The History of Greens Creek Exploration

By Andrew W. West

Chapter 3 of
Geology, Geochemistry, and Genesis of the Greens Creek Massive Sulfide Deposit, Admiralty Island, Southeastern Alaska
Edited by Cliff D. Taylor and Craig A. Johnson

Professional Paper 1763

U.S. Department of the Interior
U.S. Geological Survey

Contents

Figures

The History of Greens Creek Exploration[1]

By Andrew W. West

Abstract

The exploration history of the Greens Creek mine and district includes not only battles fought on the steep and intimidating terrain of Admiralty Island, but also in Washington, D.C., and the Oval Office of the White House. The Greens Creek mine is unique in that it is completely enclosed within a national monument. The time period that began with the initial discovery, in 1974, of the "Big Sore" ore suboutcropping and ended with the underground definition drilling of the orebody, overlapped with the largest national conservation movement of this century that ultimately led to congressional approval of Alaska National Interest Land Claims Act (ANILCA) in 1980. Not only did this legislative act have a profound effect on the subsequent exploration of the district and eventual production of Greens Creek, ANILCA shaped the economic life of Alaska as a whole.

Introduction

The Greens Creek mine (fig. 1) went from initial discovery to predevelopment and production in a fairly orderly, yet untimely manner. The Pan-Sound Joint Venture (JV), charged with mineral exploration in southeast Alaska in 1973, intersected ore in the very first "discovery" drill hole in 1975. The timeline for the project, which is shown in figure 2, demonstrates that despite nearly continuous exploration and(or) predevelopment work, production did not begin until February 1989. During this 16-year period, many changes occurred both within and between the joint venture partners. The conservation movement in the late 1970s also had a huge effect on the Greens Creek project, culminating in the passage of the Alaska National Interest Lands Conservation Act (ANILCA) in 1980. Exploration during the first years of production was successful in increasing reserves; however declining metal prices precipitated a shutdown of production in April 1993. Exploration and definition drilling of the higher grade Southwest Ore Zone from 1993 to 1994 resulted in a new feasibility study that was accepted by the joint venture partners, Kennecott Minerals and Hecla Mining. The mine reopened in 1996. National legislation reentered the picture when President Clinton signed the Land Exchange Bill in August of 1996. This unique piece of legislation allows for exploration and grants subsurface mineral rights to much of what was the original unpatented claim block that existed prior to ANILCA. The 7,301 acres of prospective ground allows Greens Creek to continue exploration activities aimed at increasing the life of the mine.

Pan Sound Joint Venture, 1973–78

The Pan Sound Joint Venture was formed in 1973 as a grass-roots exploration program to find base and(or) precious metal deposits in the northern part of southeast Alaska, the Prince William Sound area, and the Kenai Peninsula. The original partners were Noranda Exploration (29.73 percent), Marietta Resources (29.73 percent), Exhalas Resources (29.73 percent), and Texas Gas Exploration (10.81 percent). The rationale behind the exploration program in Alaska was fourfold: (1) exploration was risky in other parts of the world due to unfavorable politics; (2) exploration opportunities in the rest of North America were dwindling; (3) the geology of Alaska was seen as being highly favorable for economic deposits; and (4) the ongoing national energy crisis was underscoring the importance of a healthy domestic natural resource industry (L.M. Klingmueller and G.G. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1973). Watts, Griffis and McQuat (WGM) of Anchorage was contracted by the Pan Sound JV to carry out an extensive stream silt-sampling project in southeast Alaska. Their 1973 survey yielded anomalous zinc and copper stream silt samples collected from Cliff Creek (east of Big Sore Creek) and just southeast of Hawk Inlet (fig. 1). The sample from Cliff Creek contained 0.13 percent zinc and appeared to be associated with mineralized (disseminated pyrite and chalcopyrite) float from the Triassic Hyd basalt that forms the major cliff above Cliff Creek. Inclement weather prevented any followup work, but an intensive followup survey was recommended for the Cliff Creek drainage as well as first-pass coverage of the areas north and south of Greens Creek. WGM did not stake any claims in the Greens Creek area.

[1] Much of the information conveyed in this chapter was first documented in memoranda or reports to Kennecott Greens Creek Mining Company or its antecedents. Because they are unavailable to the public, these documents are cited in text only.

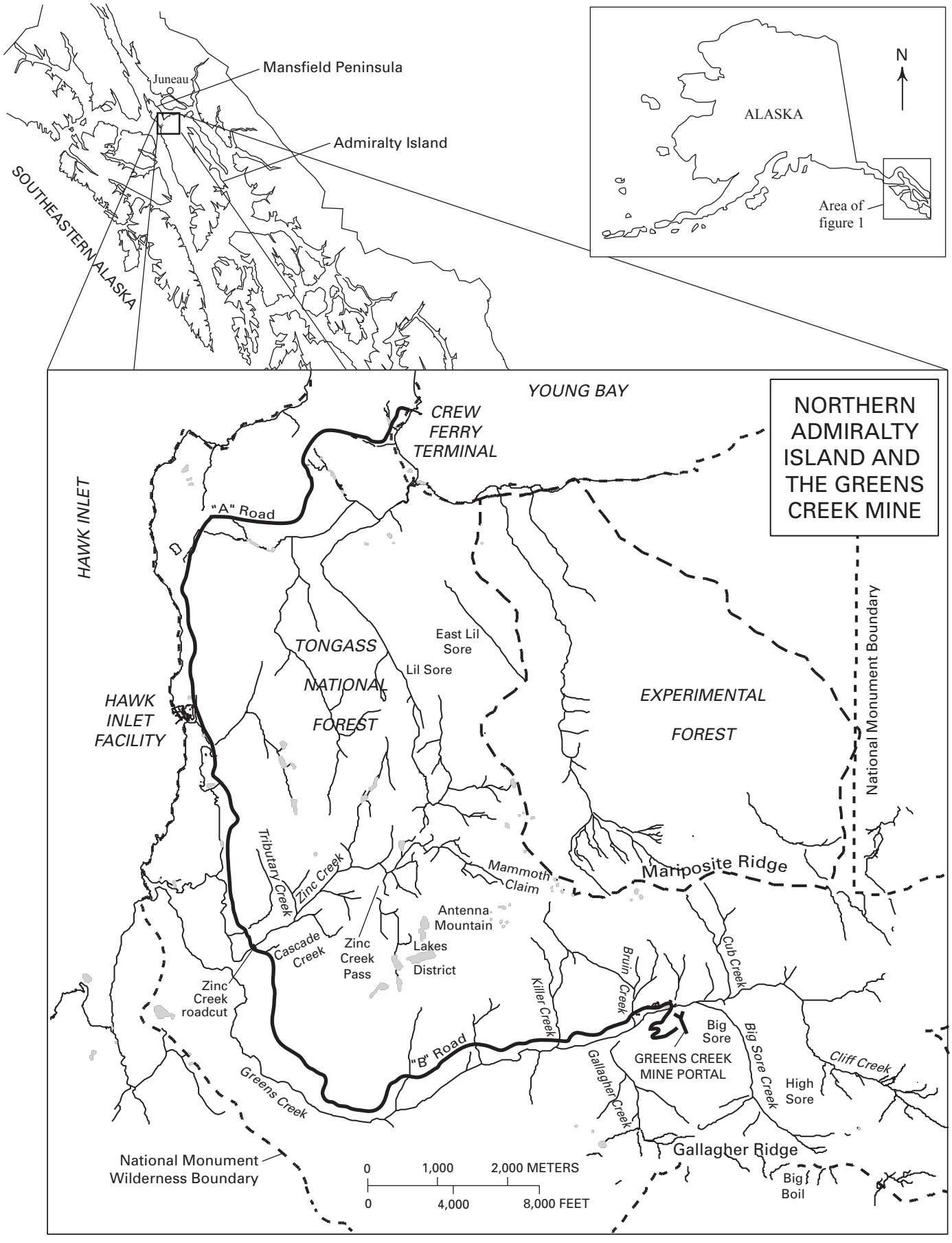
Juneau
Mansfield Peninsula
Admiralty Island
SOUTHEASTERN ALASKA
ALASKA
N
Area of figure 1
NORTHERN ADMIRALTY ISLAND AND THE GREENS CREEK MINE
YOUNG BAY
CREW FERRY TERMINAL
HAWK INLET
"A" Road
TONGASS NATIONAL FOREST
East Lil Sore
Lil Sore
HAWK INLET FACILITY
EXPERIMENTAL FOREST
National Monument Boundary
Tributary Creek
Zinc Creek
Mammoth Claim
Mariposite Ridge
Antenna Mountain
Cascade Creek
Zinc Creek Pass
Lakes District
Zinc Creek roadcut
Killer Creek
Bruin Creek
Cub Creek
"B" Road
Big Sore
GREENS CREEK MINE PORTAL
Big Sore Creek
Cliff Creek
High Sore
Gallagher Creek
Greens Creek
Gallagher Ridge
Big Boil
National Monument Wilderness Boundary
0 1,000 2,000 METERS
0 4,000 8,000 FEET

Figure 1 (facing page). Map of northern Admiralty Island showing the Greens Creek mine and other localities discussed in the text.

WGM geologists Bill "Boomer" Block and Joe Dreschler discovered the Greens Creek orebody in 1974 when they observed a large ferricrete kill zone from the air during the followup program (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1975). Dubbed the "Big Sore," this area (fig. 1) quickly became the focal point of exploration. A soil geochemistry grid laid out over the Big Sore delineated numerous silver-zinc anomalies on the order of 100 parts per million (ppm) silver and up to 1.7 percent zinc. WGM completed a Crone shootback electromagnetic (CEM) geophysical survey over 19,800 feet of gridline and a surface magnetometer survey totaling 12,500 feet. The CEM survey detected a partial conductor roughly coincident with soil anomalies. Two magnetic highs were identified in the lower reaches of Killer Creek. The WGM geologists postulated that the source of the CEM conductor was a mapped graphitic quartz-mica schist (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1975). The magnetic anomalies were due to magnetite-bearing sulfide layers discovered in Killer Creek. A float sample believed to be from the same unit assayed for more than 10 percent copper. These two items generated additional interest in Killer Creek. Most of the exposed mineralization found by WGM, other than the Big Sore itself, was from the Killer Creek area.

WGM staked 134 lode claims, named the Big Sore claims, to establish the land position. The claims stretched from the southeast corner of Cliff Creek across the Greens Creek valley to the northeast corner of Upper Zinc Creek. WGM suggested that the land on the north, east, and south sides also be staked. There was concern that the large claim block would attract attention from various competitors (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1975). Until 1974, very little competitor activity was noted for Admiralty Island except for a small backpack-supported survey of Northern Chicagof and Admiralty Islands by Placid Oil. Also, Resource Associates of Alaska (RAA) and Urangellschaft were exploring parts of Northern Admiralty Island.

The 1974 exploration results led WGM and the Pan Sound JV to believe that the "strongest reconnaissance potential for the discovery of a stratabound massive sulfide is considered to be within the Paleozoic schists located north and south of the Greens Creek discoveries on Admiralty Island" (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1975). WGM recommended additional soil sampling, extension of the CEM survey, detailed geologic mapping, and diamond drill testing of the main Big Sore anomaly. They believed that the Big Sore and Killer Creek areas had the potential to host one or more copper-lead-zinc sulfide body(s) of unknown grade with greater than 1,000 feet of strike length.

1975 Program

The Big Sore project and a detailed reconnaissance of Admiralty Island were two of three projects that the 1975 Pan Sound JV undertook. The third project was followup work on a copper prospect of Latouche Island in Prince William Sound. The 1975 Big Sore project was the most ambitious thus far with more than 1,000 soil, rock, and stream silt samples taken; 80,000 feet of CEM and magnetometer surveys; initial detailed geologic mapping; and trenching and blasting to outline drill targets. Diamond drilling also commenced with three holes completed before the end of the field season. The Big Sore project began on June 4 with a camp at Big Sore Creek. The project demobilized on September 20 when the drilling program finished.

Results from expanding the Big Sore soil grid led the WGM geologists to believe that the stratabound mineralization occurred along three to five stratigraphic horizons within Devonian units (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1976). They believed that soil sampling was the best tool to establish drill targets because of the thick glacier till, the vegetation cover, and the difficulty in defining the stratigraphy. However, WGM did not associate the geochemical and electromagnetic (EM) signatures with a chlorite-carbonate-schist and graphitic schist contact (determined later to be the mineralized horizon).

The three completed diamond drill holes totaled 997 feet. The first drillhole, DDH–1 (later renamed PS–1), was drilled about 150 feet above the Big Sore to test the high-order soil anomaly and the coincident CEM anomaly. The "discovery" hole intersected 89 feet of continuous pyrite and base-metal massive sulfide beginning at 138 feet downhole. This hole remains the longest continuous intersection of massive sulfide mineralization drilled from the surface at Greens Creek. The interval averaged 0.123 troy ounce per ton gold, 5.77 troy ounces per ton silver, 2.04 percent lead, 8.03 percent zinc, and 0.43 percent copper. A marked increase in pyrite and decrease in chlorite-muscovite near the massive sulfide interval was noted. The hole terminated at 296 feet in dolomitic graphite-quartz-mica schist, with local bands of massive sulfide. Holes DDH–1 and DDH–2 were both lost due to caving ground, a harbinger for drilling problems to come. Hole DDH–1 was not able to test the two lower targets identified from the soil sampling.

Hole DDH–2 (PS–2) was collared about 500 feet to the south-southeast of hole DDH–1, downhill from the graphite schist contact. The hole intersected graphitic schist with two massive sulfide bands containing 4.86 percent zinc and 4.3 troy ounces per ton silver over 12 feet, and 6.32 percent zinc, 7.2 troy ounces per ton silver, and 0.275 troy ounce per ton gold over 29.5 feet. The hole was lost due to poor ground conditions before it reached its target horizon. DDH–3 (PS–3) was collared 200 feet downhill from DDH–2 to test the previously untested lower soil anomaly. No visible base-metal sulfides were intersected to the termination depth of 635 feet, despite the presence of "fresh" massive sulfide float and high multi-element soil values directly below the hole.

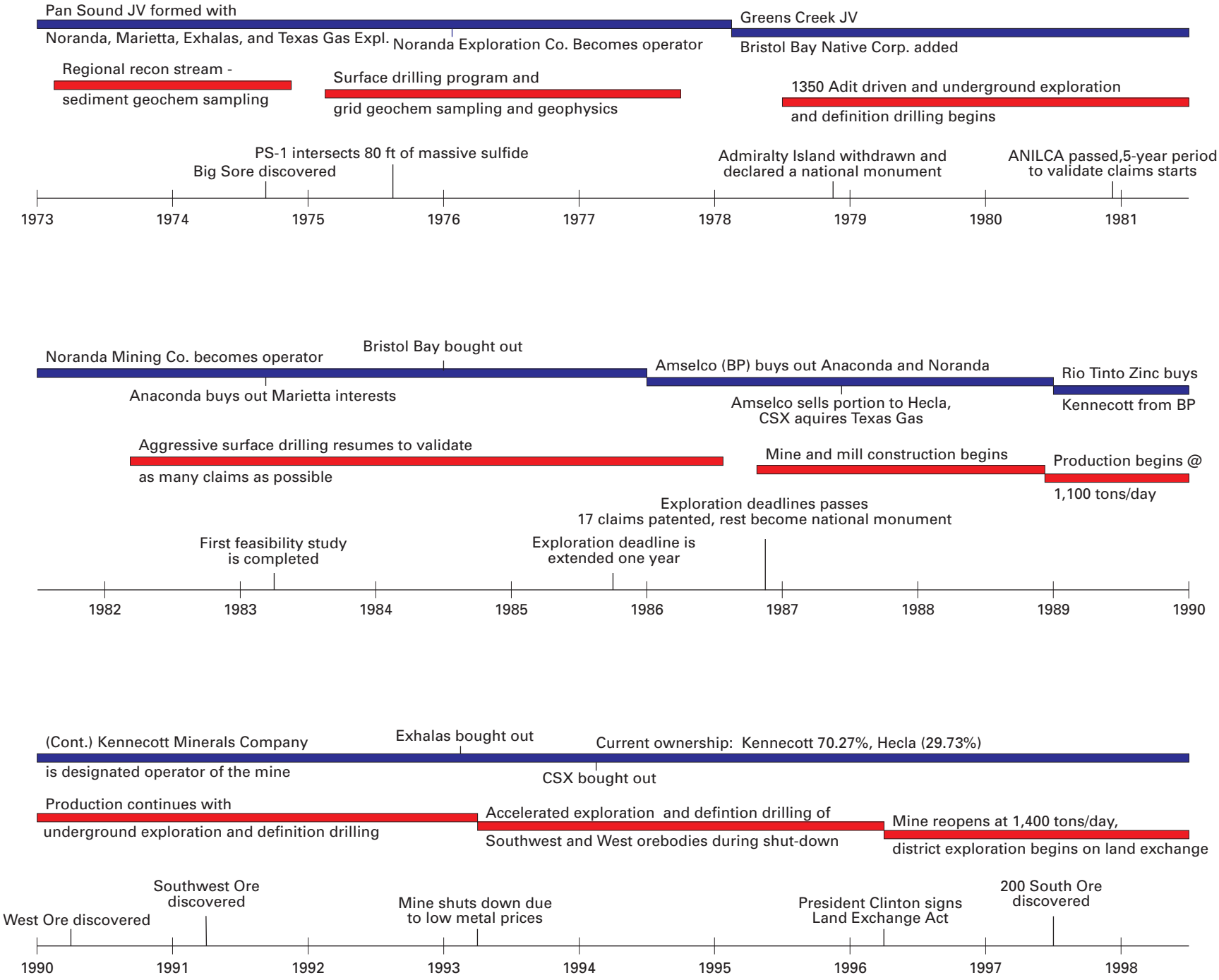
Pan Sound JV formed with
Noranda, Marietta, Exhalas, and Texas Gas Expl.
Noranda Exploration Co. Becomes operator
Greens Creek JV
Bristol Bay Native Corp. added
Regional recon stream -
sediment geochem sampling
Surface drilling program and
grid geochem sampling and geophysics
1350 Adit driven and underground exploration
and definition drilling begins
PS-1 intersects 80 ft of massive sulfide
Big Sore discovered
Admiralty Island withdrawn and
declared a national monument
ANILCA passed,5-year period
to validate claims starts
1973
1974
1975
1976
1977
1978
1979
1980
1981
Noranda Mining Co. becomes operator
Bristol Bay bought out
Anaconda buys out Marietta interests
Amselco (BP) buys out Anaconda and Noranda
Amselco sells portion to Hecla,
CSX aquires Texas Gas
Rio Tinto Zinc buys
Kennecott from BP
Aggressive surface drilling resumes to validate
as many claims as possible
Mine and mill construction begins
Production begins @
1,100 tons/day
Exploration deadlines passes
17 claims patented, rest become national monument
First feasibility study
is completed
Exploration deadline is
extended one year
1982
1983
1984
1985
1986
1987
1988
1989
1990
(Cont.) Kennecott Minerals Company
is designated operator of the mine
Exhalas bought out
CSX bought out
Current ownership: Kennecott 70.27%, Hecla (29.73%)
Production continues with
underground exploration and definition drilling
Accelerated exploration and defintion drilling of
Southwest and West orebodies during shut-down
Mine reopens at 1,400 tons/day,
district exploration begins on land exchange
West Ore discovered
Southwest Ore
discovered
Mine shuts down due
to low metal prices
President Clinton signs
Land Exchange Act
200 South Ore
discovered
1990
1991
1992
1993
1994
1995
1996
1997
1998

Figure 2 (facing page). Ownership (blue) and exploration (red) timeline.

Correlation of the above drill holes and soil anomalies led the WGM geologists to believe there were at least four, and maybe more, separate mineralized horizons to target (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1976). DDH–3 displayed wildly fluctuating foliation orientations, but folding of the mineralized horizon was not considered. Using the drill-hole results and a tonnage factor of 12, WGM estimated an inferred metal "inventory" of 2 to 20 million tons of greater than 1.5 percent lead, 6.0 percent zinc, 0.1 troy ounce per ton gold, and 6.0 troy ounces per ton silver (T.E. Andrews and others, Watts, Griffis and McQuat, Inc., written commun., 1976). WGM recommended an aggressive (>10,00-foot) drilling program to rapidly bring the Big Sore Prospect to a development decision. They believed that the 1976 drilling program would place the inventory into "exploration" or "possible" reserves category, "barring unusual structural, facies complexity, or external factors" (T.E. Andrews and C. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1975).

Exploration work was also carried out in the Gallagher Creek, Killer Creek, and North Ridge (Mariposite Ridge) areas (fig. 1). Highlights include the discovery of massive sulfide float and outcrops in Gallagher Creek containing up to 31 percent zinc and 2.1 troy ounces per ton silver (T.E. Andrews and C. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1976). The outcrops contain sulfide veins up to 2 inches wide over a mineralized interval approximately 100 feet thick. Various mineralization styles were described, sampled, and mapped from the North Ridge, mostly in the vicinity of the Mammoth claims (see next paragraph). "Impressive" values were returned for gold, silver, lead, and zinc. Preliminary sampling and mapping did not provide sufficient data to determine the structural or stratigraphic setting of the mineralization.

The land status was further enhanced surrounding the Big Sore prospect during 1975. An additional 150 claims were added to the Big Sore claim group in all directions. The claim block was extended to the north, overlapping the four patented Mammoth claims that were originally staked in 1889 and patented in 1915. The overlapping claims were not to "jump" the existing claims but to ensure no area was left open between the two claim groups (fig. 1) (T.E. Andrews and C. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1975). An abandoned adit exists on the Mammoth claim that was excavated about 1904 along a massive galena-sphalerite band. WGM suggested that the owner, Herman Meiners of Juneau, be approached to see if the property could be leased or bought outright before the increased activity at Greens Creek increased the asking price.

The separate reconnaissance program of Admiralty Island completed much of its work near Greens Creek. The Tom claims were staked (a total of 52) to the east of Hawk Inlet within the lower Greens Creek and Zinc Creek drainages (T.E. Andrews and C. Bigelow, Watts, Griffis and McQuat, Inc., written commun., 1976). WGM sampled Big Sore-type mineralization in graphitic quartz-mica schist, greenstones, and quartz-chlorite-carbonate schists with mariposite. In addition, work was done near ferricrete "sores" in a prospect named Kit Creek (now Lil Sore, fig. 1). The north-northwest-trending sores that contain up to 9,500 ppm zinc were postulated as representing a stratabound zinc sulfide body at moderate depth cut by permeable faults or fractures. No claims were staked during the field season because the land was nominated for Native Selection but was later withdrawn. Other prospects or claims explored included the Scull, Eagle Peak, and Jimbo to the northeast of Greens Creek, the Wheeler and Pyrola to the south and southwest of Greens Creek, and the JS and Barron on Mansfield Peninsula. As a result of the reconnaissance program, 472 new claims were staked on these new prospects. The Big Sore prospect was the standard with which the other prospects were compared, based on type of mineralization present and similar stratigraphy.

1976 Program

Noranda became the operator of the Big Sore program in 1976 for the Pan Sound JV. The program was composed of two projects again, one project concentrating on continued reconnaissance of Northern Admiralty Island, looking for other Greens Creek-type targets, while the other project continued exploration on the Big Sore and Tom claims. The principal objectives at Big Sore were to define the extent of the mineralized horizon intersected in DDH–1 and determine the geologic and geochemical nature of the mineralized zone (John Dunbier, Noranda Exploration, Inc., written commun., 1976). A geochemical grid with CEM and magnetic surveys was oriented north to south along Gallagher and Killer Creeks. The existing grid system was reoriented to trend N. 30° W. and center the baseline on the discovery hole. Two drill rigs were used for the program. A Longyear-34 hydraulic drill rig operated by Diamond Drill Contractors completed the deeper holes. A much smaller Winkie drill, owned and operated by Noranda, drilled 1.197-inch-diameter (AQ) core to penetrate the overburden and determine the lithology of the bedrock in areas of no outcrop. An additional 400+ claims were staked to fill in the gap between the Tom and Big Sore claims.

The diamond drilling program was successful in extending the known mineralized zone to the south-southeast, north-northwest, and slightly downdip (John Dunbier, Noranda Exploration, Inc., written commun., 1976). Three of the five holes drilled with the Longyear-34 intersected low- to high-grade ore along the contact between sericite-quartz phyllite (identified as "tuffites") and the graphitic schist unit. The other two holes intersected minor mineralization in the tuffites (the hanging wall). Hole PS–3–76 intersected 11 feet of 0.042 troy ounce per ton gold, 22.7 troy ounces per ton silver, 5.9 percent lead, and 14.6 percent zinc to extend the known mineralized zone about 300 feet to the south-southeast of the discovery hole. PS–4–76 intersected a lower grade, yet thicker 12-foot

interval grading 9.9 troy ounces per ton silver and 3.45 percent zinc about 320 feet to the north-northwest. PS–7–76 extended the envelope even farther to the north-northwest (600 feet) with a 6-foot intercept of 29.3 troy ounces per ton silver and only 1.7 percent zinc.

The Winkie drill program consisted of eight holes. Only two of the holes intersected mineralization within the hanging-wall rocks while testing soil anomalies to the northwest of PS–1. One hole, PSW–4, was later followed up by hole PS–7–76 (mentioned previously). Two of the holes were unable to penetrate the overburden. Two large-diameter holes and one Winkie drill hole were drilled in Gallagher Creek. PS–1–76 and PS–2–76 intersected only minor mineralization of up to 4.4 percent zinc over 5 feet.

Noranda Exploration initiated a geologic mapping project carried out by one of their geologists, M.D. Bingham. Noranda anticipated taking a more active role in the Big Sore prospect and wanted to gain firsthand familiarity of the project (M.D. Bingham, Noranda Exploration, Inc., written commun., 1977). His mapping outlined three units favorable for massive sulfide mineralization: the chlorite-carbonate schist, a quartz carbonate (sericitic phyllite), and a quartz graphite schist (differentiated from the graphitic schist unit intersected immediately below the ore horizon in DDH–1).

Noranda attempted to better define and describe the lithologic units, geological and structural setting, and mineralization style of the Big Sore deposit in the 1976 year-end report. The hanging wall was described as chlorite and sericitic tuffites representing volcaniclastics of a mafic to felsic cycle. The footwall rocks were described as epiclastic perigenic conglomerates and carbonaceous argillites (formerly the graphitic schist unit). The pyritic and high-sphalerite ore zones and carbonaceous cherts were classified as exhalative rocks. Essentially, Noranda was trying to pigeonhole Greens Creek into a Kuroko-type deposit. All of the lithologic units were interpreted as grading into one another. Noranda estimated that the mineralized zone contained ±0.5 million tons of ore (John Dunbier, Noranda Exploration, Inc., written commun., 1976).

An effort was made to determine the age of the described units. Despite the lack of any fossil control or unambiguous small-scale sedimentary structure (that is, graded bedding), Noranda correctly believed that the section was inverted (Noranda Exploration, Inc., written commun., 1977). The circumstantial evidence cited was the observed mafic to felsic volcanic cycle (incorrect), volcanic to sedimentary cycle, paleorelief features, and lithological and geochemical zonation within the exhalites similar to Kuroko-type deposits.

Structurally they observed that minor folds were very common, but no tight or isoclinal folds were found except within the carbonaceous argillites. The rare appearance of fault gouge, tectonic breccias, and slickensides did not allow for any major faults to be identified in the drill sections. However, evidence for intense deformation was described between the mineralized zone and footwall argillites, thought to be the result of adjustments induced by flexuring of units due to a major recumbent fold.

Noranda envisioned the Big Sore deposit as occurring in a predominantly sedimentary basin associated with a nearby mafic to felsic volcanic system. The quiescent submarine environment received ash but no intrusive or extrusive rocks from the volcanic system. The volcanic system did, however, give rise to hydrothermal systems and possible explosive exhalations (as evidenced by the conglomerates near the ore interface). Brines from the hydrothermal system settled into depressions and precipitated chemical sediments (sulfides, cherts, and carbonates). Noranda compared Greens Creek to "artesian" exhalative deposits similar to Iron King in Arizona, Faro in the Yukon, and Sullivan and Rosebury in Tasmania (Noranda Exploration, Inc., written commun., 1977). These geologic observations and deductions formed the working geologic framework for exploration work at Greens Creek and Northern Admiralty Island for the next 10 years.

1977 Program

The 1977 exploration program in the Greens Creek area included two projects; the Big Sore drilling program was the primary project, and detailed exploration of Mariposite Ridge, Gallagher, Killer, and Zinc Creeks was the other project. Noranda continued as the operator of both programs. Surface drilling included 22 holes totaling 8,810 feet, primarily along the Big Sore mineralization trend, but also in Gallagher and Killer Creeks. Soil grids were extended or established for all the prospects/areas mentioned herein. The second project was the most ambitious for the area surrounding the Big Sore prospect to date, and remained so until the passage of the Land Exchange Act spurred the exploration programs of 1996 to 1999.

Surface geologic mapping to the south and southwest outlined the carbonaceous argillite unit as wrapping around the tuffite units. The argillite unit was believed to be the upper limb of an overturned fold (John Dunbier, Noranda Exploration, Inc., written commun., 1977). A new soil grid of five lines oriented at N. 60° E.–S. 60° W. was emplaced over the upper limb contact zone. The soil anomalies generated were more erratic than those of the overturned limb, but local silver and zinc anomalous zones along the contact were delineated. A CEM geophysical survey delineated the argillite unit but did not generate any drill targets.

The 1977 drill program at Big Sore was a success in extending the known mineralized zone along strike and downdip. Eight diamond drill holes were drilled, totaling 4,446 feet, plus 1,415 feet of Hydra-Wink drilling. PS–4–77 (PS–23) intersected a 75-foot section that averaged 12.6 troy ounces per ton silver with a 3-foot high-grade section of 92.2 troy ounces per ton silver. This hole was located 900 feet to the southeast of PS–1. In addition, PS–5–77 (PS–28) intersected 6.5 feet of mineralized material about 300 feet downdip from PS–4–77. The mineralized zone was extended another 800 to 1,000 feet northwest of PS–6–76 by holes PS–6–77 (8.1 feet of 17 percent zinc and 12.25 troy ounces per ton silver) and PS–W1–77 (28 feet of 18.2 percent lead, 32.75 percent zinc,

and 10.2 troy ounces per ton silver). PS–8–77 (PS–27) intersected 20 feet of ore 300 feet downdip from PS–3–76.

The total strike length of mineralized rock along the overturned limb now totaled 3,500 feet and was open on both ends (Noranda Exploration, Inc., written commun., 1977). However, future surface drilling did not extend the mineralized zone farther along strike in either direction. The mineralized interval also extended at least 500 feet downdip on many of the sections tested. The Noranda geologist (Dunbier) realized that the main mineralized zone was at the lithologic contact between the argillites and tuffites. The calculated, geologically indicated resource was 2.1 million tons with an NSR (net smelter return) value of about $90/ton (John Dunbier, Noranda Exploration, Inc., written commun., 1977).

Dunbier's recommendation for 1978 was to verify the geologically indicated resource with an underground drill program augmented with Hydra-Wink drilling from the surface. Drill hole PS–W1–77 showed that the Winkie drill was capable of piercing the overburden and the mineralized zone. The current 300-foot drill spacing was considered inadequate for ore reserve calculations, and it was recommended that the underground holes be drilled at regular spacings between the surface holes. Additional reserves could be added by downdip testing of the mineralized zone, drilling along strike to the south-southeast, and surface exploration of the upper limb contact (John Dunbier, Noranda Exploration, Inc., written commun., 1977).

Exploration continued within the Gallagher Creek prospect to follow up on the previous CEM and geochemical soil surveys and to test the massive sulfide outcrops and float. The Noranda geologists thought the rocks in Gallagher Creek were part of the upper (upright) limb of the Big Sore fold (Noranda Exploration, Inc., written commun., 1977). One Hydra-Wink hole was drilled on the west side of the creek and intersected weakly mineralized tuffites with one 5-foot zone of 10.2 percent zinc. The contrasting sections intersected by this hole and the two 1976 drill holes led them to believe that a fold or shear (later to be mapped as the Gallagher fault, a significant right-lateral fault) ran along Gallagher Creek.

Killer Creek was also extensively explored in 1977. The 1976 Gallagher–Killer Creek soil grid was extended, and a new grid with a baseline oriented southeast-northwest was surveyed in middle Killer Creek. The new Killer Creek grid generated 16 primary soil anomalies. Noranda identified three types of mineralization associated with the anomalies, which were tested by drilling. PS–77–1 (PS–20) tested below surface exposures of stringers, veins, and clots of coarse sphalerite with pyrite, magnetite, galena, and chalcopyrite within a talc-serpentine-chlorite-carbonate rock. No significant mineralized rock was intersected. A stratiform massive chalcopyrite, pyrite, and pyrrhotite band within greenstone in Upper Killer Creek was tested by two Hydra-Winkie holes, PS–W4 and PS–W5–77 (PS 32 and PS–33). Both holes intersected copper-bearing mineralized rock with grades up to 2.3 percent. Two other holes were attempted in lower Killer Creek to test stratiform sphalerite-galena sulfide bands, but the attempts failed to drill through the thick glacier till overburden.

Noranda recognized the Killer Creek sequence of rocks as distinct lithologies from Big Sore, consisting mostly of andesites, andesitic tuffs, and three types of serpentinites (one described as being a magnesium-rich exhalite)(Noranda Exploration, Inc., written commun., 1977). Noranda envisioned Killer Creek as a tectonic hinge zone, next to a subsiding sedimentary basin (Big Sore and Gallagher prospects), with active faulting, mafic volcanism, and associated exhalative activity. Noranda looked favorably upon the results and estimated that Killer Creek had the potential for 1–3 high-grade (greater than 10 percent zinc) deposits of more than 50,000 tons, at least one deposit of 2–5 percent zinc greater than one million tons, and one to three 1.5 percent copper deposits of greater than 100,000 tons.

Soil surveys, CEM and magnetic geophysical surveys, and geologic mapping were also carried out on the Zinc Creek and Mariposite Ridge prospects. The results from Zinc Creek were not encouraging: only weakly anomalous soil samples (as compared to Big Sore and Killer Creek grids) and no finite geophysical anomalies. On the other hand, the Mariposite grid generated nine soil anomalies associated with vein, disseminated stratiform, and massive stratiform lead-zinc mineralization within, or along the contacts of, the mariposite-carbonate unit. The Noranda geologists believed this unit was a metacarbonate (Noranda Exploration, Inc., written commun., 1977). Noranda suggested that the joint venture attempt to purchase the Mammoth claims not only for its mineral potential, but because its "main value would be as bargaining chips during land negotiations with federal bureaucrats" (Noranda Exploration, Inc., written commun., 1977).

The 1977 exploration program identified many targets and prospective areas outside the immediate Big Sore prospect and recommended continued work, including drilling at Gallagher and Killer Creeks and Mariposite Ridge. However, the urgency of proving-up the Big Sore deposit and events in Washington, D.C., worked against any further work until 1982.

Initial Underground Development and Land Battles, 1978–80

The Pan Sound Joint Venture was dissolved in 1978 and the Greens Creek Joint Venture formed in its place. The Pan Sound Joint Venture was redrafted in part due to the addition of Bristol Bay Native Corporation. The members of the Greens Creek Joint Venture decided in January of 1978 to begin underground diamond drilling and initiate an environmental baseline study after carefully analyzing the political, environmental, geological, and economic aspects of the project (Ernest Simmons, memorandum to W.W. Holmes, 1978). The Greens Creek Joint Venture agreed to a plan to drive a 4,200-foot drift from which to drill about 30,000 feet of core. The environmental baseline study began April 1 and was carried out by VTN Consulting.

The project's first legal battle came on May 2, 1978. The Southeast Alaska Conservation Council (SEACC), with the legal aid of the Sierra Club, appealed the Regional Forest Supervisor's decision to approve the exploration operation plan. They believed that public involvement was not adequately sought in the process. They cited the overwhelming opposition to the planned ferry dock on the north side of Douglas Island and the public's overall negative sentiment toward Noranda (Ernest Simmons, memorandum to W.W. Holmes, 1978). SEACC was also concerned with recent turbidity measurements in Greens Creek that violated USDA Forest Service regulations. Their appeal was denied by the Regional Forest Supervisor on grounds that public involvement is not necessary for an exploration plan and that Noranda was taking the proper steps to mitigate the turbidity exceedances caused by heavy rains.

Driving of 1350 Drift

Noranda contracted the Mining Company of Denver, Colorado, to drive an exploration drift (1350 Drift) at the 1,350-foot elevation mark. Glacial overburden was removed from the portal site by July 13, 1978, and the initial bench round was drilled out on July 14 (Ernest Simmons, memorandum to W.W. Holmes, 1978). By the end of the year, 1,667 feet of drift had been driven, including drill station cutouts at 150-foot spacings. Work continued through the winter and spring months (with a 45-day weather shutdown in February and March) in an effort to complete the 1350 Drift (T.A. Butler, memorandum to S. Nakata, 1979). The drift was finished in November 1979. A total of 4,190 feet of drifting with a 219-foot rise was completed along with 24 diamond drill stations, assorted sumps, and an underground shop. All work was completed using helicopter support and a camp located just below the portal. The total cost for the 1978–79 drifting and drill program was $5.05 million (Noranda Exploration, Inc., written commun., 1980).

The initial underground drilling program began in October 1978 and finished in December 1979. Drilling took place on an intermittent basis as new drill stations were cut, and water and power became available from the drifting program. Fifty holes (GC–1 to GC–50) were drilled during this period, totaling 20,240 feet (Noranda Exploration, Inc., written commun., 1980). Most of the drill stations (14 out of 24) were drilled out to help confirm the 2,750 feet of strike length of mineralized rock. The fifty drill holes encountered 59 ore intercepts. Noranda estimated the drill indicated reserves to be about 3 million tons with an approximate grade of 10–16 troy ounces per ton silver, 0.1 troy ounce per ton gold, 7–10 percent zinc, 2–2.5 percent lead, and 0.5 percent copper. The ore zone was still believed to be open downdip and along strike to the southeast (Noranda Exploration, Inc., written commun., 1980).

Noranda performed a base cash-flow model for Greens Creek to estimate the economics of the project. The order of magnitude estimates indicated that the project had a DCF–ROR (discounted cash flow – rate of return) of 39.3 percent, NPV (net profit value) of $22.6 million, with payback in 1.8 years (Noranda Exploration, Inc., written commun., 1980). Assumptions and criteria used for the estimate included metal prices at $300 per troy ounce gold and $10 per troy ounce silver, a production rate of 800 tons per day (TPD), $18.4 million in preproduction costs, $65 per ton operating costs, and 15.75-year mine life. However, Noranda concluded that "Political imponderables far exceed the technical unknowns insofar as the Greens Creek project is concerned" (Noranda Exploration, Inc., written commun., 1980).

The land status of the Greens Creek property changed greatly during the underground drifting and drilling program. Nineteen Big Sore claims were surveyed for patent in July and submitted to the Cadastral Survey Office in April 1979 (T.A. Butler, memorandum to S. Nakata, 1979). The Greens Creek Joint Venture employed the law firm of Pruitt and Gushee of Salt Lake City to aid in the intricate patenting process. An additional 27 lode claims were staked during 1978: 23 to the south of the Big Sore group to cover the downdip projection of the current orebody, three on the southwest to cover an area dubbed the "football field" that was a potential tailings site, and one to cover an open area that developed as a result of the patent survey. A total of 136 mill-site claims were staked to the south and east of the Hawk Inlet Cannery site between November 27 and December 1. The latter date, December 1, proved to be a very fateful day that would change the whole scope of the project and have repercussions throughout the entire State of Alaska.

Federal Proclamations

Federal land-management policy in Alaska was one of the hotly debated topics during the 95th Session of the United States Congress. The Alaska Native Claims Settlement Act (ANCSA) of 1971 provided an 8-year time limit for Federal action on protecting or otherwise designating use of "special national interest lands" that up to 1978 were termed "d-2" lands. The largest conservation lobby ever assembled along with politicians like Congressman Morris Udall and Secretary of the Interior Cecil Andrus were concerned with the fast-approaching 8-year deadline of December 18, 1978 (Nash, 1982). They were worried that if no protective action were taken, there would be a huge "land grab" by mining companies and other developers within pristine parts of Alaska. They felt once the deadline was passed, State, Native, and private parties would be able to stake claims on Federal land, which constituted 99 percent of Alaska. If this happened, they reasoned it would be hopelessly complicated to establish any new national parks or wilderness areas. Bill HR–39, which would have protected 92 million acres of Federal land in Alaska, passed through the House of Representatives by a wide margin. However, Alaska Senator Mike Gravel's threatened filibuster of any bill that withdrew or placed restrictions on Federal land in Alaska stalled the bill in the Senate (Nash, 1982).

The Carter administration took action once it was evident that Congress was not going to pass any Alaska land bill by the end of the congressional session. Interior Secretary Andrus withdrew 110 million acres of Federal lands in Alaska from all forms of development for 3 years on November 16. He used the 1976 Federal Land Policy and Management Act to authorize this action. This act was controversial, and many thought it to be unfair since it was made before the close of the comment period (November 20) on the draft Environmental Supplement (T.E. Butler, written commun., 1978). The Environmental Supplement was to document, in part, the impact on Alaska citizens of the closing to development of land in Alaska. The lands withdrawn included most of Admiralty Island, including Greens Creek.

The big move came on December 1, 1978, when President Jimmy Carter declared 56 million acres of Federal land, including most of Admiralty Island, as national monuments under the authority of the 1906 Antiquities Act, which was designed to protect places of historical interest. Never before had the act been used on such a colossal scale (Nash, 1982). This move was applauded by the numerous conservation and environmental organizations and by the American public in general. Most Alaskans reacted with shock and outrage. The national monument status still had to be approved by Congress, giving the Greens Creek Joint Venture time to formulate a strategy to lobby Congress.

Immediately the land position of the Greens Creek Joint Venture was in jeopardy. The Greens Creek Joint Venture felt that their prior existing rights to the claims would be honored (T.E. Butler, memorandum to S. Nakata, 1979). However, there was a question as to whether a mine could be established within a designated monument, since there was no legal precedent. The 1979 Minerals Availability System Deposit Summary Report by the Bureau of Mines listed the land environmental factor as "prohibitive" until the status is legislatively determined in court (T.E. Butler, memorandum to S. Nakata, 1979). Claims could no longer be staked, nor could any surface construction activities not already approved under the 1978 Exploration Work Plan take place until the USDA Forest Service validated those claims. Considerable energy and resources were expended during the next 2 years to gain legislative relief from the Carter administration decision.

The next 2 years saw extensive lobbying by both sides. Noranda and the Joint Venture partners were actively lobbying Congress for a less restrictive designation for the Greens Creek drainage. One such group that the JV helped fund was the Citizens for Management of Alaska Lands (T.E. Butler, memorandum to S. Nakata, 1979). On the other side of the fence was the Alaska Coalition made up of the Nation's five leading conservation groups (Sierra Club, Wilderness Society, the National Audubon Society, Friends of the Earth, and the National Parks and Conservation Association), the largest and most powerful conservation group ever assembled in American history (Nash, 1982). The House passed Bill HR–39 in May of 1980, which would have recognized the Greens Creek deposit but would have surrounded it with land designated as wilderness. The Senate passed a much less restrictive bill (S–9) sponsored by Alaska Senator Ted Stevens that excluded Greens Creek from the national monument. House leaders initially did not wish to compromise on their bill, but on November 4 Ronald Reagan was elected president and they realized they had only a small window of opportunity left to pass a bill that would not be vetoed (Nash, 1982). The compromised bill was named the Alaska National Interest Land Conservation Act (ANILCA).

President Carter signed ANILCA into law on December 2, 1980. The act set aside 104 million acres of Federal land in Alaska for permanent protection. The Greens Creek deposit was included in the newly created Admiralty Island National Monument but was excluded from wilderness classification. It was decided legislatively that the Greens Creek project should proceed. Section 504 of ANILCA allowed for exploration on previously located, unpatented claims that fell within three-quarters of a mile of a valid mineral discovery. However, exploration would have to cease in 5 years and any claims not "perfected" would revert to national monument status. Thus the Joint Venture had until December 2, 1985, to perfect any of the 127 claims that fell within the 0.75-mile radius.

1980 Exploration Program

Exploration work was limited while the above political and legislative battles took place. Restrictions were placed on surface activities, and the previously approved plan of operation was only valid until May 31, 1980. Resources were directed toward finishing the environmental impact statement (EIS), which was taken over by International Environmental Consultants. Thirty-three drill holes (GC–51 to GC–83) were completed by the end of March (Noranda Mining, Inc., written commun., 1981). Another 35 feet of drifting intersected the footwall argillite at the south end of the 1350 exploration drift. An important milestone in 1980 was the USDA Forest Service Mineral Examiner's report that recognized valid discoveries on seven Big Sore claims (Noranda Exploration, Inc., and Noranda Mining, Inc., written commun., 1981). These seven claims formed the core claims with surface and subsurface rights.

Race to "Perfect" Claims and Predevelopment, 1981–85

1981 Exploration Program

With the political situation clarified by the passage of ANILCA, the Greens Creek Joint Venture members approved the appointment of Noranda Mining, Inc., as the operator, replacing Noranda Exploration. This change emphasized the point that Greens Creek was passing from the exploration

stage to development. Much of the activity in 1981 reflected this change in status. The primary emphasis was on environmental and engineering studies of various components of the project. The various projects completed included road alignment surveys from Young Bay to the Hawk Inlet Cannery, drilling and geophysical investigations of the tailings site near the cannery, and boat transportation study. The draft EIS was completed by December (Noranda Exploration, Inc., and Noranda Mining, Inc., written commun., 1981).

No surface exploration work was documented for the 1981 summer season. Despite the fact that the clock was already ticking on the 5-year exploration limit, Noranda chose to work on development issues. The USDA Forest Service approved the exploration permit in April; thus, the permit was not the limiting factor for exploration. Noranda lost one valuable season for perfecting claims as they pursued other studies of the project.

Underground development continued in 1981. A 424-foot crosscut was driven from the 1350 adit to expose the ore zone. The drifting continued along the ore to the north and south for a distance of 176 feet (Noranda Mining, Inc., written commun., 1981). This provided material for a 4,200-pound bulk sample for metallurgical bench flotation tests in Salt Lake City. The first exposure of the ore zone in three dimensions provided a "quantum leap" in the knowledge of the deposit (Noranda Mining, Inc., written commun., 1981). The exposure helped to confirm that three types of ore (Massive, White, and Black) were present and relatively lithologically discrete from each other. Vein mineralization, especially with regard to precious metal upgrading, was found to be more prevalent than thought from data obtained from the diamond drill core. Coarse visible gold was intersected in several areas. Overall, the Noranda geologists believed that the original reserve and grade estimates were too conservative based on the precious metals intersected and the inability of the LHDs (load, haul, dump equipment) to carry a full bucket of ore (Noranda Exploration, Inc., and Noranda Mining, Inc., written commun., 1981). A tonnage factor of 9 cubic feet per ton was more realistic than the original estimate of 11 cubic feet per ton. The crosscut also exposed ubiquitous intermediate scale folds (25–75-foot wavelengths) oriented normal to the interpolated large-scale folds that would have great implications for mining methods and grade, tonnage, and dilution estimates.

More legal difficulties arose in 1981. The Southeast Alaska Conservation Council (SEACC) and the Sierra Club challenged the USDA Forest Service's granting of the exploration permit for a second time. They appealed the granting of the exploration permit to the Chief Forester on the basis that the original claims were not valid as of December 1, 1978 (Noranda Exploration, Inc., and Noranda Mining, Inc., written commun., 1981). They argued that the Greens Creek deposit did not pass the marketability test, and no reclamation costs were included in the study. The Regional and Chief Foresters sustained the previous decisions, stating that the mineral inspector used the correct criteria for determining that the seven core claims contained valid mineral discoveries.

1982 Drill Program

Noranda shifted emphasis back to surface exploration and drilling in 1982. The goal was to validate unperfected claims and add to the total mineral inventory. Noranda Exploration, Inc., led by Joe Drechsler, was contracted by Noranda Mining, Inc., to manage the program (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). Noranda drilled 12 holes totaling 11,210 feet during the summer field season. Nine of those holes were in the Big Sore area, two in Gallagher Creek, and one in Bruin Creek, on the north side of Greens Creek.

The Big Sore drilling program successfully intersected discoveries on unperfected claims. Three holes were drilled to test the northwest strike extension of the orebody on claims 1107 and 1108. All three intersected only minor mineralization, and the lack of chert buildup (siliceous alteration) along the argillite/phyllite contact suggested that the ore pinches out to the north (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). On the south side of the orebody, only argillite was contacted in hole GC–82–9 (PS–50) targeting claim block 901. Holes GC–82–2 (PS–43) and GC–82–7 (PS–48) tested the downdip extent of the argillite/phyllite contact. Both holes intersected thin (4-foot) ore intercepts with high-grade silver up to 26.7 troy ounces per ton. The ore intercepts in these two holes were at a higher level (about 500 feet) than expected from projections from previous holes, indicating flattening of the ore horizon due to folding or faulting. Holes GC–82–8 and GC–82–10 (PS–49 and PS–51) were drilled from claim 1106. GC–82–8 intersected 12 feet of 26.7 troy ounces per ton silver and 11.93 percent zinc. The other hole intersected a barren contact. The final hole of the season, GC–82–12 drilled from claim 1107, intersected a 6-foot interval of argillite running 6.22 troy ounces per ton silver, 3.75 percent lead, and 4.10 percent zinc. Noranda did not make clear in the yearly report which of these intersections would qualify for discovery and claim validation.

The two holes in Gallagher Creek attempted to better outline the mineralization present there from intercepts from the 1976–77 drilling program and test for Greens Creek-type stratigraphy. Drill hole GC–82–5 (PS–46) was successful in intersecting 15 feet of high-grade zinc mineralization (10.22 percent). The hole was located on claim 1304 at the western edge of the 0.75-mile limit. The other hole, GC–82–11 (PS–52) located farther south, intersected minor zinc enrichment. The Bruin Creek hole GC–82–6 (PS–47) was drilled on claim 1213 and intersected several 3–5 foot sections of chert-carbonate rock containing up to 1 percent zinc. However, Noranda did not view the results as being favorable for discovering any significant sulfide occurrences in the area (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982).

Noranda still saw Greens Creek as being open along strike to the northwest and downdip, with the potential of another 2–5 million tons of ore (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). Noranda felt

that five of the holes drilled on unperfected claims intersected mineralization of sufficient quality and quantity to be considered "discoveries." However, section 504(e)(1) of ANILCA left some doubt as to what constituted a valid discovery; whether the standards applied would be those of the USDA Forest Service Mineral Examiners or the stricter Bureau of Land Management (BLM) requirements for issuance of a patent (which appeared to be how the section was worded) was unclear. An unofficial draft of the Mineral Examiner's report stated that claims 1304 and 1305 in Gallagher Creek contained valid mineral discoveries, but claim 1605 in Killer Creek did not. Noranda maintained that drillcore of 2.3 percent copper is a valid discovery, but their legal counsel suggested that this interpretation would not hold up in court (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982).

Noranda and the JV partners reviewed other options and strategies to protect the exploration potential of Greens Creek. The alternatives to the current aggressive discovery-oriented drill program included a minor boundary change putting Greens Creek outside the national monument, a land swap, or extension of the 5-year period to prove the claims (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). The first choice was to lobby the USDA Forest Service for a minor boundary adjustment, a power the USDA Forest Service had under one of the provisions of ANILCA. The other two choices were less attractive because a land swap would be costly and an extension would only delay resolution of the problem.

The cost of the drill program was becoming a concern for Noranda. More definition drilling was necessary to bring the "new" 1982 geologically inferred reserves into indicated reserves (J.S. Drechsler, Jr., and others, Noranda Mining, Inc., written commun., 1982). Even at 400-foot spacings, it would require about 11,000 feet of surface drilling to validate indicated reserve status, leaving very little funds for perfecting claims. Drilling on 150-foot centers, which was preferred, would be extremely expensive. Underground drilling would be less expensive, but the platforms did not exist and would be best established simultaneously with mine development and mining, still years away. Underground and surface drilling both would require helicopter support, adding to the cost. Drilling would be much less expensive after road construction, but road construction might not be possible until after the expiration of the permit period due to political and budget constraints. Noranda was faced with either continuing drilling at a higher expense or pursuing the above-land options and risk losing potential mineral assets.

Noranda Exploration geologist Daryl Scherkenbach completed a geologic mapping project at a scale of 1 inch=500 feet for the Greens Creek area. This work was the basis for his geologic model of the Greens Creek deposit. He suggests that the Big Sore orebody formed within a second- or third-order extensional basin (D.A. Scherkenbach, written commun., 1983). In his model, tectonic extension was accompanied by mafic and ultramafic volcanics and shallow intrusives. The serpentinization of these rocks is a strong indicator of hydrothermal activity that caused the metal transportation. The effusive vents for the hydrothermal fluids manifested themselves as slump breccias, as mapped within the footwall tuffites. These vents formed fault scarp basins, in which the metallifereous brines could settle and deposit metals. The massive ores accumulated near the vents while black ores accumulated distally, hundreds of meters from the vent. The white ores represented remobilized sulfides as the solutions migrated around sulfide-clogged vent areas. Scherkenbach thought the difference between the sericitic and chloritic tuffites/sediments was due to different source areas or modes of deposition. The highly negative δS isotope values for the argillite and black ore indicate biogenic reduction of seawater sulfate. The less negative values for the remaining ore types and tuffites suggest a mixing with magmatic sulfur.

1983 Feasibility Study

Noranda completed a feasibility study in 1983 that outlined the economic viability of the project. The study was based on probable and possible reserves (including dilution due to mining method) of 2.84 million tons at 0.093 troy ounce per ton gold, 14.42 troy ounces per ton silver, 2.93 percent lead, and 8.56 percent zinc located above the 950-foot level. An additional geologic reserve of 1.45 million tons was estimated to be below that level (Noranda Mining, Inc., written commun., 1983). Noranda envisioned using conventional cut and fill mining methods utilizing jacklegs within "captured" stopes. Five to six separate levels/portals on 200-foot spacings would be connected by a winze and raises. Rail haulage would take place on all levels. Noranda preferred this method to mechanized cut and fill to reduce the amount of ramp development and allow for more selective mining where the ore is too narrow for rubber tire equipment. Mining rates were estimated at 1,200 tons per day (TPD) with dilution at 17 percent and mining recovery at 90 percent. Carbon, lead, and zinc concentrates would be produced over the estimated 20-year mine life (including development time). The mine would have a workforce of 344 people. The economic/cash-flow model given these parameters required a 1987 silver price of $22.95 for a 15 percent DCF–ROR. The estimated capital investment was $254.3 million with an operating cost of $151.85 per ton (Noranda Mining, Inc., written commun., 1983). This was a huge contrast from the 1980 estimate of 39.3 percent DCF–ROR and $65 per ton operating costs.

1983 Exploration Program

The objectives of the 1983 program were much the same as before, to validate peripheral claims and continue detailed definition drilling of the southern end of the orebody. The management of the program fell back to Noranda Mining, Inc., with Edwin Harrison supervising. The decision to proceed with the drill program did not come until July 7, and the four crews required for the work were not completely mobilized until August 1 (E.D. Harrison, Noranda Mining, Inc., written commun., 1983).

A total of 17 holes were drilled during the season. Most of the holes (15) were drilled from the southern core claims (902, 903, and 904). The aim was to upgrade the southernmost part of the resource to measured reserves status. Noranda viewed the south end as being critical to the initial mine design and development, and they needed a better understanding of the fold closure (E.D. Harrison, Noranda Mining, Inc., written commun., 1983). Three holes drilled updip from the 1982 ore crosscut intersected white, massive, and black ore of economic length and grade. One hole drilled at the southernmost known limits of the orebody intersected 12 feet of high-grade precious metals (0.644 troy ounce per ton gold and 55 troy ounces per ton silver). This hole also tested the upper limb argillite but intersected no mineralization. The remaining nine holes were in-fill drillholes of which five intersected significant ore intervals. The in-fill holes helped "prove" the continuity of ore in the south end of the designed mine plan and helped define the major fold closure controlling the ore to the south (E.D. Harrison, Noranda Mining, Inc., written commun., 1983).

Many high-grade intercepts were assayed during the drill program. A 2-foot interval from PS–62 assayed greater than 11 troy ounces per ton gold, which was confirmed by numerous re-assays. Noranda considered the question of cutting high gold/silver assays for reserve calculations. They felt this idea should be studied closely and put into practice (E.D. Harrison, Noranda Mining, Inc., written commun., 1983).

Little effort was made in proving unperfected claims in 1983. Only two holes were drilled and an older hole was reentered and wedged in a different direction. PS–70 was drilled on claim 1107. Perfecting this claim was a high priority because the 1350 portal, mine camp, and waste dump were all located there. The hole intersected a short (1-foot) but high-grade (109 troy ounces per ton silver) mineralized zone deemed sufficient to prove the claim. The attempt to prove claim 1003 was an expensive ordeal (E.D. Harrison, Noranda Mining, Inc., written commun., 1983). The target was a recumbent drag fold intersected just outside of the claim by PS–48 (1982). An attempt was made to reenter that hole and place a directional wedge to deflect the hole onto claim 1003. The wedge failed to deflect the hole. A new hole, PS–54, was collared at the same site. Despite orienting the hole to compensate for the expected deviation, downhole surveys showed the hole was going to miss the projected contact to the northeast. Poor weather forced the postponement of the drill program before another mechanical wedge could be used to correct the hole. Thus, a valid discovery was made on only one unperfected claim in 1983, with only 2 years remaining on the exploration permit.

The first change within the Greens Creek Joint Venture partners occurred in 1983. Anaconda purchased all of Martin-Marietta's interest in the Greens Creek Joint Venture in March of 1983 after first approaching them in December of 1982 (Anaconda Minerals Company, written commun., 1984). Anaconda already had exploration experience in southeast Alaska, including the Pyrola claims to the south of Greens Creek. Anaconda's Project Evaluation Report in January of 1984 justified their purchase on the basis of Noranda's prefeasibility study. They believed that Noranda's approach was too conservative and estimated the minable reserve greater by 0.5 million tons with higher silver (16 rather than 14.4 troy ounces per ton) and gold (0.11 rather than 0.093 troy ounce per ton) grades. In addition, they thought that utilizing the mechanized cut and fill mining method would reduce capital costs for full production by 20 percent from Noranda's conventional cut and fill proposal.

Anaconda saw many potential problems with the project. They were concerned with the marketability of the concentrates produced due to the high level of contaminants (cadmium, arsenic, antimony, and mercury). Other concerns were the limited size and accessibility of Juneau, making it difficult to obtain and keep experienced personnel. They felt the lower levels of the deposit lacked the necessary drilling for production to be justified. Anaconda foresaw future delays in the project due to political and environmental factors. However, they did not see the pending exploration deadline and land issues as having an adverse effect on the base case economics. Anaconda's preferred solution to the land situation was a land exchange with the Federal Government (Anaconda Minerals Company, written commun., 1984).

1984 Exploration Program

The 1984 drill program budget was $3.3 million, a fivefold increase from the $0.655 million budget of the previous year (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984). The increased budget, and the primary objective of the 1984 drill program to extend the proven claim block to the north and south, underscored the increasing pressure of the exploration deadline. The northern claims were tested to the 0.75-mile limit by surface holes while the southern claims could only be tested practically by underground drilling. Surface holes would be too long as a result of the increase in topography and southeast-plunging ore zone. An 847-foot-long drift (1984 crosscut) was driven to the edge of the unperfected claims, with drill-cuts along the way for detailed ore reserve drilling.

The secondary objective of the 1984 program was to increase the downdip potential of the previously defined ore zones. The deposit was now divided into three ore zones, the North, South, and Central zones. The drilling took place from the 1350 drift and the new 1984 crosscut. Much rehabilitation work had to be completed on the 1350 drift due to numerous ground falls since 1981 before drilling took place.

The farthest north and northwest drilling in Gallagher Creek (PS–83), Killer Creek (PS–82, PS–86), and Bruin Creek (PS–76 to PS–81 and PS–84) failed to intersect mineralization sufficient to perfect claims. Likewise, hole PS–75 located near the camp on claim 1108 did not intersect mineralization along the argillite/phyllite contact. Drillholes closer to the core claims were more successful. PS–72 and PS–73 extended the now-named North Ore zone downdip another 250 and 350 feet, respectively, although the intersections occurred on

already perfected claims. PS–74 intersected the North Ore zone at the 400-foot level with a 7-foot interval of 17 troy ounces per ton silver and 5 percent zinc. This was the deepest ore intersection to date and perfected claim 1105. Another hole, PS–85, tested claim 1106 and intersected the North Ore zone and 9.4 feet of "black" ore mineralization. This hole perfected claim 1106.

Most of the barren surface holes intersected chloritic sediments or mudstones instead of cherty sericitic tuffites above the argillite contact. Noranda believed that the chloritic rocks were not very conducive to Greens Creek-type ore mineralization, though they did not state any geologic reasoning for their conclusion (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984).

No claims were perfected on the south end of the ore trend. Three holes were attempted from the southern end of the 1984 crosscut, and all three terminated within 220 feet of the collar due to poor drilling conditions caused by a major northwest-trending fault (later defined as the Maki fault). Another attempt was made to perfect claim 901 to the south by drilling from a station farther back in the crosscut. However that hole, GC–91, intersected a barren contact within that claim. The in-fill drilling was very successful in increasing the reserves. Two stations were drilled from the new 1984 crosscut to test the downdip potential of the South Ore zone while one station was drilled from the 1350 exploration drift to test the downdip potential of the Central Ore zone. Hole GC–86 intersected numerous fold-repeated ore intervals, the lowest of which was located within the southeast corner of unperfected claim 1003. Noranda thought that the 5.9 feet of 16 troy ounces per ton silver would be sufficient to perfect this claim (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984). Two holes drilled in the South Ore zone, GC–88 and GC–94, intersected ore of higher precious metal grade, coarser grain size, and silica-baritic groundmass that had not been identified previously. Noranda thought that they might be approaching the primary vent to the south and that the grades might continue to increase downdip and to the south (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984).

The underground drilling program was successful in delineating more reserves below the 950-foot level and provided more insight to fold and fault structures, especially in the southern part of the deposit. Noranda did not add these new reserves to the "probable" category because they were not drilled on 150-foot centers (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984). However, they believed that the number of good ore intercepts supported the assignment of these areas into the geologic resource category. Thus, they classified the preliminary estimate of 670,000 tons to the "possible" category, with the majority of the tons in the North and South Ore zones. The increase in possible reserves, especially for the North Ore zone, was expected to have a large effect on the mine plan.

Other work included mining of ore underground for two bulk samples, one to be tested by Noranda and the other by Anaconda. Noranda geologist Floyd Branson initiated a trenching program in an attempt to expose the productive contact and patent claims 1007 and 1107. "Discovering" mineralization on the surface would allow the Greens Creek Joint Venture to exert extralateral rights under the Apex Rule (E.D. Harrison and others, Noranda Mining, Inc., written commun., 1984). The work was very difficult and expensive due to the difficulty in locating the contact under the thick glacier overburden.

Tom Crafford of Anaconda began his active role in the project by completing an extensive geologic mapping project to the north and east of the Greens Creek core claims. Crafford's surface mapping included defining two northwest-trending faults, one on Mariposite Ridge just west of the Mammoth claims, and the other at the head of Big Sore Creek. He believed that these faults were the same structure (T.C. Crafford, written commun., 1984). Sampling of mineralization on the Mammoth claims showed ore-grade material within mariposite-carbonate rocks, which Crafford thought might represent a link between that alteration style and the mineralizing event. Several rock samples were taken for conodont analysis for age determinations, as there was a debate whether the age of the Greens Creek orebody was Paleozoic or Triassic. However, these samples were barren. He also mapped to the northeast of the mine to determine whether or not the overturned limb of the Big Sore anticline reappeared on the surface, but he found no evidence of a fold repeat.

Some of Crafford's ideas expressed in his report were contrary to Noranda's view of the geology. He did not agree with the tuffite designation for the footwall rocks. He viewed these rocks as hydrothermally altered mafic rocks that were proximal to vents (T.C. Crafford, written commun., 1984). He was also doubtful of the large-scale anticline hypothesis.

The end of the year saw a change in the ownership of the Greens Creek Joint Venture. Anaconda and Noranda equally bought out Bristol Bay Native Corporation's properties at Hawk Inlet for a cash payment and a 0.28-percent net smelter royalty. The land would revert back to Bristol Bay upon termination of the Greens Creek Joint Venture.

1985 Surface Exploration Program

The objectives remained much the same as previous years for the 1985 drill program, the final year of the exploration permit granted under ANILCA. The surface drilling of 10 holes totaling 12,266 feet was designed to perfect as many claims as possible. The underground drill program involved definition drilling on 150-foot centers to place 1984's "possible" tons into the probable reserve category. This was the largest underground drill program to date, totaling 47 holes and 34,749 feet of drilling.

PS–87 was the only surface hole successful in perfecting a claim. The hole was drilled vertically from the northwest corner of claim 1206 to test the area between Gallagher Creek to the west and the North Ore zone to the east. The hole intersected 11.3 feet of "black ore" averaging 0.114 troy

ounce per ton gold, 16.88 troy ounces per ton silver, and 4.9 percent zinc (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985). The intercept was 40 feet inside claim 1207 due to hole deviation. A wedged hole off of PS–87 also intersected 5.6 feet of ore-grade material, but it too missed claim 1206. Ed Harrison recognized this intersection as a separate orebody that to this day is still isolated from the nearest defined orebody by about 1,000 feet. PS–88 through PS–92 were drilled from already perfected claims 1106 and 1107 to define the eastern edge (or upper shelf) of the North Ore zone. PS–92 was the first and only hole drilled on the east side of Big Sore Creek, above the High Sore, another ferricrete kill zone (fig. 1). Highly fractured and deformed argillite was the only lithology encountered in PS–92. The remaining four holes were drilled on claims 1207, 1208, and 1209 to follow up the ore intercept in PS–87. None of these holes intersected significant mineralization.

The underground drill program was successful in delineating more reserves in all three ore zones. Noranda nearly doubled the probable reserves, adding another 1.33 million tons to the already identified 1.333 million tons (fig. 3). The total tonnage of 2.663 million at 0.13 troy ounce per ton gold, 22.24 troy ounces per ton silver, 3.49 percent lead, and 9.00 percent zinc exceeded their original goal of 2.1 million tons (Noranda Mining, Inc., written commun., 1985). Noranda was very optimistic due to the fact that the grades were increasing with depth and all three ore zones were still open at depth. Hole GC–139, drilled from the southern end of the 1984 crosscut, succeeded in perfecting claim 1002 with numerous 8- to 13-foot ore-grade intercepts. Four holes were attempted from the same station to perfect claims 901 and 1001 to the south. They were all abandoned or lost, however, due to poor drilling conditions in the fault zone where three drill holes were lost in 1984.

The Greens Creek Joint Venture's land position was augmented in 1985 with the signing of an exploration/development agreement with the owners of the Mammoth claims. The agreement was a 10-year lease with a drill commitment and royalty payment due to the owners on any production (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985). The old "Mammoth Tunnel #2" was cleared and mapped. Other old pits and trenches were sampled. A grab sample of a tetrahedrite-bearing outcrop just above the portal assayed at 0.778 troy ounce per ton gold, and 17.91 troy ounces per ton silver. An additional 85 claims were staked to the north of the Mammoth claims, just outside the monument boundary, to cover ground not claimed by the Lil Sore claim group controlled by the Norbritex Venture. The crew spent more than 3 weeks staking claims, enduring snow depths up to 12 feet (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985).

The south face of the 1981 ore crosscut was advanced to test the ability of the miners and grade-control geologists to stay on the ore and to test the lateral variability of the ore types. This experience left Noranda feeling that it would be a face-to-face requirement of the production geologist to follow the highly deformed ore (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985). A United Nuclear's silver probe was successfully tested as a grade control tool in estimating silver content of drill-core and face chip samples.

Land Strategies and Negotiations, 1983–85

While the exploration projects tried to perfect as many claims as possible before the December 2, 1985, deadline, efforts were underway to find a legal solution or compromise to the dilemma. Just prior to the deadline, the Greens Creek Joint Venture filed proof of discovery of nine additional claims (1002, 1003, 1004, 1005, 1105, 1106, 1107, 1207, and 1304) to add to the original eight core claims (E.D. Harrison and M. Severson, Noranda Mining, Inc., written commun., 1985). The Greens Creek Joint Venture was concerned that the accelerated exploration was too costly and risky, and other avenues needed to be explored to remedy the land situation. The three separate avenues that were explored are discussed in the following paragraphs.

The first option was a boundary change regarding the Admiralty Island National Monument (AINM) and wilderness areas. ANILCA (section 103b) allowed for the Forest Service to make minor boundary adjustments to the various land selections. This idea was being pursued as early as 1983. The Greens Creek Joint Venture was hoping to exchange 18,174 acres of private land in the Young Bay/Young Lakes area for 17,225 acres within the Greens Creek area. However, the Sierra Club was against the boundary change even if it meant no net loss to the AINM because it would set a precedent for boundaries based on economics. Attorneys for Noranda thought any changes in boundaries were unlikely because the USDA Forest Service would be named as the defendant in any litigation, threatening their power to grant minor boundary changes (J.P. Tangen, esq., memorandum to P. Richardson, 1983). In addition, Noranda would not be involved directly in the litigation, thus losing control of the nature and timing of any solution.

The second option that was pursued was legislative relief through extension of the exploration permit (J.P. Tangen, esq., memorandum to P. Richardson, 1983). Representative Don Young, Alaska's sole representative, introduced bill H.R. 2651 on June 3, 1985, to amend section 504 of ANILCA. The amendment would allow the Greens Creek Joint Venture to renew the 5-year exploration permit up to six times so exploration could continue until December 2, 2020. Senator Murkowski of Alaska introduced an identical bill as S. 1330. These bills would only provide for exploration within the 0.75-mile limit. However, neither bill made it out of committee.

The third option was a proposed land exchange involving Sealaska, the southeast Alaska Native corporation. The first iteration of the land-exchange proposal called for Sealaska to exchange subsurface mineral rights in the Cube Cove area for subsurface rights in the Greens Creek area. This land was

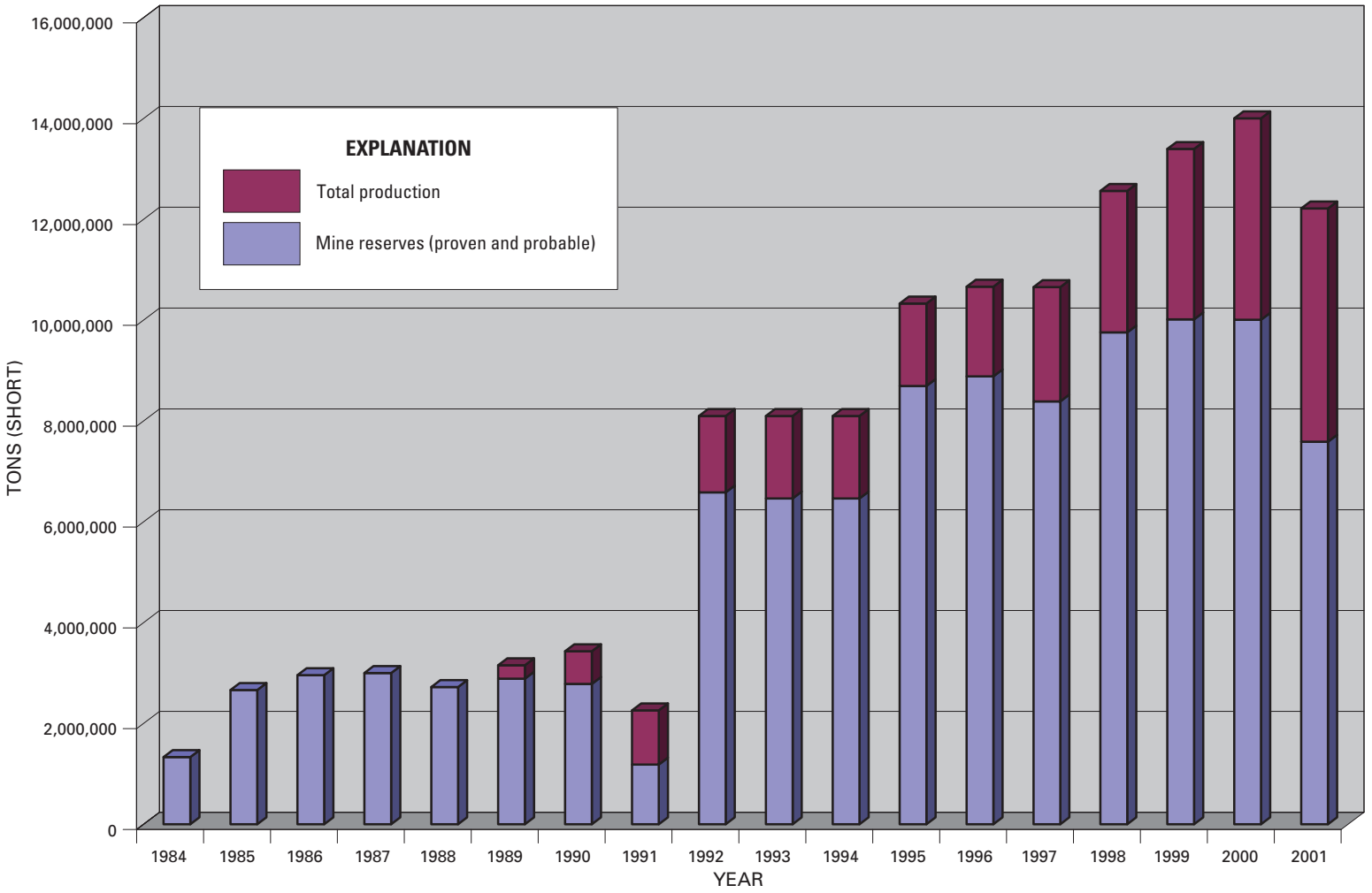

Figure 3. Chart showing proven and probable reserves compared to total (cumulative) production (Kennecott Greens Creek Mining Company, written commun., 2001).

selected by Sealaska under ANCSA. The tentative agreement reached in November of 1985 called for Sealaska to lease these rights to the Greens Creek Joint Venture in return for a yearly lease fee to be negotiated and a 3.5-percent net smelter return royalty on any ore mined outside the existing core and perfected claims and extralateral rights from those claims. The lease would have a life of 25 years with mandatory work commitments made by the Greens Creek Joint Venture for each year. Sealaska saw themselves as a "passive" landowner (Birch, Horton, Bittner, Pestinger, and Anderson, written commun., 1985). This agreement hinged on at least a one-year extension of the exploration permit deadline to allow Sealaska adequate time to complete the land exchange.

The exchange with Sealaska Corporation was seen as the best option. The attorneys employed by Sealaska believed that the various environmental groups would support only this option. Litigation was unlikely since Sealaska, a Native corporation, was involved. Sealaska and the Sierra Club were trying to link the Greens Creek land exchange with another land-management dispute on Admiralty Island. The Shee Atika Native corporation was planning to harvest trees on the land at Cube Cove for which Sealaska owned the mineral rights. This clearcutting plan had the Sierra Club up in arms. Sealaska thought that the Sierra Club and the Forest Service would support a plan that halted the imminent harvesting (Birch, Horton, Bittner, Pestinger, and Anderson, written commun., 1985). However, Greens Creek wanted the issues resolved separately so that no additional complications would arise. Many groups, including the Shee Atika, the Alaskan congressional delegation, and the Greens Creek Joint Venture, were becoming increasingly dubious about Sealaska and their actions (Steven Silver, memorandum to P. Richardson, 1985).

The exploration permit was extended by one year in 1985. This allowed for continuing negotiations with Sealaska and further exploration to prove additional claims. By 1988 the USDA Forest Service rendered a decision denying the land-exchange proposal. The land exchange still could be completed if the agreement involved the surface rights to the Cube Cove land. This would require a direct agreement with the Shee Atika owners. Despite these problems, the Greens Creek Joint Venture felt that a land exchange opening the remainder of the Greens Creek area to subsurface mineral development was just a matter of time (T.C. Crafford, memorandum to H. Griffith, 1988).

Ownership Changes and Consolidation, Development, 1986–89

A major ownership change occurred at the beginning of 1986. Amselco (parent company, BP) purchased Noranda's and Anaconda's (which had just been liquidated by its parent company, ARCO) interest in the Greens Creek Joint Venture. That gave Amselco 70 percent of the total interest in Greens Creek, and they became the operators of the property. The geology staff did not change.

1986 Surface Exploration Program

The 1986 surface exploration program drilled surface and subsurface drill holes in an attempt to perfect four claims. Two of the claims (1001 and 1208) would be considered strike extension claims that Amselco believed, if allowed to patent, would extend their extralateral rights to the north and south (E.D. Harrison, Greens Creek Mining Company, written commun., 1986). The other two claims, 1104 and 1206, were believed to be covered under existing extralateral rights but were drilled anyway to test for downdip mineralization. Three surface holes were completed, totaling 4,694 feet, and one underground exploration hole was drilled to 1,271 feet.

The first hole drilled, PS–97, was the only one of major success. Two ore intervals were intersected consisting of mineralized gray chert and massive to semimassive sulfides. The lower intercept was at an elevation of 760 feet and was 25.9 feet long, averaging 0.08 troy ounce per ton gold, 16.68 troy ounces per ton silver, and 6.2 percent zinc. The rocks were unusual in that the mineralized chert was complexly folded and(or) interfingered with argillite, and the contact was 500 feet above the projection of the ore horizon in holes from the North and lower Central Ore zones. Ed Harrison believed the mineralization was continuous (E.D. Harrison, Greens Creek Mining Company, written commun., 1986); however, later drilling would define this as a separate ore zone, the Upper Southwest. The claim line between 1103 and 1104 had not been accurately surveyed and the ore horizon was right along the apparent boundary, thus making it difficult to prove the claim. The other two surface holes, PS–98 and PS–99, did not intersect mineralization on claims 1208 or 1206, respectively.

An underground hole was yet another attempt to prove claims to the south (1001) by drilling through the major fault at the end of the exploration drift. For the first 250 feet of hole GC–143, which corresponded to the faulted zone, 3.25-inch-diameter (PHR) core was taken, and then 2.5-inch diameter (HHR) core was taken to 411.3 feet. The core diameter was reduced to 1.875 inches (NQ) to 1,271 feet. The hole intersected ore grade intervals (up to 16.4 troy ounces per ton silver and 23.7 percent zinc), 3 to 100 feet wide, of mostly faulted white baritic ore (WBA) within argillite. This hole extended the known mineralization of the South Ore zone another 300 feet to the south into an unperfected claim.

Surface mapping and exploration were mostly limited to the Mammoth and Mariposite claim groups. The first occurrence of silver sulfides on Greens Creek Joint Venture lands was sampled in a 10-foot zone just to the north outside of the Mammoth claims. The sample assayed at 53.75 troy ounces per ton silver. Four diamond drill targets were outlined for drilling in 1987 on the Mammoth claims, as specified in the work commitment spelled out in the lease agreement (E.D. Harrison, Greens Creek Mining Company, written commun., 1986).

Tom Crafford's 1986 map and report outlined his ideas and conclusions concerning Greens Creek geology. He verified through field evidence that the linear aerial photography

features do represent major faults of probable right-lateral movement with possible oblique or reverse slip components (T.C. Crafford, written commun., 1987). The youngest cleavage identified (now defined as S_3) within the Greens Creek rock package is a fracture cleavage related to the above major faults. He believed the first structural event is manifested by the recumbent isoclinal folds (later described as the D_2 event). He further refined the Mammoth claim geology and thought that the previously exhalative explanation for the QCM (quartz-carbonate-mariposite) unit was incorrect. Field evidence supports the idea of the altered mafic tuffs grading into the QCM unit, thus being serpentinized mafics (T.C. Crafford, written commun., 1987).

Four EM and magnetic survey lines were flown over the Greens Creek area piggybacked on Amselco's Mansfield aerial geophysical survey. No magnetic anomalies were identified from the survey. However, 6 of the 11 EM anomalies coincided with soil geochemical anomalies in the Big Sore area (E.D. Harrison, Greens Creek Mining Company, written commun., 1986).

Underground work continued to define the orebody in greater detail and to test different drifting and grade-control practices. A footwall drift was extended 94 feet from the east rib of the 1981 ore crosscut. The 9-foot-wide by 8-foot-high drift driven by jacklegs tested for mining problems within argillite. Four 1.432-inch diameter (BX) core holes were drilled using a CP–65 pneumatic drill rig from the new footwall drift. Two holes were drilled from the 1981 ore crosscut. These holes were drilled at tight 10- to 15-foot spacings along the contact to obtain more detailed structural data than from the drilling at 150-foot spacings. Detailed sampling of this core was carried out to determine the actual ore-waste boundary. The contact between the ore and hanging-wall argillite was the most important contact to define because most of the high-grade precious metals were found within 6 to 18 inches of that contact (E.D. Harrison, Greens Creek Mining Company, written commun., 1986).

1987 Surface Exploration Program

The exploration permit for the Big Sore and Tom claim groups was not extended another year by legislative means. The Greens Creek Joint Venture lost all rights to the Big Sore claims except for the eight core claims and the nine additional perfected claims. Negotiations were continuing with the USDA Forest Service and Sealaska to work out a land-exchange agreement.

The 1987 program concentrated on prospects away from the Greens Creek mine area. The Mammoth claims received the bulk of the attention and funds. Four diamond drill holes were completed, totaling 1,441 feet (W.C. Meyers, written commun., 1988). Three of the holes tested the mineralization seen on the ridgetop exposure of the QCM unit, and one hole targeted the lower QCM band. All holes intersected minor mineralization over short (less than 3-foot) intervals, assaying up to 0.236 troy ounce per ton gold, 1.72 troy ounces per ton silver, and 3.8 percent zinc. The mineralization occurred within the QCM units for the ridge trend holes, while the mineralization occurred with the graphitic schist unit in the lower band. Six additional holes were outlined for drilling in 1988, mostly along strike of the graphitic schist/QCM contact.

Exploration work also was completed within the Fowler, Lil Sore, and Mariposite claim blocks. The first two claim groups were part of the original Norbritex Joint Venture. This joint venture was formed by Noranda, Bristol Bay, and Texas Gas in 1980 to explore lands outside of the Big Sore and Tom claim groups in which the other members of the Greens Creek Joint Venture did not wish to participate. Norbritex drilled one hole in Lil Sore that intersected a quartz-sericite unit overlying a graphitic unit, both thought to be part of the mine stratigraphy (W.C. Meyers, written commun., 1988). Soil sampling and CEM geophysics were carried out on soil grids to outline possible Greens Creek-type volcanogenic massive sulfide (VMS) targets or epithermal gold targets. Six anomalous soil geochemical zones were outlined, two of which occurred proximal to, or over, a sericitized pyrite breccia unit. Some of the soil anomalies had coincident CEM conductors. Additional soil sampling (in-fill), mapping, and trenching were recommended for these three claim groups.

The Greens Creek Joint Venture recognized the need for a better understanding of the structural geology of the mine, especially for mine planning. Three structural geology consultants (John Proffett, Ken McClay of the University of London, and Brian Marten of BP Minerals International) were contracted to perform separate structural studies. Marten's study was the first undertaken in early April of 1987. Marten deemed his results to be very preliminary by himself after he discovered that the 2 weeks he allotted for the study were "totally inadequate due to the unexpected structural complexity that was found" (B.E. Marten, BP Minerals International, written commun., 1987). He concluded that at least two intense penetrative shear deformational events were present that have been refolded by a third fold phase (D_1 through D_3). Marten believed that the first deformation had the greatest effect on the massive sulfides and result in milling, brecciation, and plastic flow. The hanging-wall breccia was also a result of this intense shearing (not phreatoclastic). He stated that the ore zone was likely a major shear zone. He expressed concern that the previous quantity and quality of structural observations underground, in drill core, and on surface were woefully inadequate for ore reserve calculations and mine planning (B.E. Marten, BP Minerals International, written commun., 1987).

John Proffett largely agreed with Marten's observations, though he did not see direct evidence for the first deformation event and he added a fourth, open-fold event (J.M. Proffett, written commun., 1987). He saw the second event to be the most intense, giving rise to S_2 axial planar to steeply plunging isoclinal F_2 folds. Gently south-southeast-plunging F_3 folds in turn fold F_2. He thought that the S_2 was nearly parallel to bedding. The S_2 foliation is the dominant foliation seen in all rock types (compositional banding within the phyllites and ore,

and the slaty cleavage in argillite). He found no evidence for major thrust faulting along the ore/argillite contact. In addition, he mapped local F_4 folds that plunge nearly parallel to F_3. The structural nomenclature suggested by Marten and refined by Proffett is still accepted and used by mine geologists at Greens Creek. McClay also largely agreed with Marten and Proffett. He adds a later D_5 event to describe the later brittle faulting (K.R. McClay, University of London, written commun., 1987). His conclusion mirrored Marten's that the current structural database was inadequate, and more detailed work was necessary for ore reserve calculations and mine planning (K.R. McClay, University of London, written commun., 1987). Despite the inherent structural complexities at Greens Creek, all three geologists agreed on a structural framework that still stood in 2001.

1988 and 1989 Surface Exploration Projects

Development and preproduction projects took priority over the next 2 years. Greens Creek management was waiting for the finalization of a land-exchange agreement with Sealaska (Greens Creek Mining Company, written commun., 1988). The minimum assessment work was completed on the various claim blocks in 1988, mostly consisting of mapping and trenching. Work on the Mammoth claims included the completion of one diamond drill hole. MRD–5 was drilled 600 feet southeast of hole MRD–4, testing for sulfides along the quartz-carbonate/graphitic schist contact. The hole did intersect minor disseminated galena and sphalerite, though no assay numbers are reported.

The Greens Creek Life of Mine Plan was released on March 25, 1988. The plan called for the startup of production operations in early 1989 with concentrate being produced by that February. Full-production rate was expected to be 1,000 tons per day (TPD) operating 355 days a year. The mine life was expected to be 11 years. Total capital expenditures necessary for development and startup were reported as $105.8 million, with another $12.1 million expected over the life of mine.

This plan proved workable. The Greens Creek mill processed the first ore from the mine on February 5, 1989. This was achieved despite the ferry dock being severely damaged by a winter storm on January 30 (Greens Creek Mining Company, written commun., 1989). Crews were transported to and from the mine by way of helicopters and float planes until a temporary dock was installed on February 7. The mill processed 8,150 tons of ore during the first month of operations.

Surface exploration activities consisted of two holes drilled from Big Sore claim 1105, targeting downdip of the North Ore zone. PS–100 was abandoned after 456 feet due to poor drilling conditions. PS–101, drilled from the northwest corner of the claim, reached 2,106 feet and intersected three barren contacts. No record exists of any assessment work done on the outlying claims. One significant underground drilling discovery was made. Hole GC–265, drilled along section 33, intersected 235 feet of ore-grade massive sulfide at a lower elevation than that of the North Ore zone. This was an apparent new ore trend in a previously untested area (Greens Creek Joint Venture, written commun., 1994). This zone was later defined as the (Central) West zone.

Continuing Underground Exploration, Production to Shutdown to Reopening, 1990–95

The 1990 surface exploration campaign was very active after two summers of mostly minimum assessment work during startup. Diamond drilling took place on validated and unvalidated claims to the west of the established orebody. Drilling was allowed off the validated claims and within the national monument nonwilderness after the USDA Forest Service determined the Greens Creek Joint Venture had sufficient claim of extralateral rights (William Edwards, written commun.,1990). This final effort to validate claims to the west of the core claim group was the largest surface drilling project to date (10 holes totaling 23,287 feet).

The first hole, PS–102, was drilled at the same site as PS–100, which was abandoned the previous year. This hole did not intersect any economic mineralization. However, the next three holes all intersected ore from widely scattered drillpads. PS–103 was collared along the very southern edge of claim 1105 to test the possible southwest extension of the North Orebody. The hole intersected three ore-grade intervals along a contact between a siliceous breccia and argillite. The bottommost 5.5-foot intercept included visible electrum that ran 0.524 troy ounce per ton gold and 86.4 troy ounces per ton silver (J.G. Baughman, memorandum to T. Crawford, 1990). PS–104 was drilled 1,200 feet to the southeast of PS–103 and intersected two ore intervals, including 24 feet of 0.102 troy ounce per ton gold, 35.99 troy ounces per ton silver, and 9.1 percent zinc at the 860-foot level. PS–105, 500 feet from PS–103, tested the northwest extension of this mineralized interval. This hole intersected ore-grade massive sulfide at the 950- and 500-foot levels. The drill program geologists believed that the mineralization was continuous for over 1,600 feet, but they could not confidently correlate it with other recognized orebodies (J.G. Baughman, memorandum to T. Crawford, 1990). PS–103 and PS–105 were the first holes to intersect the Northwest West Ore zone on the west side of the Maki fault. The underground drilling program intersected significant base-metal intervals in hole GC–502, drilled from the 33 Exploration drift. This hole helped to define the Central West Ore zone as a separate orebody (Greens Creek Joint Venture, written commun., 1994). PS–104 intersected the top of what was later defined as the Southwest Ore zone.

Three more surface holes tested the extent of the mineralization intersected by GC–502: PS–108 and PS–110 to the south, and PS–109 to the west. Only hole PS–110 and a wedge drilled off the hole (PS–110a) intersected significant mineralization. A 16.1-foot-long ore-grade interval (2.11 troy ounces per ton silver, 16.69 percent zinc) was intersected deep (2,050 feet) in the hole. This pierced the 5250 orebody (a somewhat

continuous satellite of the West Orebody). The other two holes of the 1990 summer program, PS–106 and PS–107, tested downdip (to the southwest) of the intersections in PS–103 and PS–105, respectively. Both holes intersected only stratigraphic footwall (phyllite) rocks.

The 1990 surface drilling program intersected three new orebodies: the Central West, the Northwest West, and the Southwest. Much more drilling from underground was needed before most of the structural complications could be solved and the three new orebodies roughly defined. The following 2 years involved a very aggressive underground drill program to define the Central West Ore zone on 100-foot centers. By the end of 1990, underground drilling had increased the indicated reserves from 3.6 million tons to 6.9 million tons (Greens Creek Joint Venture, written commun., 1990) of which 2.8 million tons were in the probable category (Kennecott Greens Creek Mining Company, written commun., 2001). No additional surface drilling took place until the passage of the Land Exchange Act in 1996.

Assessment work continued on the claim groups to the north, and minor geologic mapping and geochemical sampling took place within the AINM boundary. Two soil geochemistry grids were completed in Fowler Creek and the "L" zone along the Maki fault (Upper Zinc Creek), south of the Lil Sore grid. Only the "L" zone showed any geochemical anomalies (D.L. Lorge and others, written commun., 1990). Previously unidentified mineralization was sampled on Antenna Mountain, Zinc Creek Pass, and the Zinc Creek roadcut south of the Zinc Creek bridge (fig. 1). The latter was the most significant at 8.07 percent lead and 22.86 percent zinc.

A different geologic model for the Greens Creek deposit emerged from the geologic mapping and sampling completed during the summer. The surface crew consisting of David Lorge, Eric Lalechuer, and William McClelland felt that all the anomalous soils and surface mineralization occurred along major faults (D.L. Lorge and others, written commun., 1990). Their new deposit model envisioned these faults (presumably the northwest-trending Maki-type faults) as being the main ore control and horizons. They interpreted the faults as forming during metamorphism and formation of the S_2 foliation. These faults were structural channels for the intrusion of ultramafic plutons and replacement mineralization. In a separate report, McClelland (W.C. McClelland, written commun., 1990) suggests that the Greens Creek deposit is a replacement of Upper Triassic sediments associated with a hydrothermal system driven by Upper Triassic volcanic rocks and(or) Late Triassic hypabyssal mafic to ultramafic intrusions. He cited the presence of an Upper Triassic *Halobia* fossil within an ore-enclosed concretion as evidence of replacement of the surrounding sediments. He described that much of the mineralization observed in core and on surface was controlled by veins that crosscut the S_2 foliation. All of the workers felt confident that additional massive sulfide deposits could be discovered within the Upper Triassic units with exploration concentrated along suspected northwest-trending faults (D.L. Lorge and others, written commun., 1990).

1991 Exploration Program

Underground exploration and continued production were emphasized in 1991. Only the minimum amount of assessment work necessary for claim maintenance was completed on the surface. Underground drilling to define the West Orebody was successful and resulted in subdividing it into three distinct zones (Greens Creek Joint Venture, written commun., 1994). Drilling to the south and west of the projected trend of the West Orebody intercepted high-grade intervals in holes GC–738, GC–739, and GC–753 that further defined the Southwest Ore zone. Continued definition and exploration drilling underground to the south was given an additional boost when the Forest Service's mineral examiner and council gave positive comments during a preliminary meeting discussing extralateral rights to the south of the Big Sore claim block (Greens Creek Joint Venture, written commun., 1991). The 1991 definition drilling campaign increased the ore resource to 13.0 million tons, an increase of 6.1 million tons (Kennecott Greens Creek Mining Company, written commun., 1991). The proven and probable reserves, however, dropped to 1.2 million tons (Kennecott Greens Creek Mining Company, written commun., 2001).

On-Line Exploration from Anchorage was contracted to complete the assessment work required for claim maintenance. Their work concentrated on the leased Mammoth claims and unpatented Mariposite claim block. A soil geochemistry grid just north of the Mammoth claims yielded two minor discoveries. The first was a barite-bearing outcrop with visible gold (J.E. Adler and others, On-Line Exploration Services, Inc., written commun., 1991). However, assays did not confirm anomalous gold. The other discovery was disseminated sphalerite, galena, and chalcopyrite within a quartz vein. Both mineralized occurrences had slight soil geochemical expressions. On-Line Exploration recommended drill testing on the "L" zone pyrite, previously mapped and sampled within the Mammoth claims (J.E. Adler and others, On-Line Exploration Services, Inc., written commun., 1991).

1992 Exploration Program

The 1992 surface exploration program consisted of diamond drilling to fulfill the annual assessment work requirements. Wink Drilling of Juneau was contracted to drill 2,000 feet on unpatented claims north of the AINM boundary (Greens Creek Joint Venture, written commun., 1992). Two drill holes, MC–1 and MC–2, tested a weak silver-zinc soil anomaly on the Mariposite claim group defined by the 1991 program. Both holes were abandoned before reaching the target depth and did not intersect any mineralized intervals. Drilling was completed on the HI East and HI West claims leased from NERCO on the Mansfield Peninsula with no success. The underground drilling program completed drilling of most of the West Ore zone on 100-foot centers.

Ed Harrison recommended dropping the Mansfield claim groups in order to focus resources on the Fowler, Lil Sore,

Mariposite, and Big Sore claim groups. Harrison also advocated continued drilling on the Mariposite block and forming a Greens Creek joint venture exploration company with a separate budget from the mine because Kennecott Greens Creek Mining Company finances lacked the necessary funds to mount an effective exploration campaign (E.D. Harrison, memorandum to C. Davis, 1992).

Negotiations began on a new land-exchange proposal that only involved Greens Creek and the Forest Service. Greens Creek submitted a "bare-bones" proposal to the Forest Service in September of 1992. The proposal called for Kennecott Greens Creek Mining Company to purchase $1,375,000 worth of private land in-holdings on Admiralty Island and other areas of the Tongass National Forest and convey the land to the Forest Service in exchange for the subsurface mineral rights to 6,875 acres surrounding the core claims (Steven Silver, memorandum to R. Pierce and C. Davis, 1992). The agreement also called for a net smelter interest paid to the Forest Service for any minerals produced from the area. This item proved to be the most contentious in the negotiations. Congressional approval was necessary for any land exchange involving a national monument. Greens Creek finally received title to the 17 core claims and one millsite claim after the USDA Forest Service and Bureau of Land Management approved the final validity test in December, 14 years after the process had been initiated (Greens Creek Joint Venture, written commun., 1992).

1993 Closure

Kennecott announced in February 1993 that production mining and milling operations would cease by mid-April. The primary cause of the closure was low metal prices (Greens Creek Joint Venture, written commun., 1993). Greens Creek lost $2.2 million during the month of February alone. Milling ceased on April 10 and all but 24 employees were laid off by April 30 (Greens Creek Joint Venture, written commun., 1993). The remaining personnel were involved in the maintenance of permits and in development of the West Ore zone to satisfy the Forest Service's requirement of "use" of the property.

Underground diamond drilling began on July 17 to explore and define the Southwest Ore zone. The drilling occurred mostly from the 36 Exploration drift, which was being driven to the west of the 920 Main Haulage at the same time. Tim Hall was hired as the new Chief Geologist, and Deborah Apel returned to supervise the drilling program in November. A total of 30,261 feet was drilled along 200-foot spacings from section 3200 to 2400.

1994 Exploration

The Greens Creek Joint Venture agreed on November 17, 1993, that the Southwest Ore zone would require drilling at tighter (50-foot) spacings to adequately define the resource (Greens Creek Joint Venture, unpub. data, 1993). They approved a 120,000-foot drill program and initiated a feasibility program to explore and develop the Southwest Ore zone. Development continued in the 36 Exploration Drift to provide platforms for drilling. The drift passed through the southern boundary of the claim block in February. It was not until April that the Forest Service confirmed the assertion of extralateral rights that included the Southwest Ore zone (Greens Creek Joint Venture, written commun., 1994).

By the end of 1994, 130,803 feet of diamond drilling had been completed, mostly within the Southwest Ore zone (Greens Creek Joint Venture, written commun., 1994). Most of the drilling was accomplished on 50-foot spacings and centers. At the end of 1994 the recoverable ore reserve for the Southwest Ore stood at 2.4 million tons at 0.244 troy ounce per ton gold, 32.86 troy ounces per ton silver, 5.91 percent lead and 12.35 percent zinc (Greens Creek Joint Venture, written commun., 1994). The feasibility report called for startup of the mill by January 1, 1997, at a rate of 1,320 TPD using the higher grade Southwest ore. The plan also called for expansion to 2,000 TPD by 1999, with additional lower grade ore sourced from the West Ore zone.

The land-exchange agreement with the USDA Forest Service was signed in Washington, D.C., on December 17, 1994, after much bargaining over a sliding royalty scale based on net smelter return (NSR). A compromise was reached in September when Greens Creek accepted the Forest Service's sliding royalty of 3.0 percent for ore greater than $120/ton in exchange for reducing the $1.5 million in-holding purchase amount to $1.0 million (Greens Creek Joint Venture, written commun., 1994). A royalty of 0.5 percent was imposed on ore between $80/ton and $120/ton. The next step was to gain congressional approval through legislation.

Very little surface activity took place in 1994. Geologists from Kennecott Exploration completed a reconnaissance sampling program in the mine area and on Mariposite Ridge. Paul Lindberg began a 4-year stint as a consulting geologist to work on various projects, including geologic investigation of the Southwest Ore zone and interpretations and reconstructions along the Maki fault and other shears. Lindberg's interpretation of drillcore from the Southwest Ore zone led him to believe that much of the ore horizon was rooted in the argillite section and not at the argillite/phyllite contact (P.A. Lindberg, written commun., 1994). He also (re)identified the Klaus fault, which he believed decapitated the Southwest Orebody, displacing the top 700 feet to the northwest (P.A. Lindberg, written commun., 1994). The imminent completion of the land exchange led Lindberg to comment on future exploration. He proposed allowing a great deal of lead time to compile and digitize historical exploration data and maps that had been essentially archived for the past 4-plus years (P.A. Lindberg, written commun., 1994). Other ideas for initiating the exploration program were airborne geophysical and photometric surveys and liaising of the new exploration personnel with current geology staff.

The leased claims in HI East and HI West with NERCO were dropped as the area of Joint Venture was reduced to the lands south of Young Bay and east of Hawk Inlet (Greens Creek Joint Venture, written commun., 1994). The Joint Venture changed when Kennecott bought out CSX (Exhalas was bought out by the three remaining partners in 1993). The ownership split was 70.27 percent Kennecott and 29.73 percent Hecla.

Land Exchange Act and Continuing Production and Exploration, 1995–Present

The Greens Creek Land Exchange bill was introduced to the Resource Committee of the U.S. House of Representatives on March 16, 1995. The bill was cosponsored by Don Young (R-Alaska) and George Miller (D-California), who were usually on the opposite side of an issue from each other. The bill did not make it out of committee in 1995. Greens Creek employees received good news when the Kennecott Board of Directors, on April 5, 1995, approved the allocation of $87.3 million to reopen Greens Creek with production at 1,320 TPD (Greens Creek Joint Venture, written commun., 1995).

Paul Lindberg and Norm Duke of the University of Western Ontario completed a preliminary geologic mapping and sampling project in and around the Greens Creek mine in the summer of 1995 while the Greens Creek Land Exchange bill was in legislative limbo. They spent 2 weeks traversing various parts of the property, including the Mammoth claims, Cliff Creek (the area of the original geochemical anomaly leading to the discovery of Greens Creek), Gallagher Creek, Killer Creek, and along the road corridor. Duke concluded that the Greens Creek orebody was upgraded by remobilization of syngenetic lead-zinc-silver from the argillites (SEDEX model) and gold sourced from the strongly carbonitized mafic and ultramafic rocks (N.A. Duke, written commun., 1996). Duke subsequently refined and redefined his model based on his regional geologic mapping.

1996 Exploration and Reopening

The 12-year battle for gaining exploration rights to the original claim group finally ended on April 1, 1996, when President Bill Clinton signed the Greens Creek Land Exchange Act. Work began immediately on purchasing $1.0 million of private in-holdings, primarily from a list of preferred properties compiled by the USDA Forest Service. This process took nearly 2 years to complete.

Steve Newkirk was hired during the winter of 1995 to resurrect an active surface exploration program after a 7-year hiatus. Staking and filing 213 Federal lode claims in unclaimed holes south of Young Bay further refined the land picture. In addition, 15 State tideland claims were staked along upper Hawk Inlet. However, the State of Alaska also selected the land for potential community development and thus its status remains in limbo. The 10-year lease of the Mammoth claims expired at the end of 1995. Negotiations took place over several months with the owner, Herman Meiners, to renew the lease or to purchase the claims outright. However, Meiners did not budge from his high asking price and evidently shopped the property around to other potential buyers with no results (S.R. Newkirk, written commun., 1996). No further negotiations took place.

Surface diamond drilling was limited to the patented claim block until the land-exchange lands were fully conveyed. The Forest Service would allow only nonimpact activities such as helicopter landings, soil and rock sampling, airborne and ground geophysical surveys, and geologic mapping. The 1996 program initially involved one drill rig operated by Connors Drilling. However, poor advance rates due to poor ground conditions, frequent mechanical failures, and driller inexperience with Greens Creek-type conditions necessitated mobilizing a second drill rig.

Nine holes totaling 7,755.5 feet were completed. The first three holes, PS–111, PS–112a (abandoned after 487 feet), and PS–112, were collared from the 1350 adit access road and targeted the possible northwest extension of the North Ore zone. Neither completed hole intersected significant mineralization. PS–113 through PS–117 were drilled from three drillpads targeting the Upper Plate Extension of the Northwest West Ore zone (the Maki offset on the west side of the West Ore zone). This thin, flat-lying mineralized horizon had been intersected in a few holes from underground but was not systemically explored. PS–115 had the only significant intercept, a 1.5-foot interval of ore running 0.16 troy ounce per ton gold, 19.44 troy ounces per ton silver, 3.4 percent lead and 6.8 percent zinc. PS–118 targeted the possible north extension of the West Ore, first intersected by PS–87 in 1984. The hole was located 600 feet north-northeast of PS–87 and did not intersect mineralization.

Numerous geophysics methods were tested at Greens Creek to determine which might be more effective in surface exploration. Airborne EM, radiometric, and magnetometer surveys were completed in conjunction with Kennecott Exploration's Mansfield project. The surveys, carried out by Aerodat, flew more than 1,200 kilometers of line that covered the entire Greens Creek area, including the land exchange. Distinct magnetic anomalies corresponded with already mapped ultramafic bodies (for example, Killer Creek serpentinite). The EM survey proved useful in identifying graphitic rocks, such as the Hyd argillite. Underground and surface gravity surveys were completed. The underground survey, extending from the portal to the end of the 36 Exploration drift, detected a subtle ~1.5-Mgal anomaly over the West Ore zone. The surface survey over the Northwest West Ore zone failed to detect any coincident anomaly. Two test lines over the West and Northwest West Ore zones were surveyed by the CSAMT (controlled source audio-magnetotelluric) method. A resistivity low associated with the Northwest West Ore zone

and Maki fault was detected, but the West Ore zone was not. A time-domain electromagnetic (TEM) survey was also completed over eight lines in the same area and measured a strong response from the West Ore. Downhole TEM surveys were completed on surface and underground holes. GC–1530, an underground exploration hole, produced a strong EM anomaly within the West Ore. This geophysical test work was done to develop the tools for a multiyear exploration program (S.R. Newkirk and others, written commun., 1996).

Norm Duke and Paul Lindberg completed reconnaissance and detailed geologic mapping and sampling within the land-exchange boundary. Their work culminated in a completely revised 1 inch=1,000 foot scale district map and numerous 1 inch=200-foot scale mine geologic maps. The prospective mine stratigraphy was traced to the south and north (S.R. Newkirk and others, written commun., 1996). The land-exchange boundary survey was finalized in November. Kennecott Greens Creek Mining Company developed a cooperative research agreement with Cliff Taylor of the USGS for a program to focus on many of the outstanding geologic problems of the Greens Creek mine (reported in this volume).

The work completed in 1996 was designed to lay the groundwork for a multiyear exploration program. The geologic mapping and research agreement was to refine the geologic model for the deposit. A GIS system, using ArcView software, was set up to aid in organizing the 20+ years of data. Historical geologic maps and geochemistry were digitized for the GIS project during the summer and fall.

Underground exploration was limited to definition drilling in the Northwest West and 5250 Ore zones. Preproduction drilling, consisting of horizontal fans of short (100- to 400-foot) holes, was carried out from various ore accesses in the Southwest Ore zone. These holes drilled on 10- to 25-foot centers aided in stope planning. The recommissioned mill began running ore from the Southwest orebody in July 1996. Kennecott Greens Creek Mining Company produced about 143,000 tons of ore averaging 0.108 troy ounce per ton gold, 23.80 troy ounces per ton silver, 4.84 percent lead, and 10.3 percent zinc. Almost all of the ore was sourced from the Southwest Ore zone.

1997 Exploration

Surface exploration activities were accelerated on the land-exchange property. Seven new grids totaling 230,000 linear feet, were cut and sampled within the Greens Creek Joint Venture lands. The grids within the land exchange included High Sore, Bruin, Lower Zinc, Upper Zinc, and Gallagher. The "A" Road and East Lil Sore (fig. 1) were cut within the unpatented claim groups north of the land exchange. Detailed work along each grid included soil sampling, gravity, magnetic and TEM geophysical surveying, and geologic mapping. No high-priority, near-surface coincident gravity and TEM anomalies (possible shallow massive-sulfide bodies) were identified (S.R. Newkirk and others, written commun., 1997). Soil sampling and geologic mapping outlined drill targets or areas for detailed followup work in Bruin, Gallagher, and Lower Zinc Creeks. The "A" Road prospect was discovered in 1995 during the road traverse of Paul Lindberg and was thought to be a possible distal "mine" horizon with exhalative quartz, barite, and pyrite (P.A. Lindberg, written commun., 1997). Work in 1997 defined soil anomalies coincident with the exhalative horizon, but convincing evidence was not found to determine whether or not it was the mine horizon. Norm Duke and Paul Lindberg completed reconnaissance scale and detailed geologic mapping. John Proffett returned for the first time since 1987 and carried out structural mapping. Lindberg completed detailed mapping of the road corridor and borrow pits, all of which was compiled in a 15-sheet map folio (P.A. Lindberg, written commun., 1997).

Four diamond drill holes totaling 6,316 feet were completed in 1997. All were drilled from pads constructed on patented Big Sore claims because the land exchange had not been conveyed. Hole PS–119 targeted the lower phyllite-over-argillite contact 800 feet to the northwest of hole PS–87. Only scattered zinc mineralization was intersected in the phyllite, and two argillite intervals intersected were clearly fault-bounded and nonmineralized. PS–120 targeted the same contact, except to the north-northeast (200 feet due east of PS–118). The hole did not intersect the contact, but a downhole TEM survey mapped a steeply dipping conductor to the southwest of the hole and a subhorizontal conductor 200 feet below the hole. This hole was reentered in 1998 to test the deeper conductor but did not intersect an interval corresponding to the conductor. PS–121 and PS–122 were collared in Big Sore claims 1305 and 1304, respectively, in the Gallagher Creek grid/prospect. Both holes intersected semimassive to massive pyrite and sphalerite zones with up to 9 percent zinc over 2-foot intervals. Mineralization in PS–122 occurred at and below a contact between graphitic phyllite and chloritic phyllite, which was thought to represent a new mineralized horizon at a different stratigraphic horizon (S.R. Newkirk and others, written commun., 1997). The surface drill program was cut short by a new discovery underground.

Discovery of the 200 South Ore Zone

Preproduction drilling continued to be a major portion of the underground drilling program. During December1996, a preproduction fan was drilled from the 200 Ore Access, targeting the 164-foot level. The southernmost hole, PP0204, intersected ore widths showing that the orebody was still open to the south of cross section 18, previously modeled as the end of the Southwest Ore zone. No additional preproduction holes were drilled to the south to find the terminus of the ore because of the oblique drilling angle. The 200 South stope (at the 164-foot level) began mining from the ore crosscut shortly afterwards. The 200 South stope reached section 18, the end of the ore reserve for that level, but still showed a full face of ore. Expecting the ore to terminate at any time, mining continued on a round-by-round basis for another 300 feet. At the same time, exploration drilling to the south commenced

from the 480 Exploration drift. Hole GC–1632, drilled along section 16, intersected a 42-foot interval of zinc-rich massive ore about 200 feet below the 200 South stope. Kennecott Greens Creek Mining Company geologists quickly realized that the 200 South stope was the proverbial tip of the iceberg. Four drill rigs (including a diesel-powered surface drill rig) were mobilized to quickly define this new ore zone, named the 200 South orebody. Two drill rigs were positioned in the 480 Exploration drift and the other two in the 200 South stope, to drill the zone from the inside out. Long-section drilling from the face of the stope indicated that the ore zone continued to at least section 11. Drilling from the south extension of the 480 Exploration (4711 Drift) continued from 1998 through 2000 and defined a reserve of 2.08 million tons at 0.189 troy ounce per ton gold, 21.29 troy ounces per ton silver, 5.15 percent lead, and 12.50 percent zinc. Discovery and definition of the 200 South orebody drastically changed the mining schedule of the various ore zones. Due to the higher grade of the 200 South ore, it was mined ahead of the more accessible West Ore zone(s). The 200 South orebody accounted for 42 percent of the total mine production from 1998 to 2000.

1998 Exploration

The 1998 exploration program was boosted with the completion of the land exchange on August 5, 1998. The combined holdings of the Greens Creek Joint Venture now included 445 unpatented lode mining claims, 58 unpatented millsite claims, 17 patented lode claims, 1 patented millsite claim, and land-exchange lands totaling 17,617 acres. Drilling was completed on lands off of the validated claim block or extralateral rights assertions for the first time since 1985. Four holes (PS–124 through PS–127) were drilled in Bruin Creek, targeting the downdip potential of the north-striking phyllite-over-argillite contact. PS–124 and PS–125 were drilled from the same site as PS–47 and tested downdip and updip, respectively, from the semimassive sulfides intersected near an argillite/phyllite contact in that hole. Both holes intersected only minor mineralization in the upper phyllite unit. Both holes terminated in altered ultramafic rocks below a carbonate-rich contact zone with argillite. PS–126 was drilled near treeline in upper Bruin Creek to test coincident soil and TEM anomalies. The hole intersected a barren phyllite/argillite contact at 1,275 feet and terminated in a gabbro at 1,724 feet. PS–127 was drilled from the site of PS–81, drilled in 1984 by Noranda. This hole intersected two fault-controlled blocks of argillite with no sulfides. The only other hole drilled (besides the reentry of PS–120) was PS–123 in Gallagher Creek, testing the phyllite stratabound zinc-rich zone intersected in PS–46 and PS–122. Minor sphalerite and chalcopyrite were intersected, but to a lesser degree than in holes PS–46 and PS–122, indicating that the mineralization decreases to the southwest (A.W. West and others, written commun., 1999).

One new grid (Upper Big Sore) and extensions of three 1997 grids (Lower Zinc, Bruin, and "A" Road) were geochemically sampled and geophysically surveyed in 1998. The work outlined numerous multielement anomalies with coincident TEM anomalies, but none were significant enough to warrant immediate drilling (A.W. West and others, written commun., 1999).

John Proffett extended his 1997 mapping in the Big Sore area toward the 920 portal and west of the Maki fault. He also reviewed surface drill core from both sides of the Maki fault. He found evidence for a major shear zone (Upper Shear Zone) that juxtaposes nonmine-type slates, silts, and phyllites of uncertain age over mine-type argillites, phyllites, and ultramafic rocks (J.M. Proffett, written commun., 1998). Subsequent work in 1999 defined a deeper shear zone (Lower Shear Zone). These two shear zones bracket the mine stratigraphy (J.M. Proffett, written commun., 1999). The amount and direction of offset along the two shear zones and the stratigraphic position of the upper-plate rocks remain outstanding and important questions for surface exploration.

1999 Exploration Program

1999 was the first exploration season entirely focused in the land exchange. However, the season began poorly when the contracted Bell-206 helicopter crashed into the mill during takeoff on the first day of service. Fortunately, no one was seriously hurt. Two new geochemical grids were completed and one extended. A large grid was surveyed in Killer Creek, spanning 8,000 feet from the "B" Road to the Mammoth claims. Numerous high-rank, multielement soil anomalies were defined, and numerous sulfide-bearing outcrops and gossan zones were sampled and mapped. A new grid was cut in Cub Grid, just east of Bruin Creek. Two sets of major right-slip faults repeat the argillite/phyllite contact several times in Cub Creek. Anomalous geochemistry was coincident with an inferred contact zone in upper Cub Creek, near the land-exchange boundary (A.W. West and others, written commun., 2000). The Upper Zinc grid of 1997 was extended to the west. No significant discoveries were made in Upper Zinc Creek. However, two significant base-metal mineralized outcrops were sampled and mapped by Norm Duke to the southwest in the Lakes District prospect (N.A. Duke, written commun., 1999). One of the occurrences is near the contact between chlorite phyllite and possible Triassic carbonate rocks.

Ten diamond drill holes were completed totaling 12,715 feet. Seven of the holes were drilled in Bruin Creek. PS–128, PS–129, and PS–130 were drilled from the backslope directly behind (north of) the 920 administrative building. A shallow southwest-dipping barren phyllite-over-argillite contact was intersected in all three holes. PS–128 drilled through Proffett's Lower Shear Zone and into more than 1,000 feet of ultramafic rocks. PS–131, PS–133, PS–137, and PS–138 were collared from two different pads on the west side of the mapped contact in middle Bruin Creek, about 1,000 feet east of the 1998 drill holes. Only PS–137 intersected conformable argillite/phyllite contacts. PS–136 was collared on the east side of the contact and also

intersected the contact. In both holes, the contact was intersected multiple times, but no indication of mineralization was found. Three holes were drilled in Killer Creek. The first two holes, PS–132 and PS–134, were collared from the site of PS–20, drilled in 1977. Both holes intersected long intervals of semimassive to massive pyrite bands with minor sphalerite up to 15 feet wide within greenstones and serpentinites. PS–132 also intersected a deep (800 feet below the surface), fault-bounded, 3.6-foot band of massive chalcopyrite that ran 4.2 percent copper. PS–135 was drilled from a pad constructed above Pit 405, at mile 7.6 of the "B" Road. This hole intersected long intervals (up to 15 feet) of patchy zinc mineralization in chloritic phyllites.

2000 Surface Exploration

Two new prospects were drilled in 2000. Two pads were constructed in Cub Creek to test soil anomalies coincident with the phyllite/argillite contact. The targets were further refined by a CSAMT geophysical survey along three lines in Bruin and Cub Creek (three lines were also surveyed in Killer Creek). Results from the survey were of better quality than the 1996 survey due to better location of the transmitter line. The four holes drilled in Cub Creek (PS–144, PS–145, PS–147, and PS–151) did not intersect any significant metal enrichment along the contacts intersected. Data collected from these holes and two others (PS–147 and PS–148) in East Bruin Creek aided in the interpretation of the Bruin and Cub Creek regions. A large-scale recumbent syncline (cored by argillite) that closes to the west-southwest was found to be the dominant structure (A.W. West and others, written commun., 2001). The nearly isoclinal fold has mineral potential along both upper and lower limbs.

The Lower Zinc Creek prospect was drill tested for the first time from a pad constructed at the 2.8-mile mark of the "B" Road. Holes PS–152 and PS–153 were drilled to the northeast, targeting the mine contact. The contact intersected in both holes was strongly silicified and sulfidized (massive bands of pyrite). The geochemical results were highly anomalous in Ag, As, Hg, Ba, and Tl. Due to the mine lithologies intersected, abundant pyrite, silica alteration, and a distal geochemical signature, the potential of the Lower Zinc Creek prospect was upgraded (A.W. West and others, written commun., 2001).

Five holes were drilled in Killer Creek. The first two holes, PS–139 and PS–142, targeted a northwest-striking zone of zinc-rich, poorly exposed gossan. Both holes were abandoned in a wide fault zone (middle Gallagher fault) before reaching their target depth. Three holes drilled from two platforms in middle Killer Creek targeted a deep phyllite-over-argillite contact inferred from the CSAMT survey. None of the holes intersected argillite. However, all three did intersect fault-controlled secondary mineralization within 400 feet of their collars. Four moderately southwest-dipping zones with silver and zinc enrichment were defined with assays as high as 22.4 troy ounces per ton silver and 9.62 percent zinc (A.W. West and others, written commun., 2001). The intervals did not have sufficiently consistent grades or widths to be of economic significance.

Conclusion

For more than three decades, exploration, development, and production at the Greens Creek mine has been challenging. Fourteen years passed between the discovery drill hole intersecting over 80 feet of massive sulfide and the mill processing the first ore. During that time Greens Creek nearly became a casualty of a large conservation movement that included the White House and Congress. This movement culminated in the passage of ANILCA, which at first threatened to kill the project and then severely limited the land position at Greens Creek. Greens Creek emerged from this situation as an apparent incongruity: a mine within a national monument bordering a wilderness area. However, exploration for new orebodies from the surface effectively ceased. After 12 years of negotiations on local, State, and Federal levels, the land position was remedied in 1996 with signing of the Land Exchange Act. This unique act supported by conservation/environmental groups and industry alike increased Greens Creek's land position to what it was previous to ANILCA and added to the federally protected lands in the Admiralty Island National Monument and elsewhere in Alaska.

Exploration from the surface and underground has been successful in adding to Greens Creek's known reserves during the life of the mine. The nearly constant changes in ownership, personnel, and geologic models did not prevent new orebodies or extensions from being discovered. When low metal prices temporarily closed the mine in 1993, the high-grade Southwest Ore zone was discovered and drilled out. This new orebody allowed Greens Creek to reopen profitably in 1996. Since reopening, new reserves have kept pace with production, adding nearly 4 million tons of ore. The mine's proven and probable reserves, as of the end of 2001, are 7.6 million tons grading 0.133 troy ounce per ton gold, 16.67 troy ounces per ton silver, 4.57 percent lead, and 11.63 percent zinc (Kennecott Greens Creek Mining Company, written commun., 2001). The newly (re)acquired land-exchange lands provide abundant opportunities for future discoveries.

Reference Cited

Nash, Roderick, 1982, Wilderness and the American mind, 3d ed.: New Haven, Conn., Yale University Press, 425 p.