to the features found in pit A5. Knowing the age of paleochannel A and the relative ages of the Tammany, A, and B systems allows us to deduce the most likely ages of Tammany and B paleochannels. Paleochannel A cuts across paleochannel B, was cut deeper into bedrock, and its profile is 6 to 12 m lower than paleochannel B (Jerry O'Connor, oral commun., 1988); therefore, paleochannel A is younger than paleochannel B. Because we think paleochannel A is Sangamon in age, we speculate that paleochannel B probably formed during a late Illinoian interstadial episode of stream erosion and placer formation. Tammany paleochannel was cut 9 to 12 m deeper into bedrock than paleochannel A and 18 to 21 m deeper than paleochannel B (Jerry O'Connor, oral commun., 1989); it also cuts across both paleochannels A and B (fig. 2) and therefore postdates both. We speculate that Tammany paleochannel was cut in mid-Wisconsin (probably Boutellier) time when the local base level was significantly lowered following the retreat of glacial ice.

GLACIAL HISTORY OF VALDEZ CREEK VALLEY AND VICINITY

Landform evidence for widespread former glaciation of the Valdez Creek area was quickly recognized by early day geologists (Moffit, 1912). Tuck (1938, p. 123) noted a few localities where bedrock beneath sorted gravels is glacially striated, and he identified evidence for two ice advances in the area. He concluded (Tuck, 1938, p. 123) that the moraine in the vicinity of Denali was deposited by a sluggish lobe of the Susitna River glacier. Nichols (in Smith, 1981, fig. 29) identified prominent moraines and ice limits in the area and attributed them to three glacial advances: G_1 (Denali) = early Wisconsin; G_2 (Hatchet Lake) = late Wisconsin(?); and G_3 (Alpine Creek) = early Holocene(?). Smith (1981, pl. 1) mapped a prominent late Wisconsin end moraine that was deposited in the vicinity of Denali by ice derived from Valdez Creek valley and concluded that the last ice invasion of the VCM area came from Valdez Creek valley.

The purposes of our glacial-geologic investigation were to verify or modify previous mapping of glacigenic landforms and to relate past glaciations to known or likely sources of lode gold and known placers. In this study, former glacier limits and related landforms were traced on 1:51,420-scale black-and-white aerial photographs (M860, negatives 237-241) taken August 29, 1949, and on 1:65,000-scale infrared aerial photographs (ALK 60 CIR, negatives 6112-6122) taken July 19, 1980. These features were subsequently plotted on the 1:63,360-scale topographic base map of the Healy A-1 Quadrangle (sheet 1). The results of this preliminary study were then related to evidence in pit A5, VCM, to develop an integrated model of past glaciation for the Valdez Creek area.

GLACIAL EXTENTS

We recognize evidence for four distinct glacial episodes in the Valdez Creek area. Physiographic evidence of these episodes reflects varying degrees of postglacial modification of the corresponding glacial deposits and landforms in that progressively younger glacigenic landforms and deposits are consistently less altered by geomorphic agents.

FIRST GLACIATION

The storied cross profile of Valdez Creek valley displays the most obvious physiographic evidence for the earliest recognized glaciation in Valdez Creek valley. Only a deeply dissected, sloping remnant of the old glacial-valley wall is preserved between about 4,200 and 5,400 ft (1,270 and 1,640 m) elevation on the upper south-facing wall of the valley, 1,000 ft (300 m) above the modern floor (sheet 1). No primary morainal form remains recognizable there, and bedrock structures are widely visible on aerial photographs of the bedrock surface, indicating that former deposits have almost entirely been removed. Former ice limits of this age are inferred from highly modified ice-marginal channels cut into bedrock on the former glacial floor subparallel to modern contours (sheet 1). By comparison, the former ice-scoured south wall of Valdez Creek valley was virtually destroyed by vigorous subsequent alpine glaciation. All landforms there postdate the earliest known glaciation in the area, except possibly subtle notches and changes in slope between 4,400 and 4,900 ft (1,330 and 1,485 m) elevation along the crests of some ridges between fresh, deeply scoured glacial troughs (sheet 1).

Ice distribution during the earliest glaciation is not well known because most surfaces glaciated then were destroyed by later glaciation and by later slope and stream processes. Glaciers of this age apparently reached a present elevation of at least 5,500 ft (1,670 m) along the north wall of Valdez Creek valley, but tenuous evidence is preserved only as high as 4,600 to 5,000 ft (1,390 to 1,515 m) on the south side of the valley (sheet 1).

SECOND GLACIATION

Ice limits of the second glaciation are inferred from discontinuous ice-marginal channels on the lower north wall at the mouth of Valdez Creek valley, from poorly preserved lateral moraines and subtle slope breaks across colluvial blankets on slopes 400 to 1,200 ft (120 to 360 m) above modern floors of lower Valdez Creek and Timberline Creek valleys, and from three well-modified end moraines on upper Craig Creek (sheet 1). Other ice-modified surfaces inferred to have been scoured during this major advance are present between 4,500 and 5,000 ft (1,360 and 1,515 m) elevation in the notch between Gold Hill and Lucky Hill and on the upland between Roosevelt Creek and upper Valdez Creek (sheet 1). Quarrying and scouring by ice of the second glaciation were responsible for shaping most of the modern topography of Valdez Creek valley, including the inner lower valley, which is inset into the bedrock trough of the first glaciation. We do not recognize cirques occupied only by ice of this age; cirques of the second glaciation were probably reoccupied and deepened by ice of the third glaciation.

Till of the second glaciation blankets the floor and lower walls of lower Valdez Creek valley. Slope processes, primarily frost creep, solifluction, and gelifluction, have greatly modified or buried deposits of this advance there but have not completely stripped them from glaciated bedrock surfaces.

Ice of the second glaciation spread from source cirques at the head of mountain valleys in the Valdez Creek area and joined to form a compound valley-glacier system that, in turn, combined with other ice streams flowing south from Boulder Creek valley and down Susitna River valley (fig. 1). Local glaciers thickened enough to send a short lobe between Gold Hill and Lucky Hill into upper Lucky Gulch (sheet 1). Cross-cutting relations among ice-marginal channels and poorly preserved lateral moraines along the ridge north of VCM demonstrate that ice streams from Valdez Creek and Susitna River valleys did not fluctuate simultaneously (sheet 1). This situation was typical in the central Alaska Range, where short, relatively small glacier systems responded differently to climatic changes than long, relatively large glacier systems.

During the second glaciation, placer-gold-bearing till was deposited on bedrock in lower Valdez Creek valley by ice moving west to join the Susitna River lobe. Subsequent erosion and reworking of this till by stream and slope processes produced most of the rich gold placers in Tammany, A, and B paleochannels in VCM. In addition, some gold was undoubtedly transported from bedrock sources by high-energy streams.

THIRD GLACIATION

Evidence is most widespread for the third glaciation in Valdez Creek valley. Landforms indicating the former presence or passage of ice of this advance include horns; cirques; U-shaped, straight or slightly curved, steep-walled glacial valleys; arêtes and notched ridge lines; ice-modified passes across ridges; medial, lateral, and end moraines; ice-disintegration deposits; sideglacial stream gorges, channels, and related deposits; and outwash trains and fans graded to coeval moraines (sheet 1). These features are generally well preserved, except on steep slopes where slope processes have altered them.

Cirques of the third major advance have floors that range in elevation from 4,100 to 4,700 ft (1,240 to 1,425 m) and average about 4,400 ft (1,330 m). Distribution of cirque headwalls is strongly skewed toward northern aspects, indicating that a critical relation among altitude, orientation, and solar radiation existed in the Valdez Creek area at this time, as it did in the Amphitheater Mountains to the east (Péwé and Reger, 1983b). Cirque walls are still sharp and steep, although talus has begun to form aprons on lower slopes. Arêtes remain jagged and continuous along higher ridges between closely spaced glacial troughs. Ice-scoured passes across lower ridges clearly document the partial diversion of ice from one valley into the next.

On the north valley wall, an upper limit of this glaciation is delineated by well-preserved, continuous to discontinuous lateral moraines with slightly rounded crests between elevations of 3,300 ft and 4,500 ft (1,000 and 1,360 m) (sheet 1); subtle surface breaks crossing slope colluvium connect morainal-ridge segments and mark zones where slope deposits have overwhelmed former moraines.

Early phase

In pit A5, deposits of the third glaciation form the entire section above the peat that caps the alluvial fill of paleochannel A (fig. 3, unit 4), except for Holocene loess (fig. 3, unit 14) and surface soil (fig. 3, unit 15). We recognized no tills of the early phase of the third glaciation in pit A5, nor did we see unconformities where till of this stade may have been eroded. Similarly, no unconformities or tills of this stade are apparent in cross sections that are based on lines of drill holes in lower Valdez Creek valley (VCMC, unpublished data). The clear implication is that lower Valdez Creek valley was ice free during the early phase of the third glaciation. However, units 5 and 6 in pit A5 (fig. 3) document at least temporary damming of the mouth of Valdez Creek valley during this early phase, probably by ice flowing south down Susitna River valley from cirques on the south side of the central Alaska Range.

Late phase

As previously mentioned, there is disagreement in the literature over the source of the last glacial ice to occupy the VCM area. Distribution of till overlying lake deposits in several cross sections prepared by VCMC geologists from numerous drill holes in lower Valdez Creek valley demonstrates that the last ice to invade the VCM area came from Susitna River valley and flowed eastward into the Valdez Creek valley reentrant as far as 0.8 km above the junction of Timberline and Valdez Creeks. Also, Teller (written commun., 1989) interprets folded lake sediments exposed high in the southeast wall of VCM to have been deformed by ice flowing up Valdez Creek valley from Susitna River valley. Drill records and the pit A5 section record impoundment of a large ice-marginal lake in lower Valdez Creek valley when late-stade ice in Susitna River valley initially blocked Valdez Creek valley. Drill-hole observations indicate that late-phase outwash from the Susitna River lobe was deposited on top of the lake deposits as far as 2.5 km up Valdez Creek valley from the ice margin.

The maximum downvalley extent of glacial ice from the headwaters of Valdez Creek during the late phase of the third glaciation, according to logs of holes drilled as deep as 75 m to bedrock along lines across the lower valley perpendicular to the creek (VCMC, unpublished data), is the end-moraine couplet 3 km west of the junction of White and Valdez Creeks (sheet 1).

Compositions of glacial deposits in the lower valley of White Creek indicate that flow directions in late-stade ice streams changed, probably in response to changes in rates of ice production in different accumulation areas. These deposits contain diorite erratics and garnets not found in the White Creek drainage; they also contain two suites of gold nuggets, one pale in color and well worn and the other bright and rough with attached pieces of quartz gangue (Moffit, 1912, p. 64; Tuck, 1938, p. 454; Smith, 1981, p. 59). These exotic constituents indicate that the ice that brought them into lower White Creek valley actually came from the valley of Valdez Creek around the north end of the Gold Hill-Lucky Hill upland.

Recession of the compound glacier up Valdez Creek during the waning phase of the third glaciation was characterized by several stillstands and perhaps minor readvances, as documented by a series of four nested morainal loops on the main valley floor between the confluences of White and Roosevelt Creeks with Valdez Creek (sheet 1). During this interval, tributary glaciers occupying the valleys of the Rusty Creeks, White Creek, and Roosevelt Creek separated from the main ice stream in Valdez Creek valley. Patterns of moraines of the third glaciation in the high-level pass between upper Valdez Creek and Boulder Creek to the north demonstrate that north-facing cirques at about 4,700 ft (1,425 m) elevation on the ridge north of Grogg Lake (sheet 1) spread ice lobes out into the pass, where they thickened, coalesced, and flowed southwest through the pass into upper Valdez Creek.

The final episode of the third glaciation in Valdez Creek valley consisted of minor readvances by most tributaries to the mouths of their valleys (sheet 1). Bulky arcuate moraines blocking valley mouths and damming Pass, Roosevelt, and Tenas Lakes (sheet 1) imply that final-phase glaciers remained extended for a considerable time (perhaps several centuries) before final retreat to source cirques at the end of the third glaciation. The distibution of sharp-crested, arcuate lateral and end moraines between 4,500 and 5,000 ft (1,360 and 1,515 m) elevation on the small plateau at the head of Valdez Creek (sheet 1) indicates that a small ice cap of this late phase was centered over Grogg Lake. Ice tongues spread down surrounding mountain valleys as far as 3.9 km from this ice-accumulation center (sheet 1).

Colluvium interfingers with sideglacial-stream alluvium and impinges on the edges of ice-marginal stream deposits of the third glaciation; postglacial fans from valley-side gullies locally bury sideglacial alluvium. Rock glaciers tentatively assigned to this age occupy cirques between 4,100 and 5,000 ft (1,240 and 1,515 m) elevation at the heads of Timberline and Fourth of July Creeks (sheet 1). Protalus ramparts of equivalent age formed on less sheltered slopes between 4,600 and 5,300 ft (1,390 and 1,605 m) elevation.

FOURTH GLACIATION

Features of the most recent ice expansion in Valdez Creek valley include very fresh cirques (some containing small active glaciers) and sharp-crested, frequently ice-cored, blocky lateral and end moraines. During the last few thousand years, glaciation in the Valdez Creek area has been restricted to upper mountain valleys. Headwalls of most cirques of this age face northwest, north, and northeast away from strongest solar radiation. Cirque floors, bearing fresh evidence of ice scouring, and young moraines, many retaining ice cores, range in elevation from 4,500 to 5,300 ft (1,360 to 1,600 m), an average of about 4,900 ft (1,485 m) (sheet 1). Productive cirques of this age generated simple valley glaciers up to 1.6 km long that left moraines as low as 4,700 to 5,100 ft (1,425 to 1,545 m) elevation.

Rock glaciers of equivalent age range in average elevation from about 4,600 to 5,500 ft (1,390 to 1,670 m), an average of about 4,900 ft (1,485 m). Many of these rubble tongues formed by secondary flow of ice-cored moraines and represent up to three generations of activity; many of these debris tongues and benches are still active. In areas of former heavy snow accumulation near wind-swept ridge crests between 4,600 and 5,600 ft (1,390 and 1,700 m), an average of about 5,000 ft (1,515 m), inactive protalus ramparts form sharp-crested rubble ridges around the toes of former perennial snow banks. A large rock avalanche of this age was produced by massive failure of the zoned alkali gabbro that composes the large horn at the head of Eldorado Creek (sheet 1; Smith, 1981, pl. 1).

AGE AND CORRELATION

Ages and relations among the four glaciations studied in the Valdez Creek area and glacial chronologies previously established for this part of the Alaska Range are based on comparisons of landform expression or stratigraphic evidence or both.

FIRST GLACIATION

The well-dissected nature of the ice-scoured upper story of the north wall of Valdez Creek valley and the lack of bedrock cover there are typical of terrains glaciated in middle Pleistocene time in this part of the eastcentral Alaska Range (Péwé, 1961, 1965, 1975). Realizing that correlations of middle Pleistocene glaciations are tenuous at best because of fragmentary evidence, we broadly correlate the earliest glaciation recognized in the Valdez Creek area with the Darling Creek and other pre-Illinoian glaciations in the Alaska Range (fig. 7).

SECOND GLACIATION

Landforms of the second major glaciation are highly modified by erosion and slope processes so that preserved macrorelief features are well rounded, extensively dissected, and widely buried by slope debris. However, deposits of this age are not stripped from ice-scoured bedrock surfaces nearly as much as deposits of the first glaciation. The advanced state of dissection and stripping of the high-level valley-floor remnant in Valdez Creek valley compared to subsequently glaciated topography is evidence that a major period of weathering and erosion occurred between the first and second glaciations. We interpret the storied character of Valdez Creek valley to be the result of bedrock incision during an ice-free time after the first glaciation and before the second glaciation.

Our best evidence for the age of the second glaciation was exposed in pit A5 of VCM. Large, granitic erratic boulders concentrated in the bottom of paleochannel A (fig. 3, unit 1) and similar boulders scattered throughout the gravel fill of paleochannel A (fig. 3, unit 2) and forming the cobble-boulder lag (fig. 3, unit 3) are remnants of a till that was derived from Valdez Creek valley and that predates cutting and

NORTH AMERICAN GEOLOGIC-CLIMATE UNITS		CENTRAL AND EASTERN ALASKA RANGE — NORTH FLANK — DENALI NATIONAL PARK	NORTH FLANK — NENANA RIVER		NORTH FLANK — GENERAL		NORTH FLANK — LOWER DELTA RIVER	NORTH FLANK — ROBERTSON-JOHNSON RIVERS	SOUTH FLANK — UPPER DELTA RIVER	AMPHITHEATER MOUNTAINS	VALDEZ CREEK AREA WESTERN CLEARWATER MOUNTAINS		NORTHERN TALKEETNA MOUNTAINS	NORTHWESTERN COPPER RIVER BASIN
		Reed (1961)	Wahrhaftig (1958)	Ritter and Ten Brink (1986)	Ten Brink (1983); Ten Brink and Waythomas (1984)	Hamilton (1982)	Péwé (1965, 1975); Péwé and Holmes (1964)	Holmes (1965); Holmes and Foster (1968)	Péwé (1961, 1965, 1968, 1975)	Péwé (1961, 1965, 1975); Péwé and Reger (1983b)	Smith (1981)	This study	Welsch and others (1982); Thorson and others (1981)	Thorson and others (1981)
HOLOCENE		*Inner set of ice-cored, unvegetated moraines* *Outer set of vegetated terminal moraines*					Black Rapids advances	Several minor advances	Several minor advances Summit Lake Glaciation	Two historic advances Glaciation	Alpine Creek Glaciation	Fourth glaciation (*Surface loess Soil formation*)		
WISCONSIN GLACIATION	Late stade	*Two groups of older, little-modified moraines*	Carlo readvance Main Riley Creek advance	Riley Creek Glaciation (four stades)	McKinley Park Glaciation (four stades)	Donnelly Glaciation (three stades)	Donnelly Glaciation	Readvance Donnelly Glaciation	Donnelly Glaciation	Denali II Glaciation	Hatchet Lake Glaciation	Third glaciation: *Valley-mouth moraines* Late phase (*Pit A5 units 8-13*) *Tammany paleochannel*	Butte Lake Glaciation	Glaciation
	Early stade			Healy Glaciation (single advance)	Early Wisconsin III? Early Wisconsin II Early Wisconsin I	Delta Glaciation				Denali I Glaciation	Denali Glaciation	Early phase (*Pit A5 units 5 and 6*) *Paleochannel A*	?—?—?—? Clear Valley Glaciation	Glaciation (*ice-dammed lake*)
ILLINOIAN GLACIATION		*Series of older, highly modified moraines*	Healy Glaciation (two advances)				Delta Glaciation (at least two stades)	Delta Glaciation	Delta Glaciation	Delta Glaciation (*no morainal form*)		Second glaciation (*Inset valley scoured Gold-bearing till deposited*)	Thick piedmont glaciation	
PRE-ILLINOIAN GLACIATIONS			Dry Creek Glaciation Browne Glaciation	*Dry Creek terrace* Browne Glaciation Pre-Browne advance(s)?	Pre-Wisconsin III Pre-Wisconsin II Pre-Wisconsin I (*upper Nenana Gravel*)		Darling Creek Glaciation		Early glaciation	Darling Creek Glaciation (*isolated erratics*)		First glaciation (*High-level, ice-scoured bedrock surface*)		

Figure 7. *Comparison of glacial chronologies in vicinity of Valdez Creek area.*

filling of paleochannel A. In this report, we present two infinite radiocarbon dates and one probably infinite collagen radiocarbon date for the fill of paleochannel A (fig. 3). We appreciate the possibility that these dates do not completely preclude an early Wisconsin age for the channel fill. However, the presence of up to 30 cm of highly compressed peat on top of the fill (fig. 3, unit 4) and the presence of the fragmented proboscidean tusk in the fill reinforce an interglacial (Sangamon) age for the fill. The tusk implies that glaciers had receded in the Alaska Range to a degree that passes between VCM and unglaciated eastern Beringia were open to mammal migration. Thus, the second glaciation, which deposited gold-bearing till in the VCM area, is probably Illinoian in age (fig. 7).

The second glaciation in the Valdez Creek area was probably simultaneous with widespread piedmont glaciation in the Amphitheater Mountains to the east, which Péwé (1961, 1965, 1975) called the Delta Glaciation, and in the northern Talkeetna Mountains to the southwest (Welsch and others, 1982) (fig. 7). Although evidence for the areal distribution of the second glaciation remains to be evaluated south of the Valdez Creek area, it was coextensive with the Delta Glaciation, which spread through the Gulkana Upland into the Copper River basin far to the south (Péwé, 1961, 1965; Péwé and Reger, 1983b).

THIRD GLACIATION

Radiocarbon ages and other stratigraphic evidence in pit A5 of VCM provide documentation for two major stades within the third glaciation (fig. 7). Units deposited during the early stade (fig. 3, units 5 and 6) postdate cutting and filling of paleochannel A during the Sangamon interglaciation. A minimum age for deposits of the early stade is provided by the radiocarbon date of 25,900 +3,000 -1,900 yr B.P. (fig. 3, sample GX-14433) for unit 7, which is just above unit 6 (fig. 3). This date, although slightly suspect because of its large statistical variation, indicates that the underlying fan-delta sand and inferred distal-outwash gravel are pre-late Wisconsin in age. Thus, we correlate the early stade of the third glaciation with early Wisconsin events elsewhere in this region (fig. 7). This same radiocarbon date and the pollen sample taken from the base of the lower part of unit 8 (fig. 3) establish that units 8 through 13 in the upper part of the pit A5 section are late Wisconsin in age and correlate with late Wisconsin events in the Alaska Range, Amphitheater Mountains, Talkeetna Mountains, and Copper River basin (fig. 7).

Stratigraphic relations discovered during exploratory drilling demonstrate that outwash and morainal deposits of local derivation on the valley floor west of the junction of White and Valdez Creeks interfinger with and overlie lake deposits of late Wisconsin age that extend in the subsurface upvalley from the VCM area (VCMC, unpublished data) (sheet 1). Thus, these morainal deposits are late Wisconsin and not early Wisconsin in age. Apparently, in early Wisconsin time ice derived from Susitna River valley blocked the mouth of Valdez Creek valley long enough to form an ice-marginal lake, but ice did not actually occupy the site of pit A5 in VCM as it did in late Wisconsin time. The lack of recognizable early Wisconsin moraines in Valdez Creek valley also leads us to conclude that late Wisconsin advances from southern Alaska Range and Valdez Creek sources were more extensive in this area than early Wisconsin advances.

FOURTH GLACIATION

The extreme freshness and ice-cored character of many small moraines of the last ice advance in Valdez Creek valley, their limited extent relative to known late Wisconsin moraines, and their close proximity to small modern glaciers suggest a Holocene age. Landforms of this episode, both glacial and periglacial, are identical in surface expression to Holocene equivalents elsewhere in the central Alaska Range (fig. 7).

IMPLICATIONS FOR DISTRIBUTION OF PARTICULATE GOLD

INTRODUCTION

Gold placers represent end products of a complex of processes, including erosion of gold and gold-bearing gangue materials, transportation by one or more geomorphic agents, deposition, subsequent erosion, further concentration, and final deposition (Schumm, 1977; Schumm and others, 1987); rich placers generally require several cycles of reworking. Agents of erosion and transportation include running water, waves and currents in bodies of standing water, wind, and glaciers. An understanding of the ramifications of glaciation on placer distribution provides a rationale for locating undiscovered placers in the Valdez Creek area.

Glaciers effectively scour and pluck bedrock and carry away all types of material, including precious metals (Sugden and John, 1976). Where glacial ice is thick, scouring and plucking are intense and large volumes of mineralized bedrock can be milled rapidly (Bundtzen, 1980). During glaciation, precious metals are initially deposited directly from melting ice in subglacial (lodgment) or superglacial (ablation) tills in concentrations that are not economic. Typically, meltwater streams then rework these deposits, perhaps beneath the ice but most often in front of the ice, further concentrating valuable metals and, in some cases, producing rich placers. For example, on South Island, New Zealand, valuable gold placers are present in eskers, kames, and outwash gravels (Williams, 1974). Most of the ice-transported gold on the island was deposited secondarily by proglacial streams near the front of ice sheets or tongues and by reworking of till along major drainage courses during glacier recession. Gold content in glaciofluvial deposits is generally highest near the former ice terminus and decreases with increasing distance beyond it.

The geologic setting of the Valdez Creek area suggests that glaciation had a major role in the formation of gold placers there. Most pieces of gold in VCM placers at the mouth of the valley bear the characteristic morphological signatures of glacial abrasion (round to subround shape, flatness, smooth surfaces), which require at least 1,000 m of ice transportation (Averill, 1988), although these forms may also result from several kilometers of high-energy stream transport. In contrast, the majority of nuggets recovered from placers in tributary streams such as Timberline Creek, White Creek, and Lucky Gulch are still shiny, coarse, rough, and contain inclusions or attachments of gangue minerals, primarily quartz (Moffit, 1912; Ross, 1933; Tuck, 1938). These pieces have not been significantly modified by glacial and stream abrasion; they are probably close to their bedrock sources.

POTENTIAL BEDROCK SOURCES OF GOLD

Placer gold has been recovered in the drainage of Valdez Creek on several tributaries, including Rusty Creek, Little Rusty Creek, Big Rusty Creek, White Creek, Eldorado Creek, Roosevelt Creek, Surprise Creek, Lucky Gulch, and Timberline Creek (Smith, 1981; Balen, in press) (sheet 1). Geologic mapping and geochemical analyses of rock chips and stream sediments by Smith (1970b, c, 1981) identified gold lodes and bedrock-related gold geochemical anomalies in the argillite belt near Timberline Creek, Black Creek, Gold Hill-Lucky Hill and Surprise Creek (sheet 1). Wiltse identified gold-bearing quartz-carbonate-chlorite veins intimately associated with intensely sheared porphyritic andesite dikes that crosscut black phyllite, green phyllite, and monzodiorite in the vicinity of Lucky Hill, Gold Hill, and the Yellowhorn prospect (Wiltse, 1988; Wiltse and Reger, 1989) (sheet 1).

A mineralized porphyritic quartz monzodiorite intrusive, thought to be an extension of the group of small intrusives mapped by Smith (1981, pl. 1) on Timberline Creek and on lower Valdez Creek, was exposed during excavation of pit A6, phase III, in early May 1989 (Jim Wachter, oral commun., 1989). The presence of this porphyry raises the interesting possibility of a local bedrock source for the small percentage of rough gold nuggets with attached gangue material that is recovered during VCMC operations.

Elsewhere in the drainage, Smith (1970b, fig. 7) documented a single gold anomaly in pelitic schist northwest of Surprise Creek (sheet 1). In the same area, U.S. Bureau of Mines geologists (unpublished data, 1988) recovered small quantities of fine-particulate gold from placer concentrates, rock chips, and fine-grained stream-sediment samples taken from the drainages of Surprise, upper Valdez, and Grogg Creeks (Balen, in press) (sheet 1).

It has long been known that the north tributaries of Valdez Creek have yielded hardly any placer gold (Moffit, 1912). Therefore, medium- and high-grade metamorphic rocks and the quartz diorite intrusion there are probably not potential sources of lode gold (Smith, 1981, pl. 1).

The consistent fineness (852) of most placer gold recovered from VCM (Smith, 1941; VCMC unpublished data) and the long-identified bedrock sources in the vicinity of the Gold Hill-Lucky Hill upland support previous conclusions by Moffit (1912), Tuck (1938), and Smith (1981) that most of the placer gold in Valdez Creek valley came from lodes in the Gold Hill-Lucky Hill area.

A PLACER-EXPLORATION MODEL

On the basis of past glacial extents relative to known and indicated gold lodes and known placers in the Valdez Creek area, we propose six targets where significant potential exists for locating valuable gold placers derived from lode sources in the Valdez Creek drainage (table 5).

EXTENSIONS OF KNOWN BURIED PALEOCHANNELS

In his seismic profiles I and II, Smith (1970a, figs. 3 and 4) illustrated his interpretation that considerable unexploited, potentially placer-bearing gravel fill remains along the east side of the Dry Creek cut in VCM. Other reaches of the ancient Denali paleochannel system where viable gold placers probably exist are located in upchannel and downchannel directions (sheet 1; table 5).

The highest potential for locating valuable gold placers in the Valdez Creek area is upchannel of known buried channels (sheet 1; table 5). Subsurface drilling by VCMC indicates that the incised paleochannel

Table 5. *Exploration targets for placer-gold deposits in Valdez Creek valley*

Target	Inferred placer potential[a]	Inferred placer age
Upchannel extensions of known buried paleochannels	High	Sangamon and Boutellier
Downchannel extensions of known buried paleochannels	Moderate to high	Do.
Other unexploited buried paleochannels	do.	Do.
Primary medial-moraine deposits downvalley from Gold Hill-Lucky Hill area	do.	Illinoian, early Wisconsin(?), and late Wisconsin
Zones downslope of known lodes where colluvium and lateral moraines are reworked by sideglacial streams, including deposits in abandoned meltwater channels within lateral moraines	Moderate to low	Late Wisconsin
Zones where end, medial, and lateral moraines of late Wisconsin age are breached and reworked by axial and tributary streams	do.	Late Wisconsin and Holocene

[a]Potential expresses relative likelihood that valuable placer-gold deposits, if preserved, are present.
Do. = Ditto.

system exposed in the mine extends upvalley at least 6 km but that discrete paleochannels cannot be easily differentiated (Jim Wachter and Robert Petersen, oral commun., 1989). The cover of unconsolidated deposits overlying the paychannel 6 km upvalley from VCM is up to 75 m thick (VCMC, unpublished data).

Significant placer resources may also exist in buried alluvial fans of Sangamon and Boutellier age downchannel from VCM (sheet 1; table 5), as indicated by the presence of only about 5-percent fine gold (minus 200 mesh) in VCM placers (VCMC, unpublished data; U.S. Bureau of Mines, unpublished data). The coarse size and structures of gravel fills in VCM paleochannels indicate that high-energy depositional environments existed at least intermittently during placer formation. In this vigorous environment, fine gold not locally trapped around large clasts would be flushed downstream to eventually be deposited in relatively low-energy environments on alluvial fans just beyond the bedrock channel, similar to the setting of gold placers associated with Porcupine Creek in the Porcupine mining district of southeastern Alaska (Bundtzen, 1986; Hoekzema and others, 1986). We propose that there is moderate to high potential for locating valuable placers of fine gold in downstream proximal fan sediments because (1) gold placers are probably deeply buried there, and (2) the bedrock knob west of VCM could have protected preexisting placer-bearing sediments from scour by glacial ice in Susitna River valley (sheet 1; table 5). We speculate that gold concentrations in buried fan deposits will be less than that currently mined in paleochannel A of VCM and will have lobate distributions because of shifting depositional loci and dilution by rapid sedimentation. Gold values will probably be highest close to fanheads unless fanhead dissection shifted placers downfan (Schumm and others, 1987).

OTHER UNEXPLOITED PALEOCHANNELS

Although Smith (1970a, fig. 1) showed the approximate extent of an arcuate bedrock channel subparallel to and south of the gorge of Valdez Creek, we believe that depressions in his profiles I, II, III, and IV could be evidence of a more extensive, northeast-trending, possibly branching paleochannel system subparallel to the nearby VCM Dry Creek cut and parallel to the Tammany paleochannel system north of Valdez Creek (sheet 1). Seismic-refraction data indicate that this buried paleochannel is cut about 8 m into phyllitic argillite bedrock. Because particulate gold is widespread in the bench gravels, we assign a moderate to high potential that the shallowly buried paleochannel system on Denali bench contains valuable concentrations of gold (table 5).

PRIMARY MEDIAL-MORAINE DEPOSITS

Several lines of evidence support glacial transport of most of the gold in VCM downvalley from the Gold Hill-Lucky Hill area when the inset (inner) valley of Valdez Creek was scoured out during the second (Illinoian) glaciation:

1. The greatest known concentration of gold lodes in Valdez Creek valley is in the Gold Hill-Lucky Hill area (sheet 1).

2. Evenson and others (1982, 1984, 1985) demonstrated that lithologic and mineralogic compositions of moraines, especially medial moraines, in the central Alaska Range reliably reflect bedrock compositions and mineralization in morainal source areas. Sizes, shapes, and compositions of boulders in pay gravel of paleochannel A indicate that they were glacially transported from bedrock sources in Valdez Creek valley.
3. Debris-flow deposits in the gravel fill of paleochannel A, which represent little reworked till of the second glaciation, contain significant placer gold.
4. Remarkably consistent gold fineness (852) (Smith, 1941; VCMC, unpublished data) of nuggets in VCM placers indicates a common type of lode source for the nuggets.
5. Dominant nugget morphology is consistent with glacial transport of more than 1,000 m (Averill, 1988).

Our glacial-transport model predicts moderate to high potential for locating valuable gold placers in glacial drift between VCM and the Gold Hill-Lucky Hill upland (table 5), which stood as a nunatak above surrounding glaciers during Illinoian, late Wisconsin, and perhaps early Wisconsin advances. The zone with the greatest chance of containing glacially transported detrital gold roughly follows the axis of Valdez Creek valley and coincides with deposits of medial moraines formed through the joining of gold-bearing lateral moraines scoured from the four sides of the Gold Hill-Lucky Hill upland by tributary glaciers that occupied the valleys of Eldorado, Roosevelt, Valdez, and White Creeks (sheet 1). Also, we predict that the width of this belt remains fairly consistent in a westward (downvalley) direction because of the narrow valley width (Drake, 1983).

In addition to richness of the lodes eroded, gold values in morainal debris are determined by rates of bedrock quarrying and abrasion, which are influenced by flow velocities of former glaciers: faster ice velocities increase entrainment of gold into the moving glacier and slower ice velocities promote slow quarrying and increase rates of deposition (Clark, 1987). Concentrations of detrital gold in the medial-moraine belt probably decrease along a negative exponential-decay curve downvalley from the source area and eventually may approach a linear distribution (Shilts, 1976; Clark, 1987; Strobel and Faure, 1987). The exponential downvalley decrease is related to progressive dilution by nonauriferous material and to progressive comminution of particles by crushing and abrasion during transport in debris-rich ice. The area of consistent values is theoretically produced after gold particles are reduced to a terminal size (usually sand or silt) (Strobel and Faure, 1987); however, the travel distance in Valdez Creek valley may not have been adequate to reach this stage of particle comminution. In any case, the pattern of gold distribution within the medial-moraine deposits is probably complicated by multiple advances, nonuniform flow rates in and between former ice streams, multiple ore bodies, and reworking by subglacial and surface streams.

Surfaces of detrital gold carried in debris-rich ice become more rounded and polished in the downglacier direction by rubbing against other particles (Shilts, 1976; Clark, 1987; Averill, 1988). Most nuggets recovered from VCM placers exhibit this smooth morphological modification. The minority of rough gold pieces with attached gangue minerals in VCM represent either (1) detrital gold carried in debris-poor ice within the glacier, where clasts are not abraded (Shilts, 1976; Clark, 1987; Strobel and Faure, 1987), or (2) detrital gold released from nearby bedrock lodes.

REWORKED VALLEY-SIDE COLLUVIUM AND LATERAL MORAINES

Early prospectors and miners in the Valdez Creek area soon recognized the presence of coarse, angular detrital gold, many pieces with attached quartz, and angular fragments of gold-bearing gangue material in colluvium that was in some cases mixed with glacial deposits and alluvial-colluvial fan gravels downslope from gold lodes in Lucky Gulch and in the valley of White Creek (Moffit, 1912; Ross, 1933; Tuck, 1938). Because eluvial placers in these valley-side sediments are likely to be small and spotty (Ross, 1933), we tentatively assign a moderate to low potential for locating valuable gold placers in them (table 5). However, nuggets as large as 52 oz (1.5 kg) have been recovered from these deposits in lower Lucky Gulch (Moffit, 1912).

During glaciation, ice margins are frequently the locations of meltwater streams that slightly rework adjacent slope and morainal deposits. Where gold lodes are present in bedrock sources of the till and colluvium, important placers are occasionally formed along glacier margins. For example, the rich high-bench placers of Dexter, Dry, and Anvil Creeks just north of Nome were formed through retransportation of gold-bearing colluvium and till by sideglacial streams of middle Pleistocene age (Collier and others, 1908; Moffit, 1913; Cobb, 1973). In the vicinity of the Gold Hill-Lucky Hill upland, Wiltse and Reger (1989) mapped deposits of late Wisconsin ice-marginal streams and abandoned meltwater channels that have significant placer potential (sheet 1). Placer-mining operations on White Creek visible in aerial photographs taken in 1949 followed these channel deposits.

OTHER REWORKED MORAINES

Following the New Zealand example in which fluvial gold placers are related to eroded glacial moraines (Williams, 1974), we propose that there exists a significant opportunity for finding valuable gold placers in the Valdez Creek area where gold-bearing end, medial, and lateral moraines of late Wisconsin age are breached and reworked by axial and tributary streams (table 5). Gold in these late Wisconsin and Holocene fluvial placers is extracted from till of glaciers that scoured known bedrock sources of gold in the drainages of Timberline, Rusty, Little Rusty, Big Rusty, White, Valdez, and Surprise Creeks (sheet 1). We expect that initial concentrations of gold in moraines of late Wisconsin age are too low to be economic, and it is only through fluvial reworking of the till that valuable placers developed. However, the likelihood of several cycles of placer reconcentration is slight due to the brief time since deglaciation.

CONCLUSIONS

New information developed during this study indicates appropriate models for past glaciations and for the formation and locations of gold placers:

1. Stratigraphic observations in pit A5 of VCM and a brief photointerpretive study of the Valdez Creek area provide evidence for pre-Illinoian, Illinoian, Wisconsin, and Holocene glaciations in the western Clearwater Mountains.
2. Pre-Illinoian glaciation scoured the ancient upper story of Valdez Creek valley, which is now dissected and preserved only on the north upper valley wall.
3. Inset lower Valdez Creek valley was scoured during the second (Illinoian) glaciation, during which local glaciers were tributary to the large trunk glacier that occupied the valley of Susitna River. Most of the placer gold in VCM was probably quarried from lodes in the Gold Hill-Lucky area and deposited initially in lower Valdez Creek valley in till of the second glaciation.
4. The early Wisconsin advance in the Valdez Creek area was clearly less extensive than the late Wisconsin advance, whether the ice was derived from Valdez Creek valley or from the Susitna River valley. During late Wisconsin time, ice of the Susitna River glacier blocked Valdez Creek valley, producing an extensive ice-marginal lake that drained catastrophically at least once before it was filled by varved sediments, rippled lacustrine sand, outwash gravel, and till.
5. Drilling by VCMC geologists indicates that at least three principal and several other paleochannel systems were incised into bedrock in lower Valdez Creek valley. These paleochannels were filled by alluvial gravel and slightly retransported till, both containing valuable gold placers, during former interglaciations, interstades, or both, when deglaciation triggered significant lowering of local base levels. Inconclusive, but strongly suggestive, evidence indicates that paleochannel A is Sangamon in age and that Tammany paleochannel is mid-Wisconsin (Boutellier) in age. Paleochannel B was probably cut during a late Illinoian interstade.
6. Recognition that the early Wisconsin glaciation was less extensive than late Wisconsin advances in this part of the western Clearwater Mountains raises the possibility that buried placers of pre-late Wisconsin age in other glaciated areas of Alaska are preserved within the limits of late Wisconsin glaciation.
7. Additional targets for undiscovered gold placers in the Valdez Creek area include (1) upchannel extensions of known buried paleochannels, (2) buried fans composing downchannel extensions of known buried paleochannels, (3) other unexploited buried paleochannels, (4) medial-moraine deposits downvalley from the Gold Hill-Lucky Hill upland, (5) former courses of ice-marginal meltwater streams that reworked gold-bearing valley-side colluvium and till, and (6) zones where gold-bearing end, medial, and lateral moraines were breached and reworked by late-glacial and postglacial axial and tributary streams.

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