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ABSTRACT

INTRODUCTION

The Orphan Lode mine was the first of several uranium mines to be developed in collapse-breccia pipes in northwestern Arizona. The mine was located on a patented claim which predates the establishment of Grand Canyon National Park. This claim was staked for copper in 1893 and patented in 1906. Radioactivity was first detected in 1953 and uranium production began in 1956 under procurement programs of the U.S. Atomic Energy Commission (AEC). In 1962, federal legislation permitted underground mining beyond the boundaries of the claim in exchange for the federal government to receive title to the claim in 25 years. Mining ceased in 1969, and the claim reverted to the National Park in 1987. During the life of the mine it yielded 4.3 million pounds of uranium oxide (U_3O_8). In the period 1962-1969, 6.7 million pounds of copper and 106,553 ounces of silver were recovered as by-products from the uranium ore.

Sources of Data

The data used to prepare this report came from three main sources:*

1) Chenoweth examined the mine on a monthly basis for the AEC from February 1959 to November 1962. These investigations were for ore reserve and production capability studies. After 1962, until the mine closed, the mine was visited on a semi-annual basis. These observations have been open-filed by the USGS (Chenoweth, 1988).

2) C. Gilbert Bowles, USGS, mapped the geology on portions of eight different levels of the mine during the field seasons of 1964 and 1965. In addition to geologic mapping, Bowles collected numerous hand samples, some of which were made into polished thin sections. All of Bowles' data has been incorporated into this report.

3) Vivian Gornitz, a graduate student at Columbia University, examined the mine in June 1966 and 1967 for her dissertation. Thin sections and polished sections prepared during her study of the mine have been borrowed for inclusion in this report. A summary of her dissertation (Gornitz, 1969) was later published (Gornitz and Kerr, 1970).

Other than the references listed above, very little information has been published on the Orphan mine. Max G. Kofford, mine geologist, published a brief summary of the origin and mineralogy of the deposit (Kofford, 1969). Gornitz and others (1988) discussed the origin of the Orphan pipe with her dissertation information supplemented with information supplied by the USGS. All of the existing information is being merged into this report on the geology, geochemistry, mineralogy and production history of the mine.

Scope and Purpose

During the 1980s uranium-bearing breccia pipes of the Grand Canyon region became the exploration targets for numerous mining companies. Eight new mines (Hack 1,2,3, Pigeon, Kanab North, Pine Nut, Hermit and EZ-1) were found, developed and mined on the north rim of the canyon (fig. BB). At least two deposits (Canyon, Sage) were found and developed on the south rim of the canyon. These ore deposits have been the subject of an ongoing study of mineralized breccia pipes by Wenrich (1985), Sutphin and Wenrich (1989), Wenrich and Sutphin, (1988, 1989), Wenrich and others, (1989). The information developed from this study of the Orphan Lode pipe will be compared with the more extensive data from these recently developed orebodies for a better understanding of the pipe formation and ore genesis at the Orphan.

EXPLORATION AND PRODUCTION HISTORY

1893-1952 -- Early Activities

Daniel L. Hogan began prospecting in the Grand Canyon about 1890. On February 8, 1893, he and his partner, Henry Ward, located the Orphan claim between Powell and Maricopa Points on the south rim of the Grand Canyon (fig. CC). The single claim covered an outcrop of copper minerals that occurred some 1,100 feet (335 m) below the rim of the canyon. Thinking that the deposit occurred as a vein, they located the claim with the outcrops near the north end line; most of the claimed land extended to the southwest, including a few acres on the rim.

Hogan and Ward built a crude trail consisting of ropes, ladders, and rock steps down the rim to the copper showings and did a small amount of mining. Three short adits were driven into the mineralized outcrops. A few sacks of copper ore were reportedly brought out of the canyon.

After serving as a Roughrider in the Spanish-American War, Hogan returned to prospecting. Ward sold his interest in the Orphan to Charles J. Babbitt, a northern Arizona merchant, who reportedly grubstaked Hogan. The Orphan claim was surveyed on January 18-20, 1905 (Mineral Survey No. 2224) and was found to contain 20.26 acres (fig. CC). It was patented (Patent No. 43506) on March 23, 1906 with C.J. Babbitt listed as a co-owner with Hogan (Brown, 1955). The patent was reportedly signed by President Theodore Roosevelt, Hogan's old commandant (Dodge and McKlveen, 1970). Although the official name of the claim was the Orphan, Hogan referred to it as the Orphan Lode, and the Little Orphan Girl (Dodge and McKlveen, 1970).

On November 28, 1906, President Theodore Roosevelt signed a bill proclaiming the Grand Canyon Game Reserve. To further protect the area, President Roosevelt established the Grand Canyon National Monument on January 11,

1908. The primary effect of this legislation was to forbid prospecting and mining on all lands in the Grand Canyon which were not already covered by valid claims (Billingsley, 1974).

On February 16, 1919, President Woodrow Wilson proclaimed the Grand Canyon as a National Park. Congress revised the boundaries of Grand Canyon National Park in 1927. A new Grand Canyon National Monument was established by President Herbert C. Hoover on December 22, 1932 (Billingsley, 1974).

Hogan acquired full interest in the claim on April 18, 1912 when C.J. Babbitt quit-claimed Hogan his interest (Brown, 1955). Being unsuccessful in making a copper mine of the claim, Hogan built a tourist lodge on the rim portion in 1935. This structure was originally known as the Grand Canyon Trading Post, but would later be called the Kachina Lodge and Grand Canyon Inn.

Because it was located on privately-owned land within the National Park, the lodge was considered a nuisance and eyesore by the Park Service. All water for the facility had to be hauled in from outside the park. Due to the lack of tourists during World War II, and continuing problems with the Park Service, Hogan sold his Orphan claim to Mrs. Bertha Madeleine Jacobs on August 1, 1946 for $55,000 (Brown 1955). On June 1, 1951, Jacobs sold the surface rights to David and James Barrington for $125,000 (Brown, 1955).

Early in 1951, amateur prospectors discovered anomalous radioactivity on the rim of Grand Canyon, just east of the Grand Canyon Inn (Kofford, 1969). The area of the discovery was near the head of Hogan's old trail, and was where he had stockpiled his copper ore. The existence of the radioactivity became known to the employees of the Inn and to Mrs. Jacobs.

During the early 1950's, Harry C. Granger of the U.S. Geological Survey (USGS) examined all of the known and reported occurrences of uranium in Arizona

and looked for others based on geologic evidence. At the urging of Charles Anderson, USGS, Granger contacted Mrs. Jacobs of Prescott, Arizona, regarding a copper prospect in the Grand Canyon. Copper deposits in sedimentary rocks were known to contain uranium at many localities on the Colorado Plateau. Samples in Mrs. Jacobs' possession were checked by Granger using his geiger counter but were found to be so low in radioactivity that a special trip to the Grand Canyon could not be justified (H.C. Granger, oral commun., 1985). Interested in seeing a property in the Grand Canyon, Granger made a weekend trip to the canyon and examined the old Hogan workings on April 22, 1951. His geiger counter readings and chemical analysis of samples confirmed that outcrops at the portal of the lower adit contained high-grade uranium (Grand Junction Office, Atomic Energy Commission and U.S. Geological Survey, 1970, p. 110). Granger's initial observation was that the ore occurred in a slump block of Coconino Sandstone in the Hermit Shale (Granger, 1951).

After learning that the claim had high-grade uranium on it, Mrs. Jacobs leased the mineral rights to a few small mining companies. Lack of capital and inaccessibility hindered development of the deposit for a few years.

1953-1957 -- Exploration Years

Golden Crown Mining Company, a subsidiary of Western Gold and Uranium, Inc., of St. George, Utah, leased the mineral rights to the Orphan on September 29, 1953. The lease carried a 10 percent royalty with an option to purchase the mineral rights for $20,000 (Brown, 1955). A dispute with the surface owner was resolved when Golden Crown completed the lease and option. In 1956, Golden Crown acquired complete ownership of the claim including the Grand Canyon Inn.

In order to test the amenability of the ore at the Orphan claim to conventional uranium milling circuits, Golden Crown submitted a 350 pound sample to the AEC's Grand Junction Office in the summer of 1954. This was a composite sample collected in the old Hogan adit (fig. DD). Analysis by the National Lead Company's Raw Materials Development Laboratory at Winchester, Massachusetts indicated the sample contained 0.217 percent U_3O_8, 1.45 percent V_2O_5, 0.81 percent Cu, and 3.6 ounces of silver per ton (Lynch and Viklund, 1956). The sample was found to be amenable to both acid and alkaline leaching.

Geologic mapping of the old Hogan adit commenced by Golden Crown geologists and exploration diamond drilling began in October 1955. On December 14, 1955 Golden Crown issued a letter to its stockholders announcing that a major uranium deposit had been located on the Orphan claim. The deposit was purported to contain not less than 100,000 tons of ore or might contain as much as 300,000 tons averaging 0.45 percent U_3O_8. The ore-bearing structure was stated to be a pipe.

On February 16, 1956 the company released the core analyses from the first 14 holes (table ZZ). On the basis of the drilling results and favorable geology, construction of a three tower aerial tram from the rim to the north end of the claim was begun in March 1956 (fig. CC). The initial shipment of ore from the

Orphan Lode to the Atomic Energy Commission's (AEC) buying station near Tuba City, Arizona was made on April 25, 1956. This shipment consisted of 20.89 tons of ore that averaged 0.53 percent U_3O_8 (table YY). This shipment, and all following shipments were identified to the AEC as the Orphan Lode mine.

The Rare Metals Corporation of America, which had proven ore reserves in the Cameron, Arizona area, began construction of a uranium processing mill 6 miles (10 km) northeast of Tuba City, Arizona in late 1955. While the mill was under construction, the AEC opened an ore buying station at the mill site. The mill began operating in June 1956 and the buying station was closed in July 1956. Ores from the buying station were purchased and processed by Rare Metals (Albrethsen and McGinley, 1982). The mill had a capacity of 300 tons-per-day, and used a sulfuric acid leaching process to extract the uranium. Ores containing more than 6 percent lime ($CaCO_3$) were penalized, due to excessive acid consumption. Uranium concentrates produced by Rare Metals were sold to the AEC under Contract No. AT(05-1)293. Ores from independent producers, including the Orphan Lode, were purchased by Rare Metals under the terms of the AEC's Circular 5, Revised.

Ore from the Orphan Lode was trucked to Tuba City--a distance of 92 miles (148 km). The Park Service charged Golden Crown a fee of $0.02 per-ton-mile for use of roads within the National Park.

On May 24, 1956, the AEC announced the establishment of a new domestic uranium procurement program for the period April 1, 1962, through December 31, 1966. The new program guaranteed a Government market for 500 tons of U_3O_8, in concentrate (yellow-cake), per year from any one mining property or operation at a flat price of $8 per pound. Thus, in 1956, the stage was set for a continuing AEC concentrate procurement program after March 31, 1962, with an established

price for concentrates rather than for ores. The prices, premiums, and allowance paid under Circular 5, Revised, would no longer be in effect. After March 31, 1962, the AEC required that the mill operator pay "reasonable" prices to independent producers.

The original aerial tram proved ineffective and was removed. A Riblet tram was completed in May 1956 at a cost of $61,800 (Mining World, 1959). The tram was 1,800 feet (549 m) long, used an endless steel rope supported on eight towers, and descended 1,100 feet (335 m) at slopes of 37° and 57°. Two tram buckets, each with a capacity of eight cubic feet, operated in tandem and required four minutes for the trip. All mine personnel and equipment were taken to and from the mine via the tram buckets. Sustained production using the new aerial tram commenced in August 1956. When operating smoothly it could move 45 tons of ore per day to the rim.

A new adit was driven parallel to the Hogan adit, and a two-compartment, vertical exploration winze was started about 90 feet from the portal in September 1956 (fig. EE). By March 1957, the winze had reached a depth of 175 feet (53 m) (the 175 level). At the Orphan, mine levels refer to the depth below the adit level (fig. EE).

Exploration drilling during 1956 and 1957 from the 100 and 175 levels continued to locate ore on the north side of the pipe as well as within the pipe. This drilling was known as the A, B, D, E and F series of diamond drill holes. Total footage was about 4,000 feet (1,219 m) in 25 holes (table XX). The high grade ore on the north perimeter of the pipe was named the A zone and the lower grade ore in the pipe was called the B zone by company engineers and geologists (fig. EE). The initial mining at the Orphan concentrated on the A zone which consisted of Coconino sand fill which was cemented by uraninite. Production in

1956 totaled 1,666 tons of ore averaging 0.45% U_3O_8 (table WW).

In July 1957, Western Gold and Uranium, Inc. acquired full control of Golden Crown Mining Company and became the operator of the Orphan Lode Mine. Also during 1957, the service winze at the Orphan was deepened from the 175 level to the 245 level. Drilling from within the mine intercepted ore grade material as deep as the 400 level within the pipe. Drilling also indicated that the orebody on the north side of the pipe in the upper levels of the mine plunged to the north and went off the claim into the National Park.

Since there was no room on the claim to dump waste near the adit, and since the Park Service prohibited any activity off the claim, all waste from development had to be disposed of underground. This was done by backfilling stopes and other mined-out areas. Production during 1957 was 152,916 pounds U_3O_8 in 7,515 tons of ore which averaged 1.02 percent U_3O_8 (table WW). The lime content of the ore on the 175 levels was becoming a problem and reached as high as 14.00 percent $CaCO_3$ for a three-month period in the summer of 1957 (table YY).

Shipments for January 1957 totalled 726 tons averaging 2.29 percent U_3O_8, the highest monthly grade ever achieved by the Orphan Lode. C.M. Brundy (1977), a former employee of Western Gold and Uranium, noted that the highest single shipment from the mine averaged 4.09 percent U_3O_8.

1958-1961 -- Development Years

Nineteen-fifty-eight was a very important year in the history of the Orphan Lode. The developments in this, and the following years, would have a great impact on the future of the mine.

In April 1958, Western Gold and Uranium obtained Special Use Permit No. GRCA-5-58 to establish two surface drill stations north of the claim in the

National Park. From these two stations the G series of core holes were drilled in a southerly direction into the pipe. Ten holes with a total footage of 6,175 feet (1,882 m) were drilled between July and October, by Boyles Brothers, a drilling contractor (table XX).

This drilling was highly significant as it indicated: 1) the pipe increased in diameter at the Hermit - Supai contact, near the 175 level, 2) a large orebody was present on the north side of the pipe, off of the Orphan claim, 3) ore was present on the south side of the pipe, and 4) ore in the pipe extended below the 245 level.

At the same time as the G series were being drilled from the surface, a long and short hole percussion drilling program was in progress underground to outline the low grade hole of ore surrounding the high grade orebodies on the 140, 175, and 245 levels.

In May 1958, a contractor, Centennial Development Company, began sinking a 2½ compartment shaft from the rim of the canyon (fig. CC). A 1,200 foot (366 m) crosscut from the shaft was planned to intersect the pipe at the 400 level. The shaft was completed to a depth of 1,590 feet (485 m) in January 1959, with a station cut at 1,502 feet (458 m). The reported cost of the new shaft was about $800,000 which was paid in cash from profits made on the mined ore (Mining World, 1959).

The crosscut from the shaft station to the 400 level of the pipe was started on March 20, 1959. It was completed to the end line of the claim in August 1959.

All waste from the shaft and crosscut had to be hauled to a dump site the company had leased from the Forest Service near Rowes Well. A fee of $0.02 per ton mile was charged to use Park roads, the same as the ore trucks. However,

considerable quantities of the waste were purchased by the Park Service for road ballast.

Production goals for 1958 were set at 1,000 tons per month of ore averaging 1.00 percent U_3O_8 (20,000 pounds U_3O_8), in order to pay for the new shaft. The high grade ore was being mined from the A zone, and the 1,000 tons-per-month was the capacity of the aerial tram. In June 1958, Rare Metals limited the Orphan Lode to 16,950 pounds of U_3O_8 per month that would be accepted at the Tuba City mill. With this limitation, Western Gold sought markets at other mills. Shipments were made to the Vitro Corporation at Salt Lake City, Utah, Texas-Zinc Minerals Corporation at Mexican Hat, Utah, and Kermac Nuclear Fuels at Ambrosia Lake, New Mexico (table YY). The Texas-Zinc mill at Mexican Hat, had a sulfide flotation circuit which recovered copper (Albrethsen and McGinley, 1982). The production limitation at Tuba City was increased to 18,000 pounds U_3O_8 per month in November 1958.

In December, 1958, Western Gold obtained another special use permit from the Park Service to build 2.5 miles (4 km) of new road in the Park. The new road would provide access to railroad siding on the Atchison, Topeka and Santa Fe Railway right-of-way within the Park. Here, a loading ramp was built in order to make shipments to mills in New Mexico.

Drilling of the H series of core holes on the 175 level began in December 1958 (table XX). By the end of the year, drilling had indicated: 1) ore within the pipe was restricted to above the 375 level, with the higher grade occurring above the 245 level (B zone), and 2) at the 310-350 level, ore was believed to be continuous around the perimeter of the pipe, which at these levels had a diameter of approximately 450 feet. Hence, a concept of annular ring orebodies was developed. Further drilling would discover only ore in the lower levels of

the pipe in the annular ring.

Production in 1958 totalled 11,846 tons averaging 1.17 percent U_3O_8 and containing 276,258 pounds U_3O_8, a sharp increase over 1957 (table WW, fig. FF). M.E. Kofford (personal commun., 1959) reported that lime penalties through 1958 had totalled $20,307.51.

The dramatic increase in uranium ore reserves occurring throughout the United States during 1957 and 1958 was of concern to the AEC. On November 24, 1958, in order to prevent further expansion of production under its essentially unlimited purchase commitment, the AEC redefined its 1962-1966 procurement program by withdrawing portions of the program announced in May 1956. The Government stated it would buy, in the 1962-1966 period, only "appropriate quantities of concentrate derived from ore reserves developed prior to November 24, 1958, in reliance upon the May 24, 1956, announcement." Other aspects of the program announced in 1956 were retained: The AEC would buy only concentrates; the U_3O_8 price would remain at $8 per pound; and ores would not be purchased nor ore prices guaranteed. Independent producers had to negotiate ore purchase contracts with milling companies in order to sell their ores.

In the negotiations that followed this announcement, the AEC would recognize only the ore that had been developed on the Orphan claim to be eligible for a market quota (allocation). The ore that Western Gold and Uranium had developed in the Park was considered, by the AEC, to be property of the U.S. Government.

Western Gold and Uranium calculated their "indicated, inferred, and possible reserves" for the Orphan Lode as 1,543,000 tons averaging 0.42 percent U_3O_8 (M.E. Kofford, personal commun., 1959). Official AEC reserves for November 24, 1958, were 296,000 tons of indicated and inferred reserves averaging 0.38

percent U_3O_8 on the claim, and 228,000 tons averaging 0.51 percent U_3O_8 indicated and inferred reserves on Park ground. Without the Park reserves available to them, the future of Western Gold's Orphan Lode was in doubt.

Western Gold sought to obtain the Park reserves using extra-lateral rights. Under the apex rules in the 1872 General Mining Law, ore can be legally mined downdip on a lode claim even if it passes beyond the vertical plane of the side line of a claim. This is not permissible, however, across an end line. Western Gold faced a long and costly legal battle to establish that in the case of the Orphan Lode breccia pipe, the end lines of the claim were actually the side lines. Instead, it sought to negotiate with the Park Service for the ore.

During 1959, development work at the Orphan continued in preparation for starting production through the new crosscut and shaft. On the 245 level, a crosscut was driven from the service winze to the south perimeter of the pipe (fig. EE). Once the annular ring ore was reached, it was explored by drifts. The crosscut from the shaft reached the end line of the claim on the 400 level in August. Drifts were also driven in the annular ring zone on that level.

A service raise from the 400 level to the 245 level was completed in July, 1959. Other raises from the 400 level to the 245 level were completed in the annular ring zone on the southern perimeter of the pipe. These raises were then used as ore passes to bring ore from the upper levels of the mine to the 400 level where it was trammed to the ore pocket at the shaft and then hoisted to the surface.

Drilling of the H series of core holes on the 175 level resumed, and J, K, and L series of holes commenced on the 245, 400, and 320 levels, respectively (table XX). During the summer of 1959, the AEC made a study of the lime content of the Orphan Lode ore reserves. The study used shipping records, mine samples,

and core assays. It concluded that the remaining reserves in the A, B, and G zones averaged below 6 percent $CaCO_3$, those in the annular ring on the claim averaged between 30 and 36 percent $CaCO_3$, and the reserves in the annular ring in the Park averaged approximately 25 percent $CaCO_3$.

Production via the new shaft began in October 1959, giving the Orphan Lode the capability to hoist 8,000 tons-per-month instead of the 1,000 tons-per-month over the aerial tram. Use of the aerial tram to hoist ore was discontinued once the shaft became operational. In its 1959 report to the stockholders, Western Gold and Uranium reported that it had invested $1.2 million dollars in the new developments to transform the Orphan Lode into a full-fledged mining operation.

With mining operation expanding, Western Gold acquired a site outside the National Park, near the settlement of Tusayan on U.S. Highway 180, to build a mobile home park for its employees. This park would be known as Western Village.

In July 1959, Western Gold signed an ore purchase agreement with Rare Metals, that the Tuba City mill would purchase 8,300 tons-per-month of Orphan Lode ore averaging 0.30 percent U_3O_8 until the spring of 1962. Western Gold also had an ore purchase agreement with Phillips Petroleum Company to ship 500 tons-per-month to their mill at Ambrosia Lake, New Mexico. The Phillips mill had an alkaline leaching circuit and could treat high lime ores with little difficultly.

Production in 1959 was 26,124 tons of ore averaging 0.56 percent U_3O_8 and containing 291,841 pounds of U_3O_8 (table WW, fig. FF). Although the tons of ore more than doubled, the contained pounds of uranium oxide only slightly increased over 1958 since the average grade dropped over 50 percent.

In February, 1960, Arizona Senators Hayden and Goldwater introduced Senate Bill S-3094 which would give Western Gold the right to mine the ore in the Park

adjacent to the Orphan claim in exchange for the Government acquiring complete title to the claim in 35 years. The AEC approved the bill which would keep northcentral Arizona's uranium industry viable for at least six more years.

In anticipation of the passage of the bill, and receiving a satisfactory allocation from the AEC, Western Gold and Uranium and Rare Metals Corporation of America entered into an agreement that Rare Metals would install an alkaline leaching circuit at Tuba City to treat all ore mined at the Orphan Lode through 1966. The Orphan bill got, however, very little attention by Congress.

During 1960, exploration drilling of the J and K series of core holes resumed on the 245 and 400 levels respectively. The M and N series of short core holes, in fan patterns, were begun on the 310 and 350 levels respectively (table XX). The first and only fatality at the Orphan occurred on November 5, 1960 when a skiptender was struck by a descending cage at the main station.

Sinking of an exploration winze from the 400 level to the 550 level began in November, 1960. Progress on the winze was very slow due to heavy ground within the pipe.

Production during 1960 was 77,901 tons of ore containing 473,935 pounds of U_3O_8 and averaging 0.30 percent U_3O_8 (table WW, fig. FF). The sharp increase over the previous year was due to the fact that all ore was hoisted through the new shaft and development raises had been completed throughout the lower levels of the mine. During July, the mine set an all time record to date, when 7,733 tons were shipped.

During 1960, shipments of high-lime ore (20 to 30 percent $CaCO_3$) to the Phillips mill in New Mexico increased to 1,000 tons-per-month. Low-lime material from the B and G zones was blended with annular ring ore in order to decrease the overall lime content of the ore shipped to Rare Metals, which still averaged

about 12 percent $CaCO_3$. The company reported that lime penalties during 1960 averaged $3.16 per ton (M.E. Kofford, personal commun., 1961).

The Orphan bill was reintroduced in Congress in January 1961 as S-383. The earlier bill had died from lack of action in the previous session of Congress. In a move that was called political blackmail by some Congressmen, Western Gold released an artist's sketch of a luxury resort hotel it planned to build on the claim if the bill was not passed. The 800 room resort would stairstep down the rim of the canyon with a mammoth swimming pool at the bottom. Nevertheless, the proposed plan did alert Congress to the Orphan bill.

The exploration winze from the 400 level to the 550 level was completed, and drilling of the P series of core holes commenced for a station of the 550 level in February (table XX). Thirteen holes were drilled in this series, including P-13, a 1,914 foot (583 m) deep, vertical hole which bottomed in the Tapeats Sandstone. This hole, which was started in April, 1961, was completed May 10, 1962 at a reported cost of $50,000.

The R series of holes was drilled in the adit level and a new adit was started 150 feet above the original adit to develop ore in the uppermost parts of the pipe (table XX). Results of this work were largely disappointing, but the drilling did confirm that the pipe, at this level, was more circular than originally thought.

In May, 1961, surface runoff, from heavy rains, entered the adit and flooded the mine. All activity above the 245 level had to cease for several days and when the flooding was over, there was about a foot of water on the 400 level.

The production goals for the Orphan Lode during 1961 were set at 6,000 tons-per-month averaging 0.28 percent U_3O_8, all of the ore being marketed at Rare Metals mill. Blending of the lower grade, low-lime material from within the pipe

with the higher grade, high-lime annular ring zone continued. In spite of this, the lime content of the April shipment reached an all time record of 20.99 percent $CaCO_3$. By late summer 1961, the B zone was essentially mined out and the production grade from the G zone was averaging a disappointing 0.21 percent U_3O_8. The need to acquire the ore in the Park was essential to continue mining at the Orphan Lode.

During August, 1961, the Orphan claim was resurveyed. The original corners No. 3 and 4 were located and a small error in the original tie from Corner No. 1 to the southwest section corner of Section 14 was found. As the result of this modern survey, the claim was found to contain 20.64 acres, instead of the 20.26 acres listed on the original patent.

Western Gold and Uranium, Inc. was acquired by Lee Ackerman of Scottsdale, Arizona through a stock exchange. Ackerman became President of Western Gold and Uranium on September 6, 1961 and changed the name of the company to Western Equities, Inc. in November.

On December 22, 1961, the ore bin on the headframe of Orphan Lode shaft collapsed sending several hundred tons of ore down the shaft (fig. GG). There were no injuries and the miners were evacuated via the aerial tram. Damage to the headframe and shaft was estimated to be between $25,000 and $30,000. The collapse was attributed to a design error of the bin. Mining ceased on December 23, 1961 while the damage was to be repaired. Production during 1961 was 70,289 tons of ore averaging 0.28 percent U_3O_8 and containing 398,699 pounds U_3O_8 (table WW, fig. FF).

1962-1966 -- Productive Years

Shipments to the Tuba City mill ceased in January 1962, when the surface stockpile at the Orphan Lode was depleted. The mill closed in May 1962 for lack

of ore.

On May 28, 1962, President John Kennedy signed into law, Public Law 87-457, which permitted Western Equities, Inc. to mine uranium ore in Grand Canyon National Park, adjacent to the Orphan claim, in exchange for title to the claim in 25 years (1987). The law specified that all mining would be underground and that the tram would be dismantled by 1964. The Federal Government would receive a royalty ranging from 5 to 10 percent depending on the grade of the ore produced. Also, after 1966 only 3 acres in the southeast corner of the claim would be retained for mining. Thus, the Grand Canyon Inn and related cabins would belong to the Park Service in 1967.

With the ore on the Park ground now available for Western Equities to mine, the AEC negotiated a new contract with El Paso Natural Gas Company, which had acquired Rare Metals by merger in July 1962 (Albrethsen and McGinley, 1982). A new contract, AT(05-1)-910, was signed on November 19, 1962 and was effective from September 10, 1962 through December 31, 1966 (Albrethsen and McGinley, 1982). Once a new contract was signed, modification of the existing mill to an alkaline leach circuit, using sodium bicarbonate, proceeded rapidly. A flotation circuit was added to remove sulfides which are carbonate consumers. The AEC granted Western Equities an allocation of 572,766 pounds of U_3O_8 per year under the November 24, 1958 announcement.

On November 20, 1962, mining resumed at the Orphan Lode, with the ore being stockpiled at the Tuba City mill site. Crosscuts to the annular ring deposits were driven on the 245, 265, 290, 320 and 350 levels to test the ore in the Park. The drift on the 550 level was continued northeasterly into the Park. Development of the remaining high lime ore in the annular ring on the claim also commenced. When mining resumed, all ore hoisted up the shaft was stockpiled on

the ground, and the use of an ore bin was discontinued.

In April 1963, the Tuba City mill began processing stockpiled Orphan Lode ore. The sulfide flotation concentrate contained sufficient sulfide copper to be marketable at a copper smelter. A small amount of silver was also present in the concentrate. In addition, a small amount of copper solubilized with the uranium was recovered, using powdered iron, as cement copper in the ion-exchange circuit. Both products were shipped by truck to a smelter at Inspiration, Arizona (Albrethsen and McGinley, 1982). Details of the Tuba City milling circuits are given in a report by Runke (1964).

In the fall of 1963 an incline was driven from the 550 level to the 585 level of the annular ring on the northeastern perimeter of the pipe. This was the lowest level of the deposit to be developed and mined.

During 1963, the Orphan Lode produced 614,858 pounds of U_3O_8 (table WW). Of this total, approximately 47 percent came from ore mined on Park ground (table VV). This would be the second highest yearly production for the mine (fig. FF).

In 1964, a small ore zone on the 375 level of the annular ring on both the claim and Park was developed. The zone was not very productive although it existed almost entirely around the pipe.

Production in 1964 was slightly lower than the previous year, and 592,047 pounds of U_3O_8 were produced (table WW). El Paso reported to the AEC that in 1964 the Orphan Lode ore averaged about 1.30 percent Cu and that 75 percent of the total copper or 90 percent of the sulfide copper was recovered. The sulfide concentrate averaged 20 percent Cu and 10 ounces of silver per ton (Albrethsen and McGinley, 1982). No other data on copper or silver production were made available to the AEC by El Paso.

Production from the Orphan Lode reached an all time yearly high in 1965

when some 680,746 pounds of U_3O_8 were produced (table WW). Of the total pounds uranium oxide U_3O_8, some 75 percent came from the National Park (table VV). Ore in the annular ring on the northern side of the pipe, within the Park, proved to be nearly continuous from the 225 to the 365 level. Here, the large No. 1 Stope was developed in bleached, brecciated, and unbrecciated Esplanade Sandstone (fig. EE).

In the early part of 1966, Western Equities Inc. was sold to Geo Space Corporation which was merged into Westec Corporation of Houston, Texas. On August 25, 1966, Westec's stock was suspended from trading on the American Stock Exchange. Westec declared bankruptcy and the Orphan Lode closed again. With its principal supply of ore down, El Paso's mill at Tuba City closed in September 1966, three months before its AEC contract was due to expire. The last concentrate from the mill was delivered to the AEC in November 1966 (Albrethsen and McGinley, 1982).

Production in 1966 was 32,620 tons of ore containing 268,698 pounds U_3O_8 and averaging 0.41 percent U_3O_8 (table WW). Nearly 60 percent of the uranium oxide came from the Park ground (table VV).

1967-1969 -- Final Years

On August 31, 1967, Westec asked permission from the U.S. District Court in Houston, Texas to sell the Orphan claim and related properties to the Cotter Corporation of Roswell, New Mexico and Cañon City, Colorado.

During 1967, the Cotter Corporation enlarged its mill at Cañon City to process 400 tons per day in an alkaline leaching circuit and 100 tons per day in an acid circuit. A flotation cell was added to remove iron and copper sulfide minerals from the ore prior to alkaline leaching. These sulfides were acid-leached to remove uranium before shipment to a smelter (Albrethsen and McGinley,

1982).

The court approved the sale and Cotter Corporation began operating the Orphan Lode in September, 1967. The first ore was loaded on rail cars at an Atchison, Topeka and Santa Fe Railway Company's siding in Grand Canyon National Park on September 27, 1967, for shipment to Cotter's uranium mill at Cañon City, Colorado. Since Cotter's AEC contract had expired on February 28, 1965, all uranium produced after that date was sold on the private market to electrical utilities (Albrethsen and McGinley, 1982). Brundy (1977) reported that Cotter paid $875,000 in cash for the Orphan claim and Western Village, and that Westec retained a 4.2 percent royalty on ore produced. The Engineering and Mining Journal (1968) noted that the Orphan Lode had 500,000 tons of ore averaging 0.35 percent U_3O_8 blocked out when Cotter acquired it.

Production at the Orphan Lode in 1968 was reported to the AEC as 43,147 tons of ore containing 321,174 pounds of U_3O_8 and averaging 0.37 percent U_3O_8 with nearly equal amounts coming from the claim and the Park (tables VV, WW).

The Orphan Lode closed for the final time on April 25, 1969. The shutdown was attributed to a freight charge of $12.96 per ton to transport the ore by rail, some 750 miles (1207 km) from Grand Canyon to Cañon City (Pay Dirt, 1969).

After the mine closed, the AEC estimated that 500,000 pounds of uranium oxide remained in the mine in low grade material averaging 0.11 percent U_3O_8. All of this estimated uranium was above the 400 level, and the majority of it was within the pipe (B and G zones).

Epilogue

The dramatic increase in the price of uranium in the mid 1970's renewed an interest in the Orphan Lode. The Cotter Corporation conducted several feasibility studies concerning the reopening of the mine. At one time an

upgrading plant was considered in the Williams, Arizona area. Environmentalists sought to prevent ore trucks from ever again moving through the National Park. After evaluation of all possibilities, the Orphan Lode remained closed.

The Western Village site had become very valuable real estate. Records of the Coconino County Assessor's office show that on February 18, 1981, John R. Siebold of Grand Canyon, Arizona and Elling Halvorson of Redmond, Washington acquired the Western Village site and the Orphan claim. They reportedly paid the Cotter Corporation $800,000 for the property.

The Federal Government received complete title to the Orphan claim on May 28, 1987, when the last 3 acres were transferred.

Production Summary

Records of the AEC show that during the period 1956 through 1969 the Orphan Lode Mine produced 495,106.63 dry tons of ore containing 4,257,571.47 pounds of uranium oxide and averaging 0.43 percent U_3O_8 (table WW). Cotter officials estimated the value of the uranium produced at $40 million (Pay Dirt, 1969). Of the total uranium oxide produced, some 1,376,615 pounds, or 32 percent came from orebodies in Grand Canyon National Park (table VV).

The vanadium content of the Orphan Lode ores was determined at Tuba City and the contained vanadium oxide was paid for under the terms of the AEC's Circular 5, Revised. Since this practice was for carnotite type ores, it was discontinued on the Orphan uraninite ores after March 1958 (table YY). According to AEC records, some 3,283 pounds of V_2O_5 were paid for, but never recovered at Tuba City.

Cotter Corporation provided the Park Service with information on the copper and silver production. Between 1962 and 1969, 6.681 million pounds of copper and 106,553 ounces of silver were recovered as by-products of the uranium production

(National Park Service, 1977).

EVOLUTION OF THE MINE

The Orphan mine was initially developed from Dan Hogan's old adit. This adit is 1,100 ft (335 m) below the rim of the canyon at the elevation of ???? ft. This opening was designated the adit level. All levels in the mine are named for the distance between the floor of the adit level to the floor of an individual level.

Geometry of the Mine

Initial exploration of the breccia pipe located ore in the upper portion of the pipe. A service winze was excavated from the adit level to the 175 level, and later to the 245 level (fig. EE). Drifts off of the winze at the 100, 140, 175, 190, and 245 levels provided access to the ore within the pipe and on its perimeter.

After exploration drilling located ore below the 245 level both within the pipe and around its perimeter, a 1,590-ft- (485-m-) deep, vertical shaft was sunk from the rim of the canyon. A crosscut drift connected the shaft to the 400 level of the pipe. Raises from the 400 level to the 245 level were driven as ore passes and mining levels were established on the 285, 310-320, 350-365 and 375 levels. A service raise was driven to connect the 400 to the 245 level (fig. EE). This interior shaft provided access for men and supplies to the various mining levels.

In order to mine ore that had been located below the 400 level, and to explore the lower part of the breccia pipe, a service winze was sunk from the 400 level to the 550 level, where a drill station was established. Raises were driven from the 550 level to establish mining levels on the perimeter of the pipe

on the 420-430 and 525 levels. An inclined drift from the 550 level provided access to the 585 ore level. The 585 level was the lowest level of ore to be mined at the Orphan.

Mining Methods

The Orphan Lode had two different phases of mining depending on how the ore was transported to the canyon rim. The initial phase used an aerial tram, and the second was through a vertical shaft.

Initial production was in April 1956. Until October 1959, all ore was transported to the canyon rim using the aerial tram. Production of the mine was limited by the capacity of the tram, not by the developed ore in the mine. In the early years of the mine there were 4 levels below the adit level -- 100, 140, 175 and 245 (fig. EE). On each of the levels, ore was broken at the face, loaded into mine cars, hand trammed to the service winze, hoisted, and hand trammed out the adit level to the mine portal. Here, the ore was dumped into a car on an inclined track which was hoisted and dumped into ore bins on the lower terminal of the tramway. At the lower terminal, the tram buckets were loaded and hoisted to the rim and dumped into bins on the upper terminal. Trucks were loaded from the bins for haulage to Tuba City, Arizona.

Mining and exploration developed the high grade A orebody on the northeast perimeter of the pipe. The portion of the orebody between the 175 and 190 levels was mined first with the broken ore dropped through ore passes to the 245 level where it was hoisted up the service winze to the adit level. The area of the mined-out ore was then backfilled with waste rock and mining of the upper part of the A orebody commenced using cut and fill methods. This was done to protect the shaft pillar of the service winze and to prevent the Hermit Shale, outside the pipe, from caving into the mine workings. Talus material from the Canyon

slope near the adit and waste rock from mining were used as fill material. Ore from the A orebody was dropped through ore passes to the 175 level. Here, it was loaded into 16 cu. ft. capacity ore cars and hoisted up the service winze to the adit level to be put in ore bins at the lower tramway terminal. Stoping eventually connected all 5 levels (adit, 100, 140, 175, and 190) and the large A Stope was formed.

In late 1959, when the new shaft and crosscut to the 400 level were completed, mining methods at the Orphan changed. Ore within the pipe (B and G zones), and the annular ring orebodies were mined by different methods.

The massive orebody of the B zone was broken with long holes drilled horizontally from vertical raises located in, or at the edge of, the ore. The high-grade shaft pillar of the service winze was removed and backfilled with waste to keep this access to the adit level open. No timbering or roof bolts were necessary in the large stopes as the walls stood well. Ore from the B zone was collected in ore pockets on the 265 level and eventually dropped to the 400 level via ore passes (fig. EE).

To mine the G zone, a slot stope was cut adjacent to the north end line of the claim, between the 290 and 320 levels. Additional slots were cut around the orebody and G zone was mined from the 265 to the 365 levels. Ore was blasted into the slots and collected on the 365 level (fig. EE). From here it was passed to ore pockets on the 400 level. The large scale stoping in the G zone produced a grade of ore that was much lower than anticipated.

Ore in the annular ring on the claim was developed by untimbered drifts on the 245, 310 and 350 levels, which circumscribe the pipe on the claim. Raises from the 245 level to sublevels on the 190 and 225 developed ore on the claim in the annular ring. A subdrift on the 285 level was used to mine a small orebody

which occurred above a barren mudstone bed on the southern perimeter of the pipe. Underhand stoping developed a large open stope between the 310 and 350 levels on the southwest perimeter of the pipe (fig. EE). The high lime content of the annular ring zone permitted the drifts and stopes to stay open without timbering or roof bolting. The cut and fill methods of mining used in the annular ring permitted the disposal of all waste rock underground.

When the ore in the National Park became available, it was developed by crosscuts from the area of the service raise (from the 400 level) to the perimeter of the annual ring on the 245, 265, 290 and 320 levels. Drifts from the existing workings in the annular ring in the claim were extended into the Park ground on the 225, 350-365 and 400 levels. The ore in the Park portion of the annular ring proved to have a greater vertical continuity than on the Orphan claim. As a result, the large No. 1 Stope was developed between the 225 and 365 levels (fig. EE).

Slushers and hand tramming were used to move ore to ore passes where it was dropped to ore pockets on the 400 level. Here, the ore was loaded into 2.5 ton capacity Card RD-40 cars and was trammed to the shaft station by a Mancha battery-powered locomotive. At the station, ore was side dumped into a slusher trench where it was loaded into 2½ ton skips and hoisted to the surface. At the surface, ore was stored in a bin attached to the headframe, but beginning in 1962 it was stored on the ground near the shaft.

Ore in the annular ring zones below the 400 level was developed and mined by drifts on the 420-430, 525 and 585 levels. Ore on the 420-430 and 525 levels was dropped through ore passes to the 550 level, and the ore from the 585 level was hoisted up the incline to the 550 level by use of a tugger. From the 550 level, ore was hoisted up the service winze to an ore pocket on the 400 level,

for storage before it was trammed to the shaft station.

The mine was dry; all water used at the mine, as well as at the Grand Canyon Inn, had to be hauled from Williams, Arizona, a distance of 60 miles. In wet weather some seepage water was caught and utilized by the mine.

Summary of Production

Future of the mine

GEOLOGY

Stratigraphy of surrounding sediments

Desciption of sediments in pipe

ORE DEPOSITS

Uranium ore deposits at the Orphan Lode occur in two distinct geologic environments -- 1) within the pipe fill, and 2) associated with the peripheral shear zone surrounding the pipe. The latter has been termed the annular ring by company geologists and engineers.

Description of orebodies

Core Ore

Principal orebodies within the pipe include the A, B, and G zones (fig. EE). The A orebody, or zone, occurs in the northeast part of the pipe at the adit level and extends downward to about the 190 level. Since the mine closed, the upper portion of the A stope has collapsed to the surface at the adit level. It reached a maximum width of 40 ft (12 m) on the 175 level. This was a very high grade orebody (portions were greater than 1.50 percent U_3O_8) that consisted of uraninite disseminated throughout a poorly consolidated sand, derived from the Coconino Sandstone. The high grade ore from the A stope was the principal source of the Orphan uranium production in the early years (table XX). The shape of the orebody was controlled by the distribution of the Coconino sand fill within the pipe. The northeastern limit of the fill was marked by the peripheral shear zone

(annular ring) of the pipe within the Hermit Shale.

The B orebody, or zone, extended from about 30 ft (9 m) above the adit level downward to the 245 level (fig. EE). The principal area of mining was from the 140 level to the 245 level where the orebody was mined to a diameter of about 200 ft (61 m). This large orebody consisted of some very high grade (greater than 1.00 percent U_3O_8) pods surrounded by lower grade and barren material. Host rocks for the B zone included Coconino sand fill as well as a claystone breccia derived from the Hermit Shale. Calcified blocks of argillic breccia, resembling limestone, were mined on the 175 level in 1957, causing the lime content of some shipments to Tuba City to reach 14 percent $CaCO_3$. An increased permeability due to fracturing and the good porosity in the sand fill appear to have been important in localizing the B orebody. Pyrite was very common in the B orebody, especially in the lower part.

The G orebody, or zone, is essentially a downward continuation of the B orebody. Below the 245 level the ore in the center of the pipe rakes to the northeast and continues downward to the 265 level (fig. EE). The orebody is similar to the B, but not as high grade (table VV). It was mined between the 265 and 365 levels and the G stope reached a maximum mean diameter of 160 ft (49 m) on the 320 level. Breccia derived from the Hermit Shale and the Esplanade Sandstone, as well as some sand fill from the Coconino, were the host rocks for the G orebody.

Ore stringers from the B and G zones coalesce with the annular ring orebodies below the 175 level, in the northern portion of the pipe. Small pods of such ore stringers have been mined on the 245, 265, 290, 320, and 365 levels. The host rocks for these small pods were largely calcified sandstone-pipe-fill derived from the Coconino Sandstone.

Annular Ring Ore

Orebodies in the annular ring can occur -- 1) within the peripheral shear zone, 2) within collapsed pipe-fill materials adjacent to, but inside the shear zone, and 3) in undisturbed sediments outside the shear zone. Most of the ore produced from the annular ring came from deposits in the Esplanade Sandstone outside the shear zone (fig. EE). Here, ore occurs in sandy beds in relatively undisturbed sediments outside of the pipe. Vertical ring fractures appear to control the radial extent of the ore beyond the pipe; the width of the orebodies varies from 6 to 60 ft (2 to 18 m). Clay and mudstone lenses or beds in the annular ring are barren and some sandy units are also barren. No megascopic differences have been noted between the mineralized and nonmineralized sandy sections. The ore is continuous horizontally in the favorable sandy sections around the entire periphery of the pipe, but the vertical continuity is interrupted by unfavorable beds. Kofford (1969) compared the annular ring to a stack of washers, with the alternate ones being ore bearing.

The annular ring on the claim has been mined on the 190, 225, 245,* 285, 310, 350, 375, and 420 levels. The orebodies are generally about 15 ft (5 m) wide, but reached a maximum width of 60 ft (18 m) on the 350 level. The mineralization was so intense on the northwestern segment of the annular ring that the entire section of rock (referred to as the 350 stope--table UU) between the 310 and 350 levels was entirely mined out. However, an intervening 7 to 10 ft (2-3m) thick mudstone was barren on the south and southeast segment, separating this section of rock into the 310 and 350 levels. The bottom of the 350 level ore zone in the claim is marked by a second barren mudstone bed.

On the northern perimeter of the pipe, off the original patented claim and within the National park, the rock was so intensely mineralized that the

separation between the different ore levels is not distinct, resulting in the large No. 1 stope (table UU and fig. EE). The intense shearing on the pipe boundary here has resulted in good vertical continuity of the orebodies throughout the mudstone as well as sandstone. The early drilling detected this continuity and hence, this part of the annular ring was termed "the feeder zone" (Kofford, 1969). The massive orebody in the Park was mined out through the No. 1 stope (fig EE) that extended from the 225 level to the 365 level. This stope had an average width of about 50 ft (15 m), with a maximum width of 200 ft (61 m) on the 320 level.

Bleached Supai sandstones outside the pipe are very common. Normally dark reddish-brown sandstones are bleached white, light gray or pinkish gray near ore. Both increased porosity and fracturing have localized ore within the Supai sandstones.

Remains of land plants in the Esplanade Sandstone are uncommon (McKee, 1992, p. 98). However, on the 245 level, near the C raise, Chenoweth (1986) observed a small accumulation of plant fragments that were mineralized with uranium (fig. HH).

Ore in the annular ring on the 375 level, and below, is localized in sandstone beds of the Wescogame Formation of the Supai Group. Orebodies have been mined on the 375, 400, 420-430, 525, and 585 levels, but these orebodies do not have the horizontal continuity of those in the Esplanade Sandstone. The P series of drill holes (table XX) was unsuccessful in locating additional ring zones below the 585 level.

Mineralogy

Orphan Mine Minerals and stoichiometry

The Orphan mine mineral assemblage can be thought of as a fine-grained

version of the Mississippi Valley type deposits found in the Viburnam trend, with a later uranium and copper sulfide overprint. Specific examples are the Buick and Sweetwater mines. Although there is considerable controversy over whether the Viburnam trend deposits should be considered true Mississippi Valley type deposits, the purpose here is not to argue deposit classification, but rather to convey an image of the Orphan mine mineral assemblage to the reader. Unfortunately, in contrast to the large showey display crystals of such minerals as barite, calcite, chalcopyrite, galena, and siegenite collected from Mississippi Valley type deposits most minerals found at the Orphan Mine are present in crystals smaller than 1 mm. These minerals were identified by reflected light petrography using a 100x objective lens and(or) with the electron microprobe.

Orphan Mine Gangue Minerals

Orphan Mine Metallic Minerals and their Stoichiometry

The 40 minerals identified to date at the Orphan mine are listed in Table K1 under gange or under their major cation metal. Few minerals found at the Orphan mine are pure end members, with the exception of galena and chalcopyrite. Most contain either other metals substituting for their major metal cation or arsenic substituting for sulfur.

Nickel-Cobalt-Iron-Copper Sulfides and Arsenides

An extensive suite of Ni-Co-Fe-Cu sulfides and arsenides lies within the matrix of the Orphan mine ore zone breccia.

Pyrite is the most pervasive metallic mineral in the Orphan pipe. It impregnated the sand fill matrix within the orebodies, formed small cubes or massive radially-bladded nodules, and locally corroded and replaced detrital quartz grains. Locally the sand fill is totally cemented by pyrite. Much of the

bladded pyrite may have been marcasite as small marcasite blades are intergrown with the pyrite.

The cubes of pyrite are rarely pure FeS^2, but more commonly are intergrowths of pyrite with bravoite, vaesite, and villimaninite; although each of these minerals forms a discrete mineral boundary within the cube, none represents the pure mineral end member. Although bravoite is no longer recognized by the International Commission on New Minerals and Minerals Names as a discrete mineral it is used in this report as in the past literature to designate a member of the pyrite group with roughly equal amounts of Ni and Fe.

Pyrite formed at several stages during pipe mineralization; many grains are fractured by a later fracturing event and are clearly pre-fracturing, while some are not. Some of the pyrite fractures resemble dessication cracks. The cubes of pyrite group minerals appear to be some of the earlier formed pyrite.

Intricately zoned crystals of small (<1 mm), euhedral Ni-Co-Fe-As-S minerals were the first to form during the second major episode of mineralization in these pipes. Several of these phases replace minerals, such as barite and anhydrite, from the first episode. Individual crystals exhibit complex, concentric zoning of up to ten phases, mostly of the linnaeite or pyrite groups. The zoning trends from Ni-Co-rich cores, through Ni-Fe-rich bands, to Fe-rich rims. Siegenite [$(Ni,Co)_3S_4$], violarite [$Fe^{2+}Ni_2^{3+}S_4$], polydymite [$NiNi_2S_4$], pyrite, Ni-bearing pyrite (bravoite), and vaesite [NiS_2], are common, but some crystals also contain bands of millerite [NiS], cobaltian pyrite, villamaninite [$(Cu,Ni,Co,Fe)S_2$], gersdorffite [NiAsS], nickeline [NiAs], or rammelsbergite [$NiAs_2$]. Extensive microprobe work has been done on samples from two breccia pipe mines, the Hack 2 and Orphan, which are about 50 miles apart. Mineral compositions are similar except that no copper is found in the Ni-Co-Fe phases

from the Hack 2 mine, while pyrites containing 1 wt % Cu are common from the Orphan, which was mined for copper. In some of these "pyrites", Cu is dominant and the mineral is actually villamaninite. Pyrites from both mines characteristically contain 0.5 to 3 wt % As. Metal contents in zoned pyrite-bravoite-vaesite (M_1S_2) crystals at the Hack 2 mine range from Fe_1 to $Fe_{.12}$, Ni_0 to $Ni_{.86}$, and Co_0 to $Co_{.10}$. The metal content for polydymite-siegenite-violarite averages about $(Ni_{2.33}Co_{.39}Fe_{.23})(S_{3.9}As_{.1})$. Orphan mine pyrite-bravoite-vaesite-villamaninite ranges in composition from pure FeS_2 to $(Ni_{.6}Fe_{.21}Co_{.17})S_2$, and $(Cu_{.46}Ni_{.27}Fe_{.21}Co_{.13})S_2$. Of all the sulfides or arsenides found in these breccia pipes, only nickeline consistently occurs as the pure end member.

Mineral

Possible zoning in the pipe

Mineral Paragenesis and pipe evolution

Geochemistry

Statistical analysis

Elemental zoning within the pipe

Comparison with other ore-bearing pipes

South Rim

North Rim

Genesis of the ore

SUMMARY

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Table ZZ. Uranium grades and thicknesses in cores from initial drilling, Orphan Lode, Coconino County, Arizona.

Hole No.	Grade ($\%U_3O_8$)	Thickness (Feet)
1	0.378	11.0
2	0.464	11.5
3	0.284	17.5
4	0.233	30.0
5*	1.112	21.5
6	0.224	31.5
7**	1.002	53.0
8	0.152	3.0
9 & 10	Creviced - not completed	
11	0.087	217.0
12	0.042	130.0
13	0.043	40.0
14	0.051	38.8

* In hole 5, 3.5 feet averaged $3.13\%U_3O_8$

** In hole 7, 21.7 feet averaged $1.71\%U_3O_8$

Source: Golden Crown Mining Co. press release dated February 16, 1956.

Table WW. Uranium production, by year, Orphan Lode, Coconino County, Arizona

Calendar Year	Tons of Ore	Pounds U_3O_8	%U_3O_8
1956 2nd Qtr	20.89	221.41	0.53
1956 3rd Qtr	771.46	7,116.44	0.46
1956 4th Qtr	874.09	7,702.33	0.44
1957 1st Qtr	1,737.44	47,328.34	1.36
1957 2nd Qtr	1,680.17	37,714.77	1.12
1957 3rd Qtr	2,084.53	34,376.51	0.82
1957 4th Qtr	2,013.83	33,496.38	0.83
1958 1st Qtr	2,336.22	44,419.55	0.95
1958 2nd Qtr	3,422.63	71,860.51	1.05
1958 3rd Qtr	3,082.52	66,899.62	1.08
1958 4th Qtr	3,004.70	93,078.06	1.55
1959 1st Qtr	3,990.74	65,737.98	0.82
1959 2nd Qtr	5,012.93	78,561.82	0.78
1959 3rd Qtr	5,663.55	64,125.11	0.57
1959 4th Qtr	11,570.73	85,814.40	0.37
1960 1st Qtr	14,675.32	105,714.18	0.36
1960 2nd Qtr	21,180.38	152,145.98	0.36
1960 3rd Qtr	20,393.91	115,030.42	0.28
1960 4th Qtr	21,651.81	101,044.37	0.23
1961 1st Qtr	21,890.08	125,543.54	0.29
1961 2nd Qtr	16,888.96	107,215.57	0.32
1961 3rd Qtr	17,011.30	91,542.93	0.27
1961 4th Qtr	14,499.03	74,397.32	0.26
1962 1st Qtr	169.28	710.97	0.21
1962 2nd Qtr	---	---	---
1962 3rd Qtr	---	---	---
1962 4th Qtr	4,988.16	45,413.88	0.46
1963 1st Qtr	15,053.11	158,993.67	0.53
1963 2nd Qtr	14,193.75	141,602.99	0.50
1963 3rd Qtr	12,806.93	143,440.49	0.56
1963 4th Qtr	14,709.68	169,032.53	0.57
1964 1st Qtr	14,818.80	163,742.86	0.55
1964 2nd Qtr	15,787.75	130,875.28	0.41
1964 2nd Half[1]	33,387.69	297,431.15	0.45
1965	80,492.64	680,746.08	0.42
1966	32,620.49	268,697.67	0.41
1967	3,554.90	25,586.00	0.36
1968	43,147.46	321,173.82	0.37
1969	13,918.77	99,036.54	0.36
TOTALS	495,106.63	4,257,571.47	0.43

[1] - Production by quarters not available after July 1, 1964

Source: U.S. Atomic Energy Commission files, Grand Junction Office

Table XX. Summary of exploration core holes with alphabetic prefixes, Orphan Lode Mine

Prefix	No. of Holes	Location	Year(s) Drilled	Results
A, B, D, E, F	25	100 & 175 levels	1956-57	Located ore in upper part of pipe (A & B Zones).
G	10	Two stations in Park	1958	Defined the diameter of the pipe and located ore in annular ring and within lower part of pipe (G Zone).
H	10	175 level	1958-59	Located ore in annular ring.
J	63	245 level	1959-61	Located ore in annular ring.
K	30	400 level	1959-61	Located ore in annular ring.
L	11	320 level	1959-61	Located ore in annular ring, and within pipe.
M	48	310 level	1960	Located ore within pipe and in annular ring.
N	64	350 level	1960	Located ore within pipe and in annular ring.
P	13	550 level	1961-62	Explored lower part of pipe including Redwall Ls. and older sediments.
R	4	Adit level	1961	Explored pipe on, and above, adit level.

Maps showing the location of these core holes are not available.

Table YY. Vanadium, calcium carbonate and copper content of early uranium shipments, Orphan Lode, Coconino County, Arizona

Calendar Year	Tons of Ore	Mill	$\%U_3O_8$	$\%V_2O_5$	$\%CaCO_3$	%Cu
1956 2nd Qtr	21	TC	0.53	0.01	0.30	--
1956 3rd Qtr	771	TC	0.46	0.03	0.80	--
1956 4th Qtr	874	RM	0.44	0.02	0.70	--
1957 1st Qtr	1,736	RM	1.36	0.01	1.81	--
1957 2nd Qtr	1,680	RM	1.12	0.02	11.11	--
1957 3rd Qtr	2,085	RM	0.82	0.02	14.00	--
1957 4th Qtr	2,014	RM	0.83	0.01	12.90	--
1958 1st Qtr	2.336	RM	0.95	0.01	1.47	--
1958 2nd Qtr	3,423	RM	1.05	--	2.56	--
1958 3rd Qtr	1.128	RM	1.26	--	3.43	--
1958 3rd Qtr	1,955	VM	0.99	--	--	--
1958 4th Qtr	1,995	RM	1.49	--	4.26	--
1958 4th Qtr	936	TZ	1.72	--	2.81	0.17
1958 4th Qtr	34	VM	0.59	--	--	--
1958 4th Qtr	40	KM	1.49	--	--	--

TC - AEC, RM - Rare Metals, VM - Vitro Corp., TZ - Texas Zinc Minerals, KM - Kermac Nuclear Fuels

Source: U.S. Atomic Energy Commission files, Grand Junction Office.

Table UU. Distribution of ore production by level and stope, Orphan Lode Mine.

Level	Tons of ore	%U_3O_8	Pounds U_3O_8
140	2,200	0.27	10,800
175	2,000	0.31	12,400
190	6,100	0.20	24,400
225	8,300	0.26	43,200
245	12,400	0.36	89,300
265	4,500	0.33	29,700
285	3,000	0.55	33,000
310-320	30,000	0.42	255,000
350-365	65,500	0.45	596,100
375-400	12,200	0.37	90,300
420	6,500	0.38	49,400
430	1,100	0.57	12,600
525	2,800	0.32	17,900
585	1,500	0.60	18,000
Stope			
A	43,100	0.85	737,000
B	72,000	0.18	259,200
G	38,500	0.14	107,800
No. 1	88,500	0.52	929,300
335	5,300	0.17	18,000
350	89,600	0.48	887,100
Total	495,100	0.43	4,220,500

Compiled from various sources, including annual company reports, company records, AEC reports, and discussions with former company employees.

Table VV. Uranium production from the Orphan Lode reported to the U.S. Atomic Energy Commission as coming from National Park Service ground.

Calendar Year	Tons of Ore	Pounds U_3O_8	$\%U_3O_8$
1963	23,022.62	287,143.02	0.62
1964	24,005.38	259,513.79	0.54
1965	51,687.15	511,768.65	0.50
1966	11,886.42	155,458.95	0.65
1967	--	--	--
1968	23,052.19	162,730.63	0.35
1969	--	--	--
TOTALS	133,653.75	1,376,615.13	0.52

Source: U.S. Atomic Energy Commission files, Grand Junction Office

APPENDIX A

ASSAY MAPS

The assay maps show the uranium content of the material that was removed during mining. After each round was shot, a representative sample was taken from the muck pile. The sample was crushed and reduced, then assayed using a radiometric scaler. The value was then plotted on a planimetric map. The scaler was calibrated with samples that had been chemically assayed for uranium.

Copies of the assay maps of the levels between the 245 and the 585 were obtained by the USGS from Western Gold and Uranium, Inc. The individual assays have been combined into six categories on the maps used in this report: less than 0.05% U_3O_8, 0.05-0.09% U_3O_8, 0.10-0.19% U_3O_8, 0.20-0.49% U_3O_8, 0.50-0.99% U_3O_8, and 1.00% and greater.

In many cases, no samples were taken in the interior of the pipe between the B zone and the annular ring. In the A zone, the only samples taken were from the initial drifts into the ore zone. No samples were taken in areas of large scale stoping.

APPENDIX B

See attached geochemical data table.

APPENDIX C

Tables of petrographic descriptions.

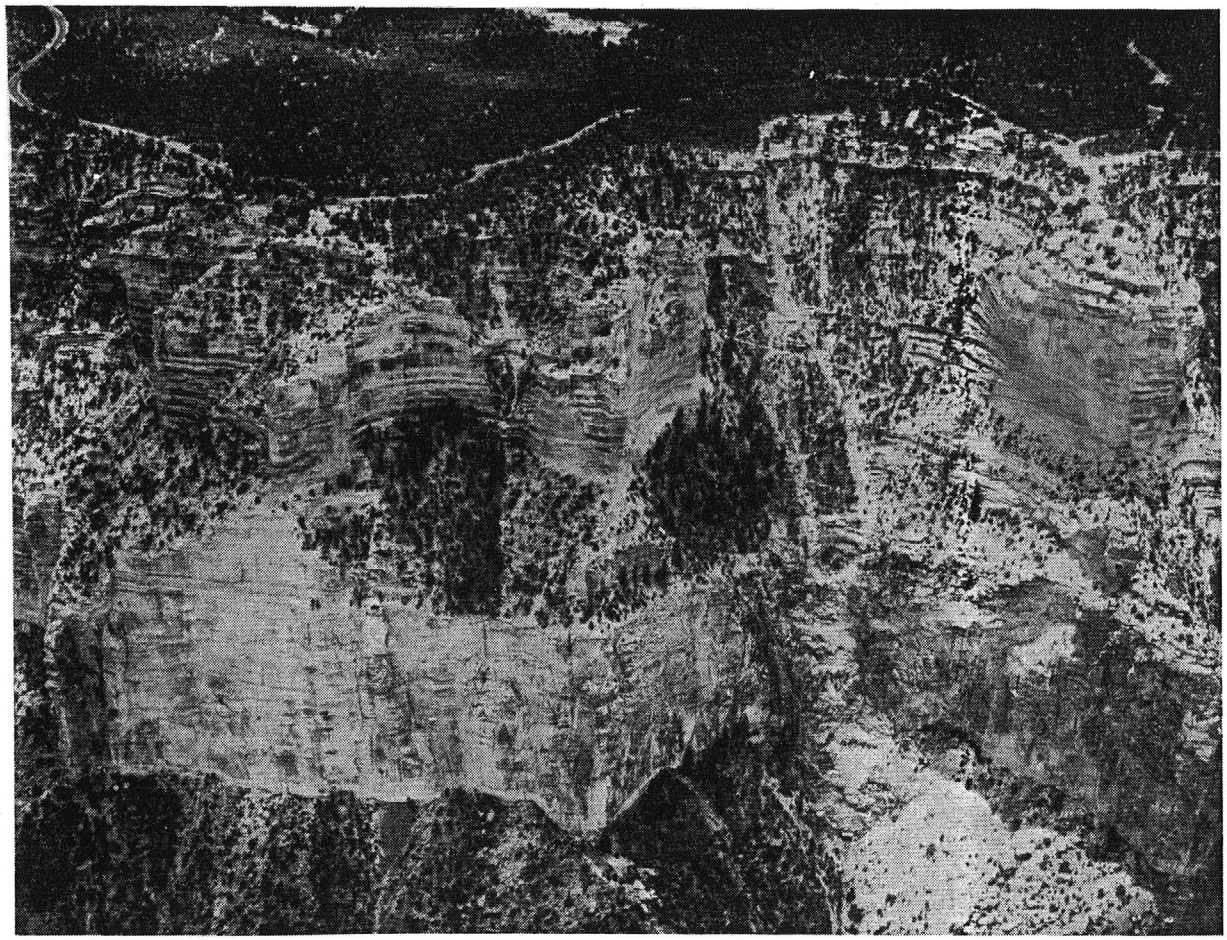


Figure 3, Oblique aerial photo of the south rim of the Grand Canyon showing Maricopa Point (center) and Powell Point (right). The Orphan claim is located between the two points. Vertical cliff in lower part of photo is the Coconino Sandstone. Top of the Orphan Lode pipe is at the Coconino and underlying Hermit Shale contact. Zig-zag scar on canyon wall is a trail that was built during the installation of the aerial tram. Photo by George Hood (AEC).

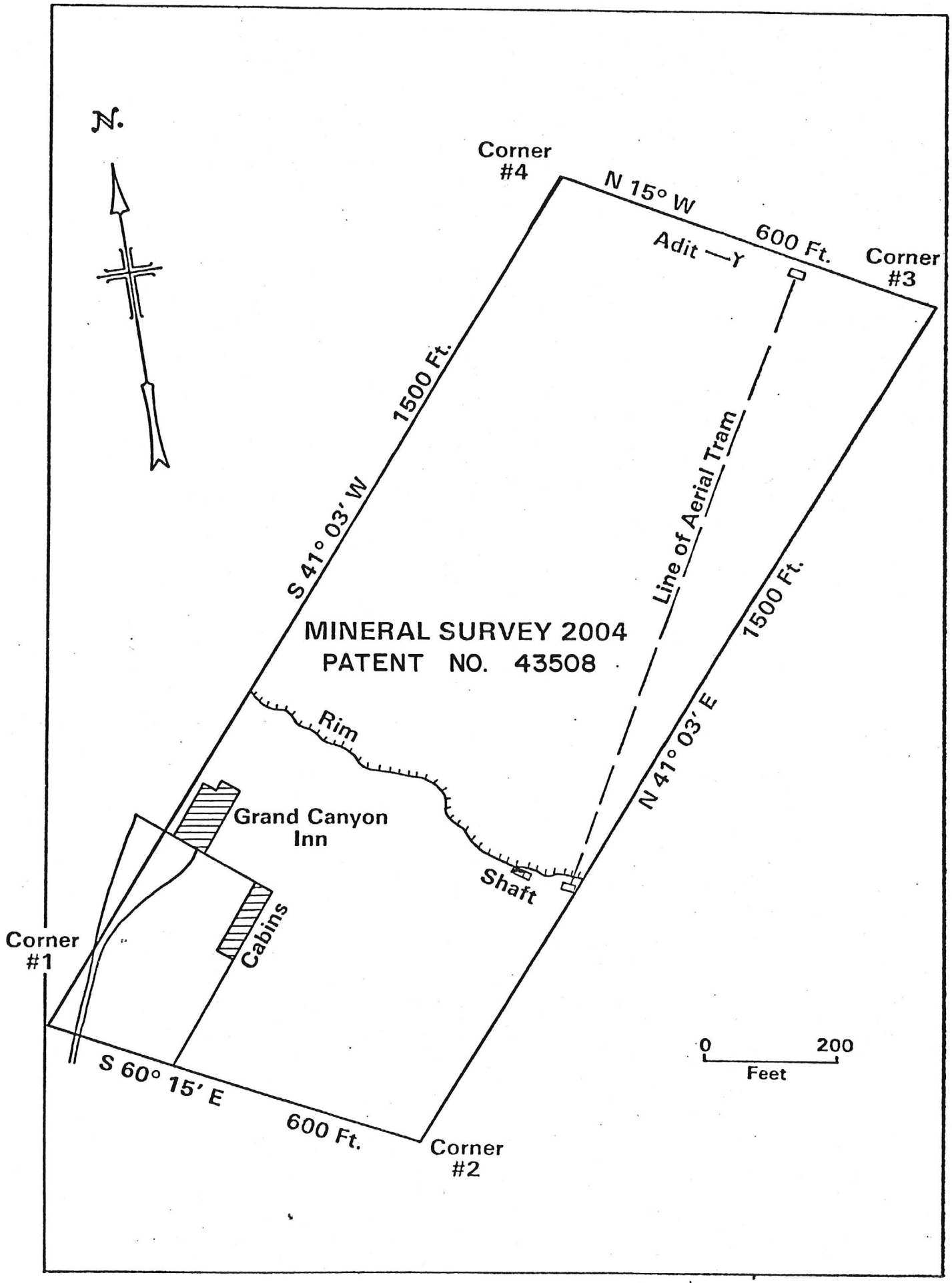


Figure 4. Index map of Orphan claim

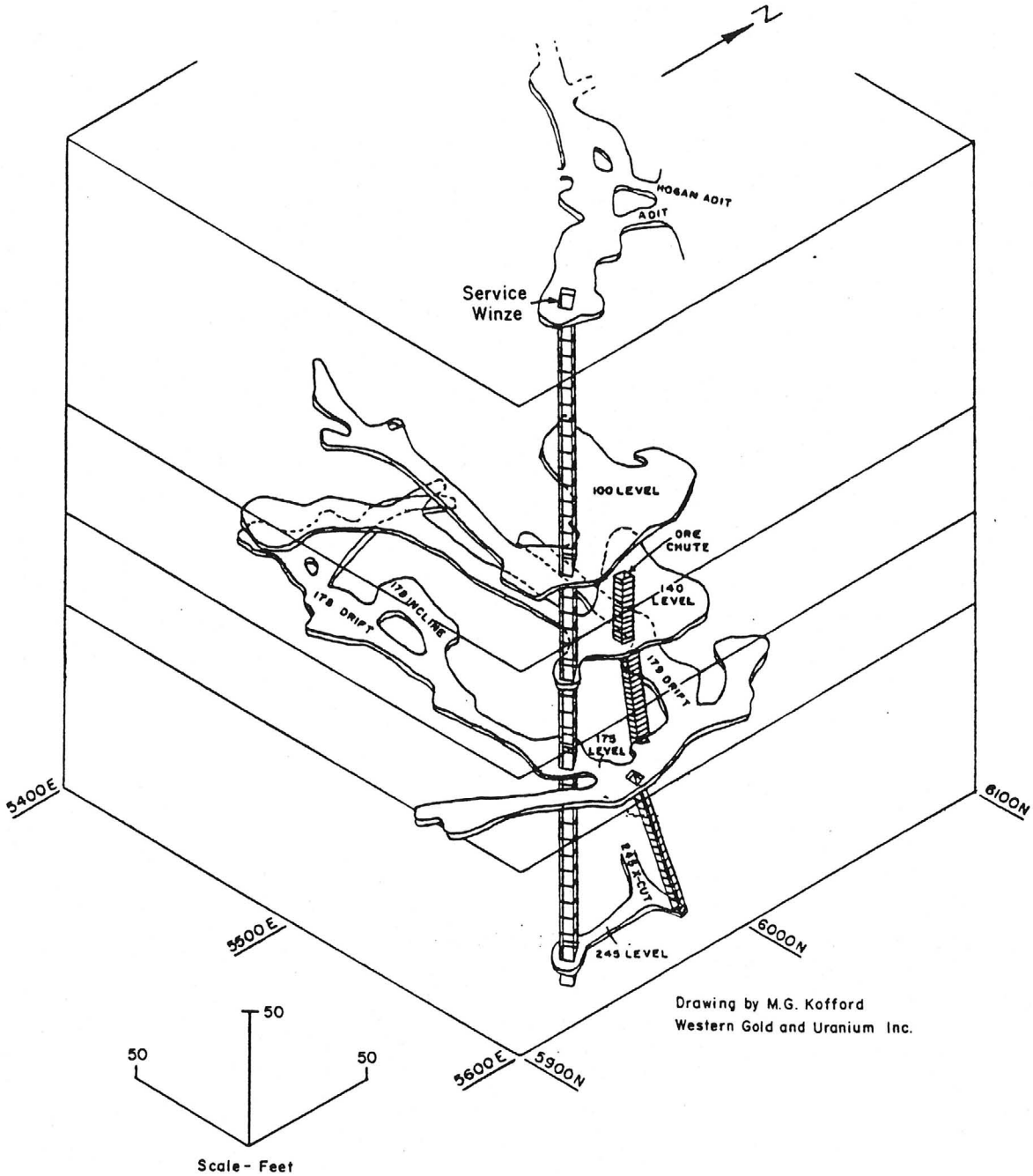


Figure 6. Isometric drawing of Orphan Lode Mine, December 1958

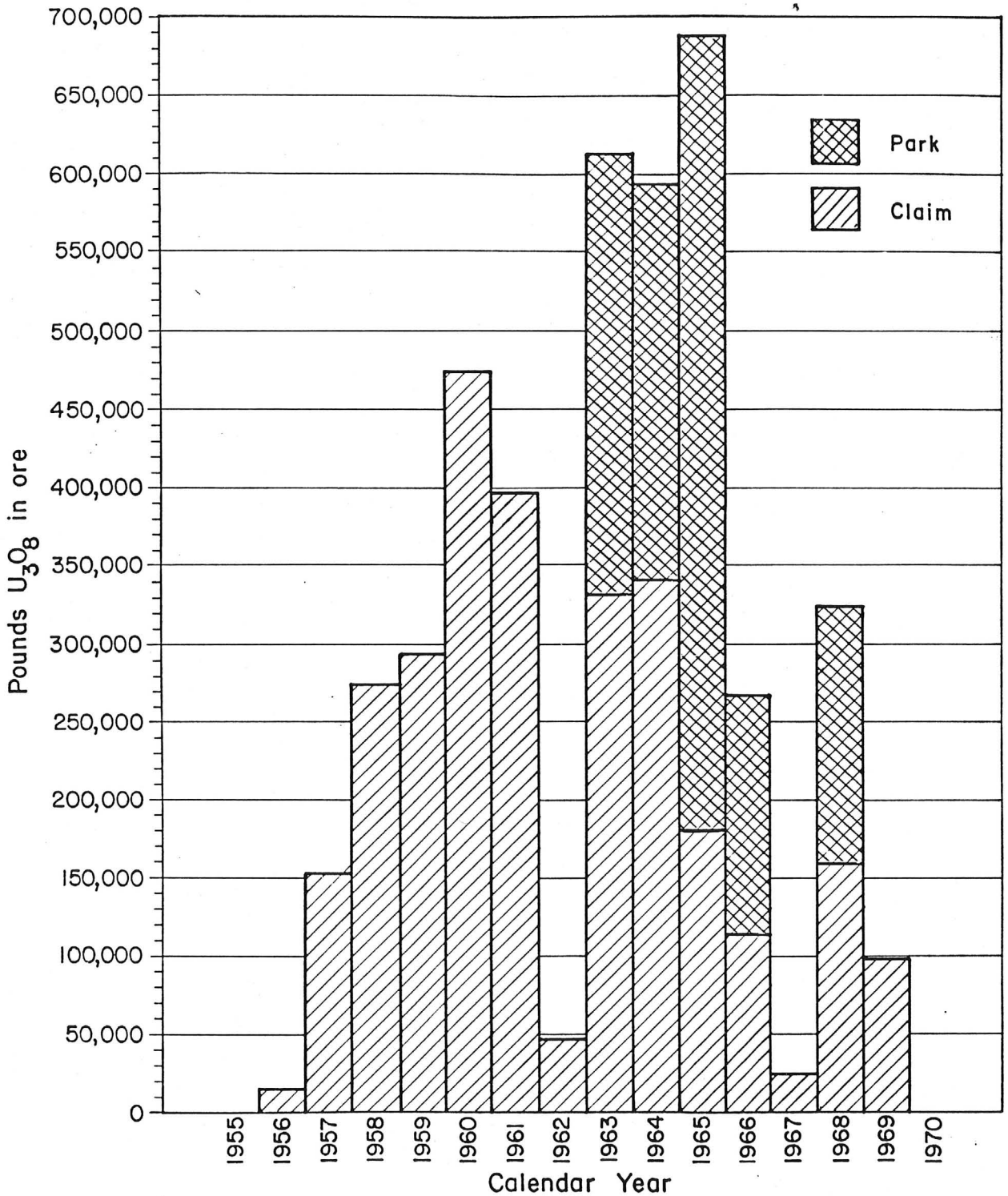


Figure 7. Uranium production Orphan Lode Mine, Coconino County, Arizona

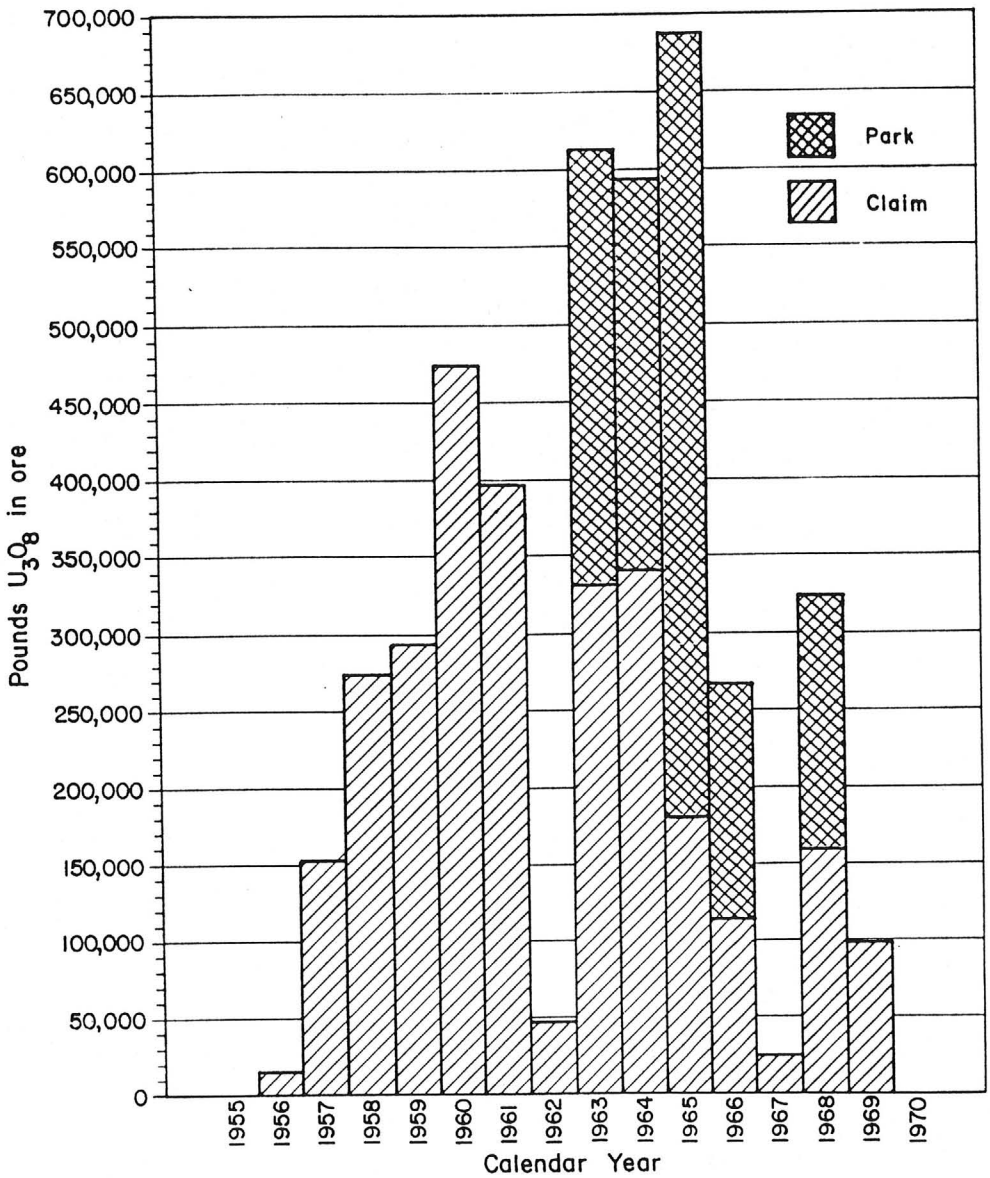
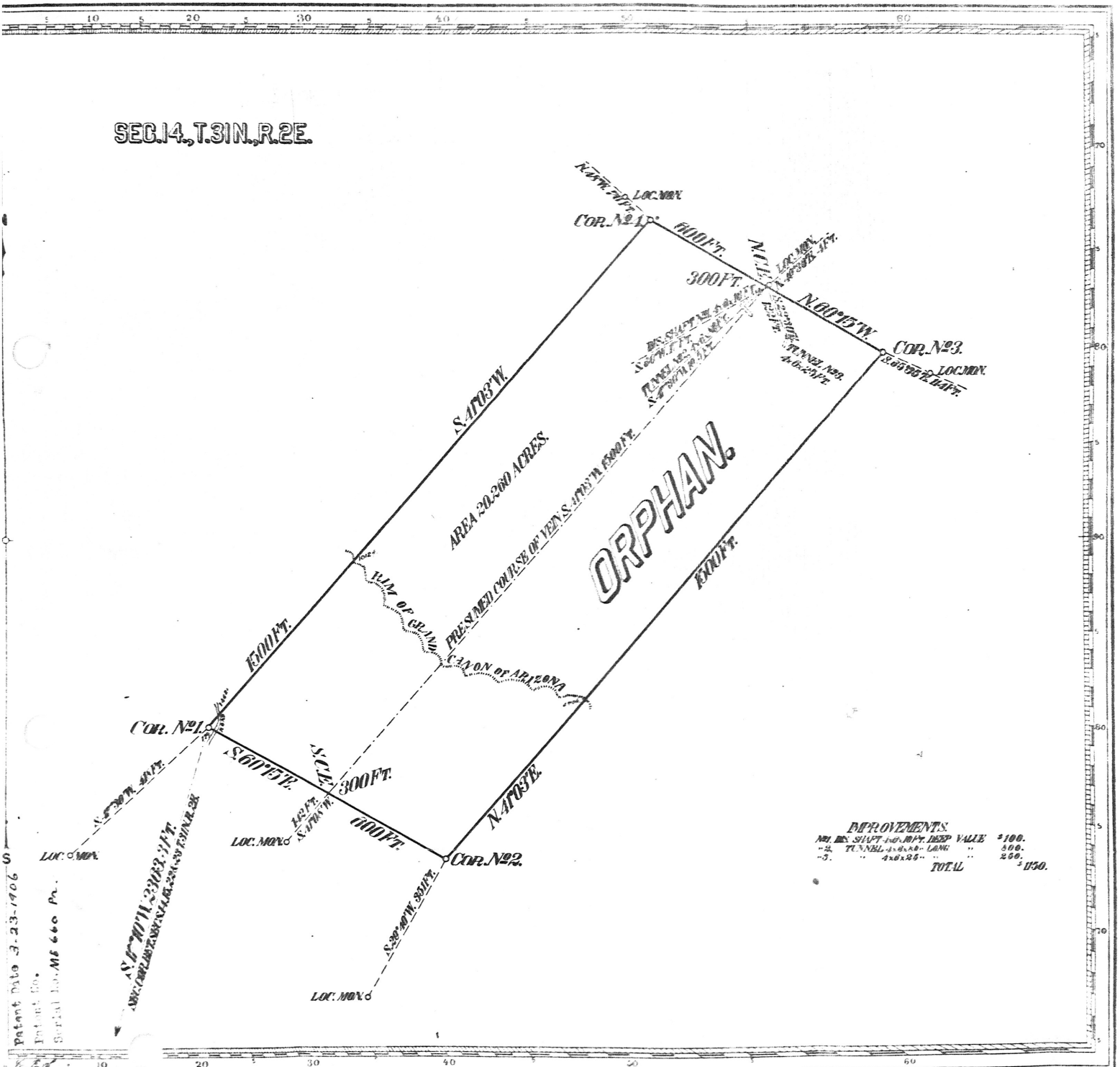


Figure 7. Uranium production Orphan Lode Mine, Coconino County, Arizona



Patent Date 3-23-1906
Patent No.
Serial No. MS 660 Pm.

Claim Located Feb. 8th., 1893.

Mineral Survey No 2004

Lot No

Prescott Land District

PLAT

OF THE CLAIM OF

D.L. HOGAN & C.J. BABBITT.

KNOWN AS THE

ORPHAN

IN GRAND CANON MINING DISTRICT,
COCONINO COUNTY, ARIZONA
Containing an Area of 20.260 Acres.
Scale of 200 Feet to the inch.
Mean Variation 15°08'30"E.
SURVEYED Jan. 18-20 1905 BY
Jno. F. Hesse
U.S. Deputy Mineral Surveyor.

The Original Field Notes of the Survey of the Mining Claim of
D.L. Hogan & C.J. Babbitt
known as the
ORPHAN

from which this plat has been made under my direction, have been examined and approved, and are on file in this office; and I hereby certify that they furnish such an accurate description of said Mining Claim as will, if incorporated into a patent, serve fully to identify the premises, and that such reference is made therein to natural objects or permanent monuments as will perpetuate and fix the locus thereof.

I further certify that Five Hundred Dollars worth of labor has been expended or improvements made upon said Mining Claim by claimants or their grantors, and that said improvements consist of (see table)

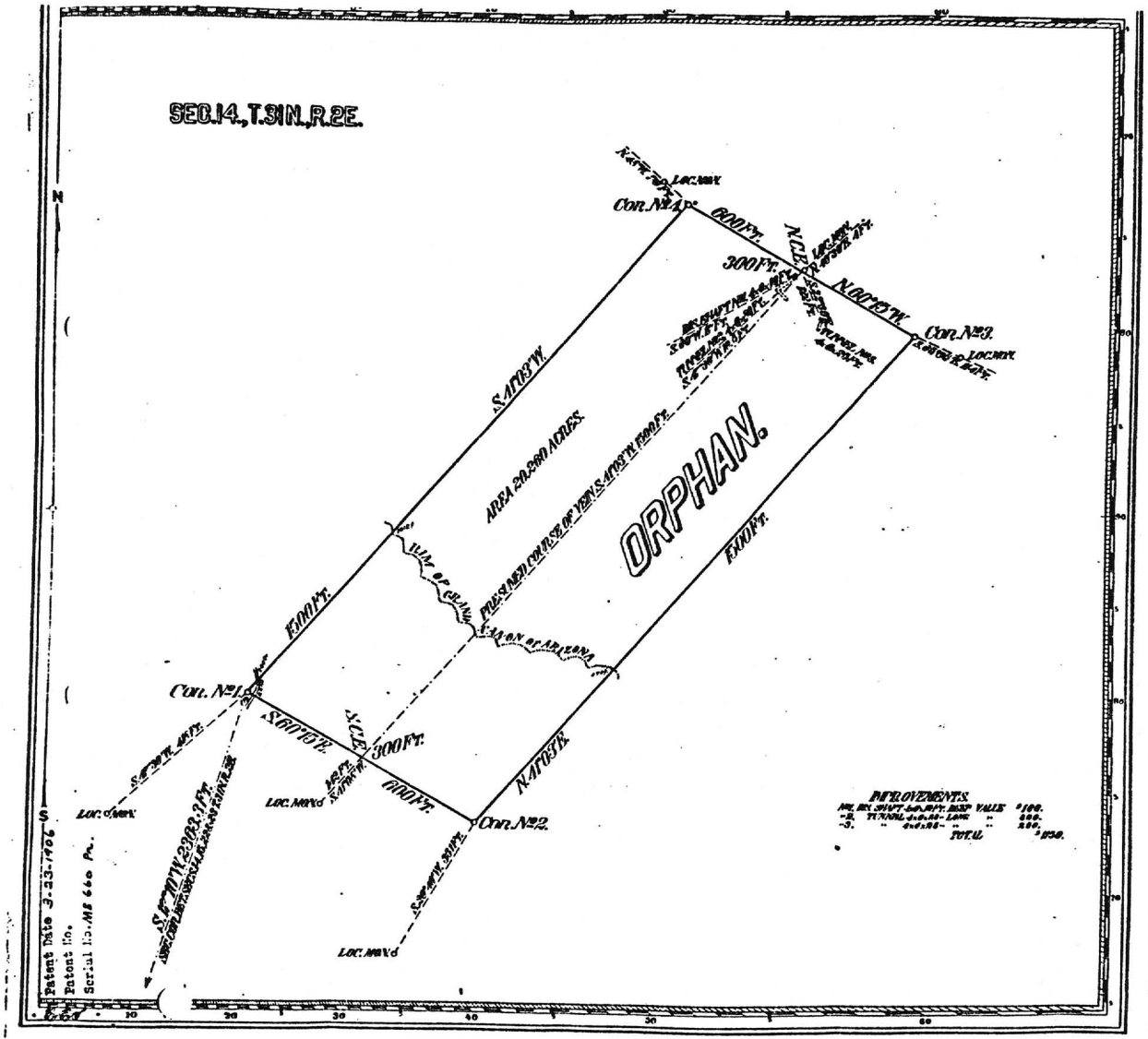
that the location of said improvements is correctly shown upon this plat, and that no portion of said labor or improvements has been included in the estimate of expenditures upon any other claim.

And I further certify that this is a correct plat of said Mining Claim made in conformity with said original field notes of the survey thereof, and the same is hereby approved.

U.S. Surveyor General's Office, Phoenix, Arizona
April 21st., 1905

Frank A. Ingalls
U.S. Surveyor General for Arizona.

(1905)



Claim Located Feb. 8th., 1903.

Mineral Survey No. 2061

Lot No.

Prescott Land District.

PLAT

OF THE CLAIM OF

D. L. HOGAN & C. J. BABBITT.

KNOWN AS THE

ORPHAN

IN GRAND CANON MINING DISTRICT,
COCONINO COUNTY, ARIZONA

Containing an Area of 20.260 Acres.

Scale of 200 Feet to the inch.

Mean Variation 16° 05' 30" E.

SURVEYED Jan. 18-20 1905 BY

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The Original Field Notes of the Survey of the Mining Claim of D. L. Hogan & C. J. Babbitt known as the ORPHAN

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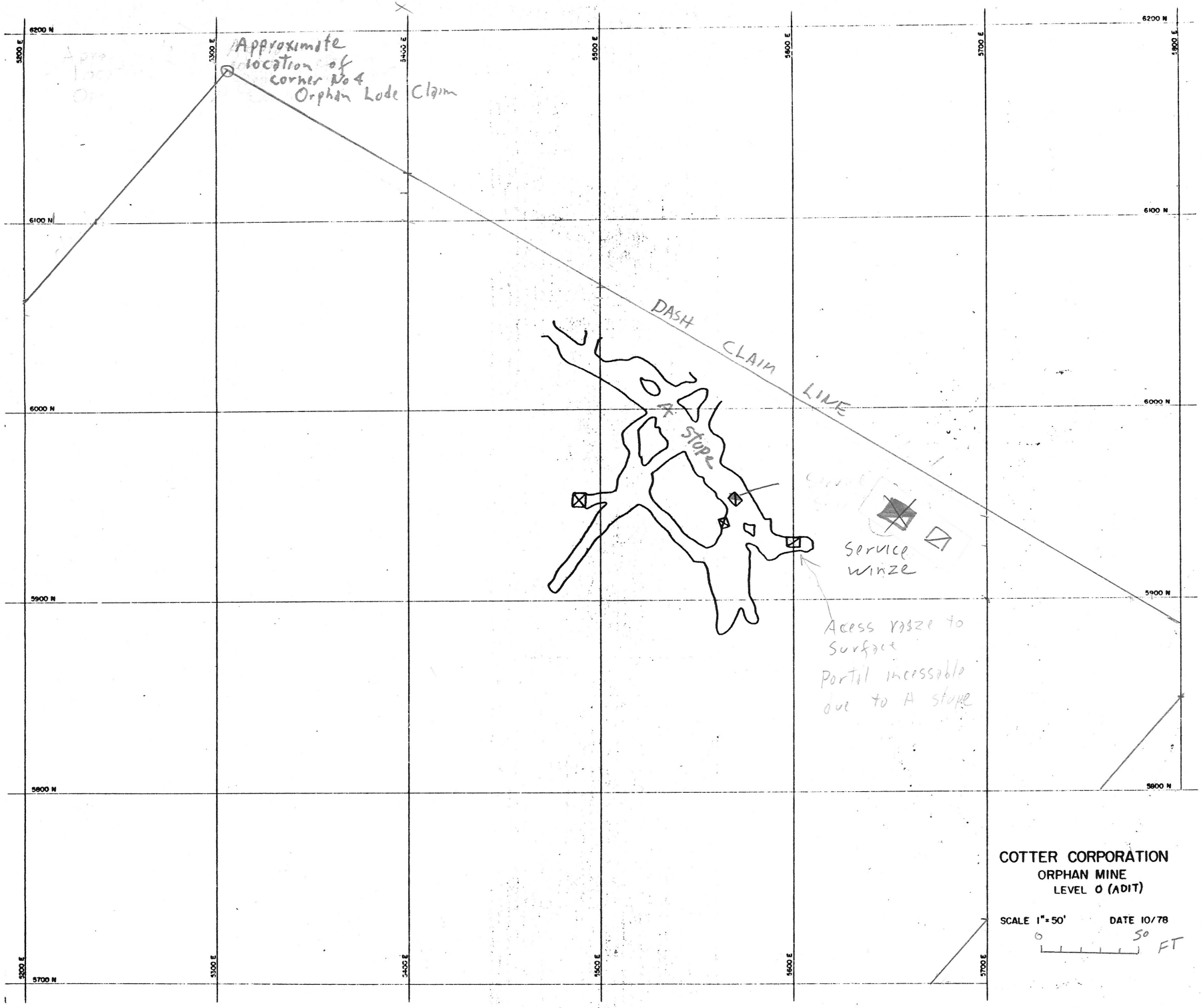
U.S. Surveyor General's Office. Frank A. Ingalls

Phoenix, Arizona U.S. Surveyor General for

April 21st., 1905 Arizona.

(1905)



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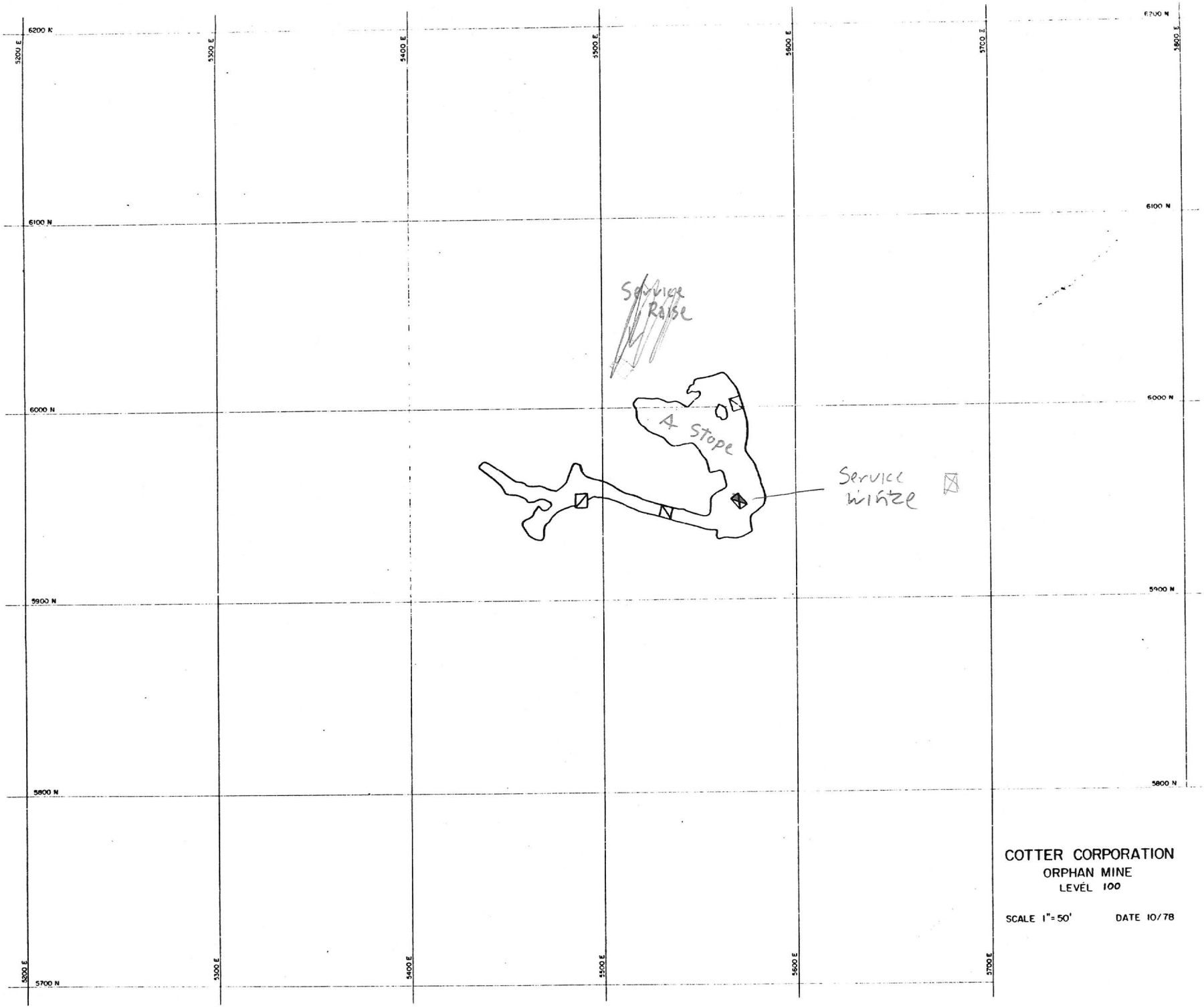
ORPHAN MINE
LEVEL 0 (ADIT)

SCALE 1"=50' DATE 10/78

0 50 FT

(2)



COTTER CORPORATION
ORPHAN MINE
LEVEL 100

SCALE 1"=50' DATE 10/78

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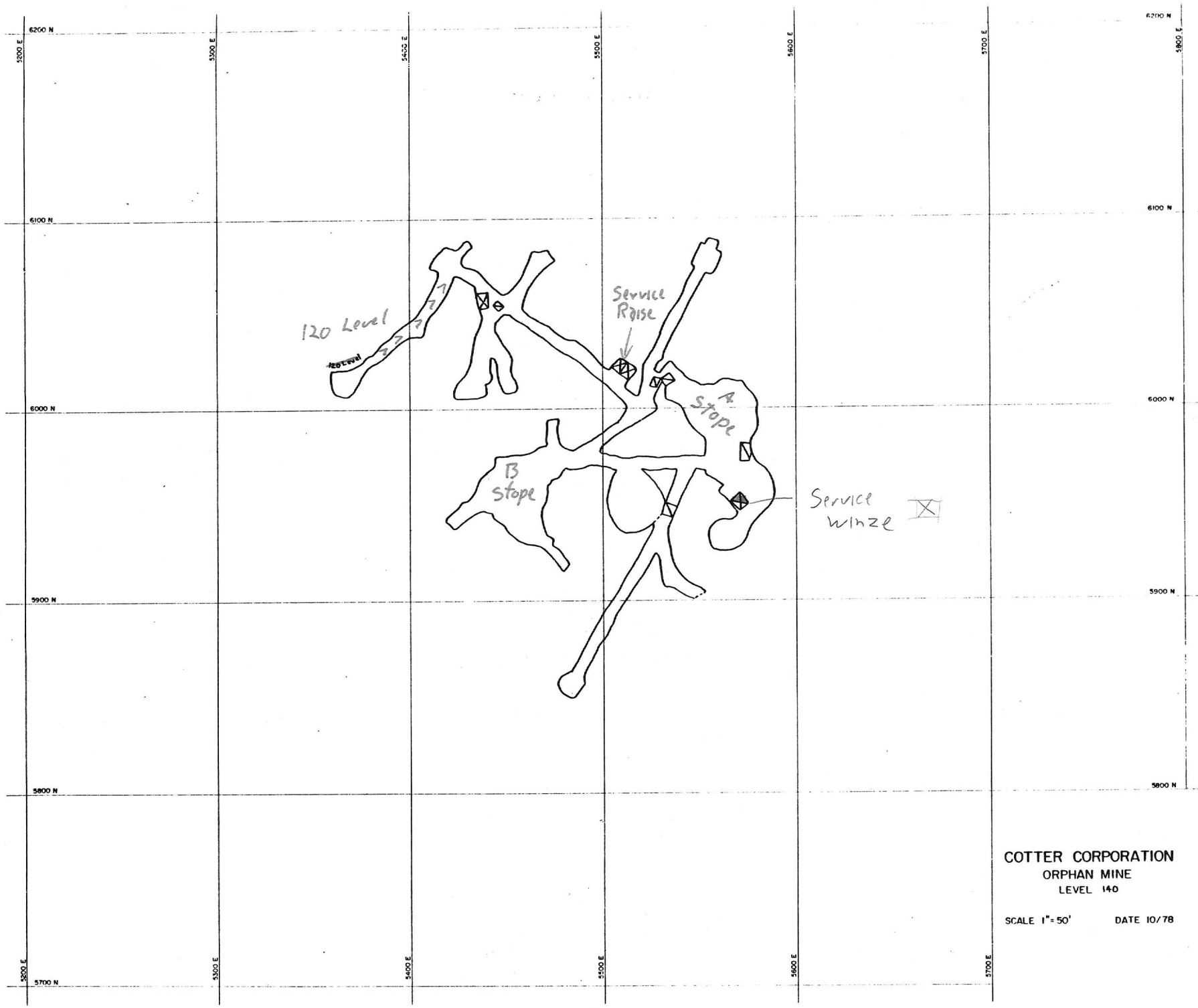

COTTER CORPORATION
ORPHAN MINE
LEVEL 140

SCALE 1"=50' DATE 10/78

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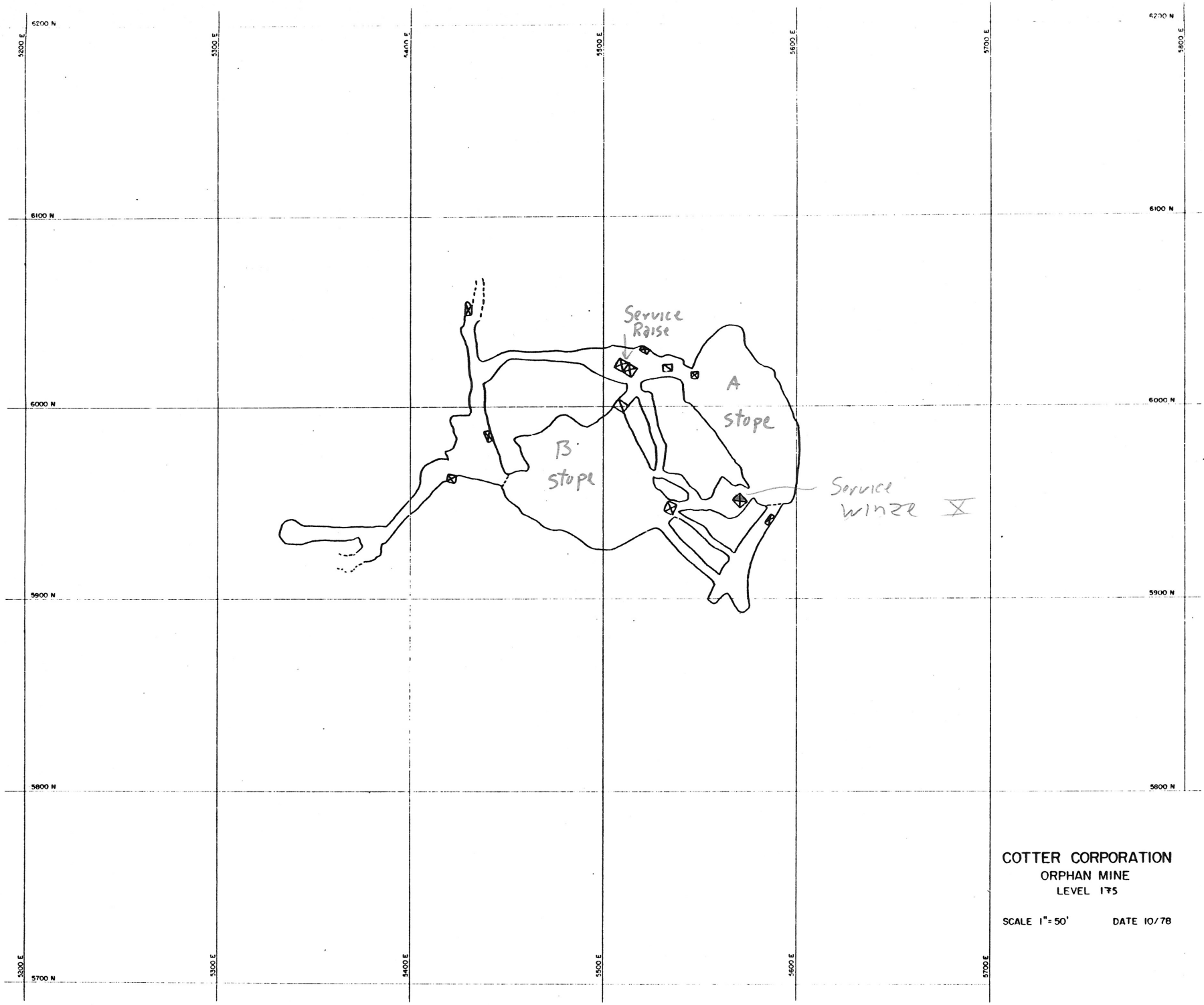
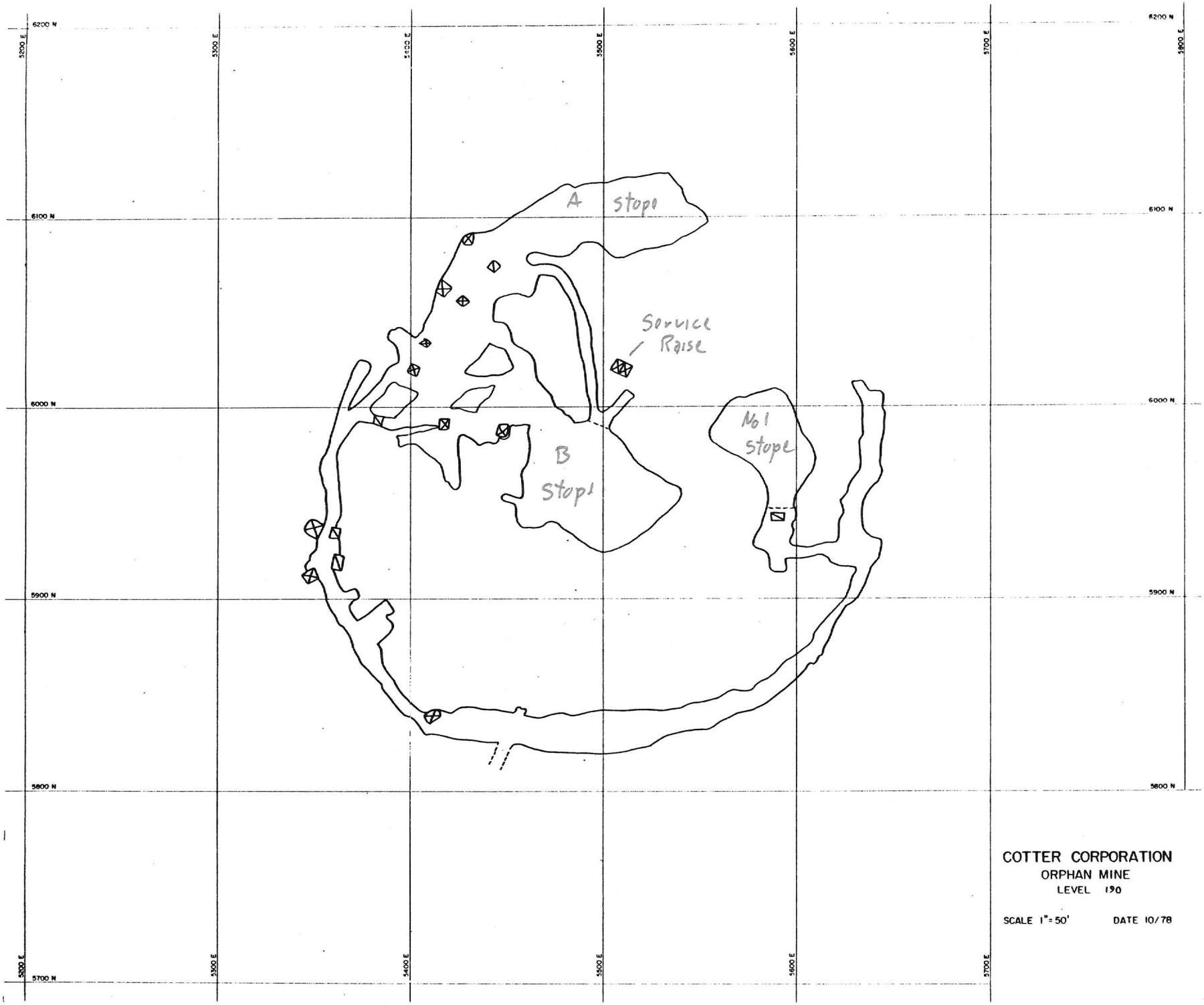


COTTER CORPORATION
ORPHAN MINE
LEVEL 175

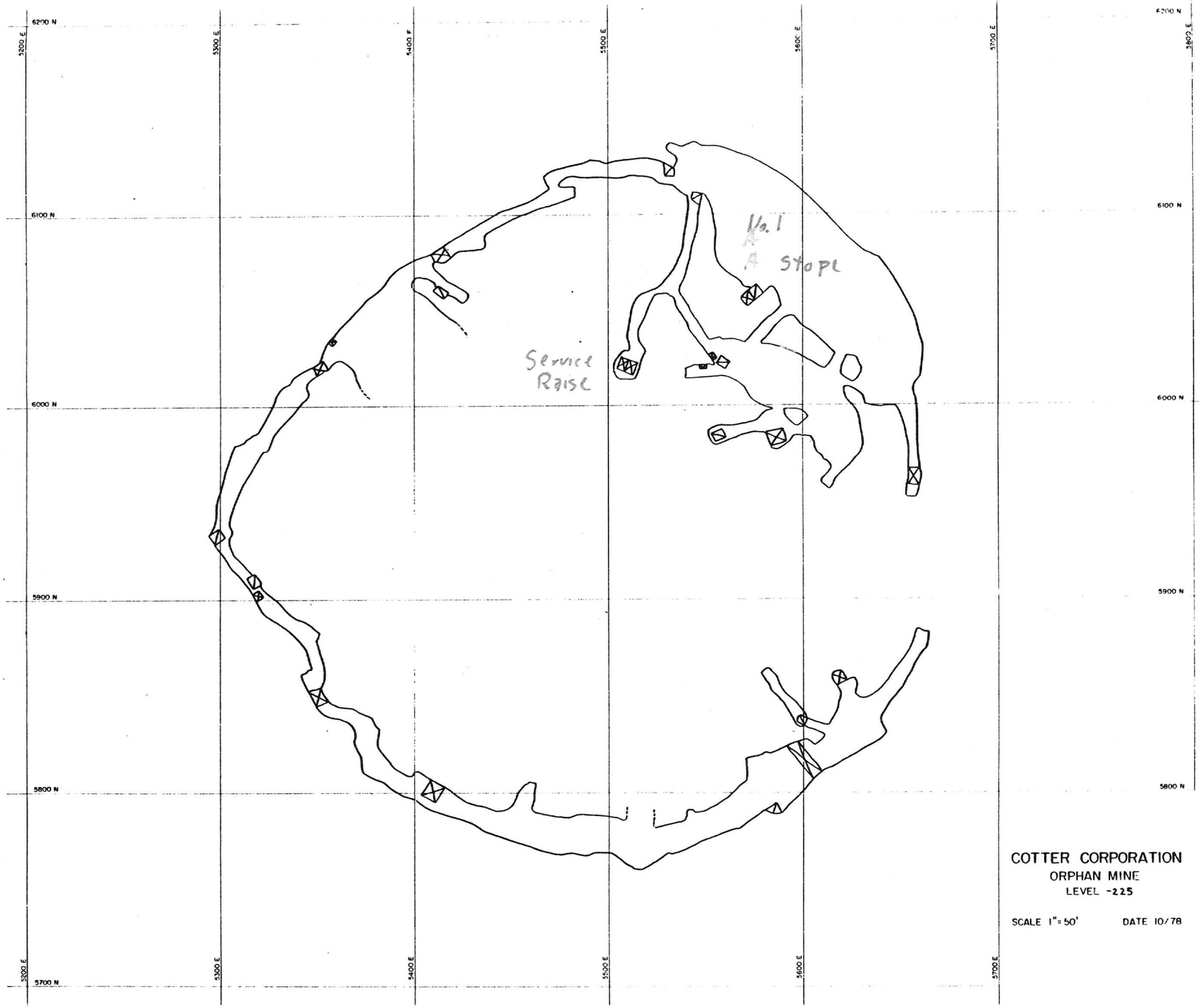
SCALE 1"= 50' DATE 10/78

(5)



COTTER CORPORATION
ORPHAN MINE
LEVEL 190

SCALE 1"= 50' DATE 10/78



COTTER CORPORATION
ORPHAN MINE
LEVEL -225

SCALE 1"=50' DATE 10/78

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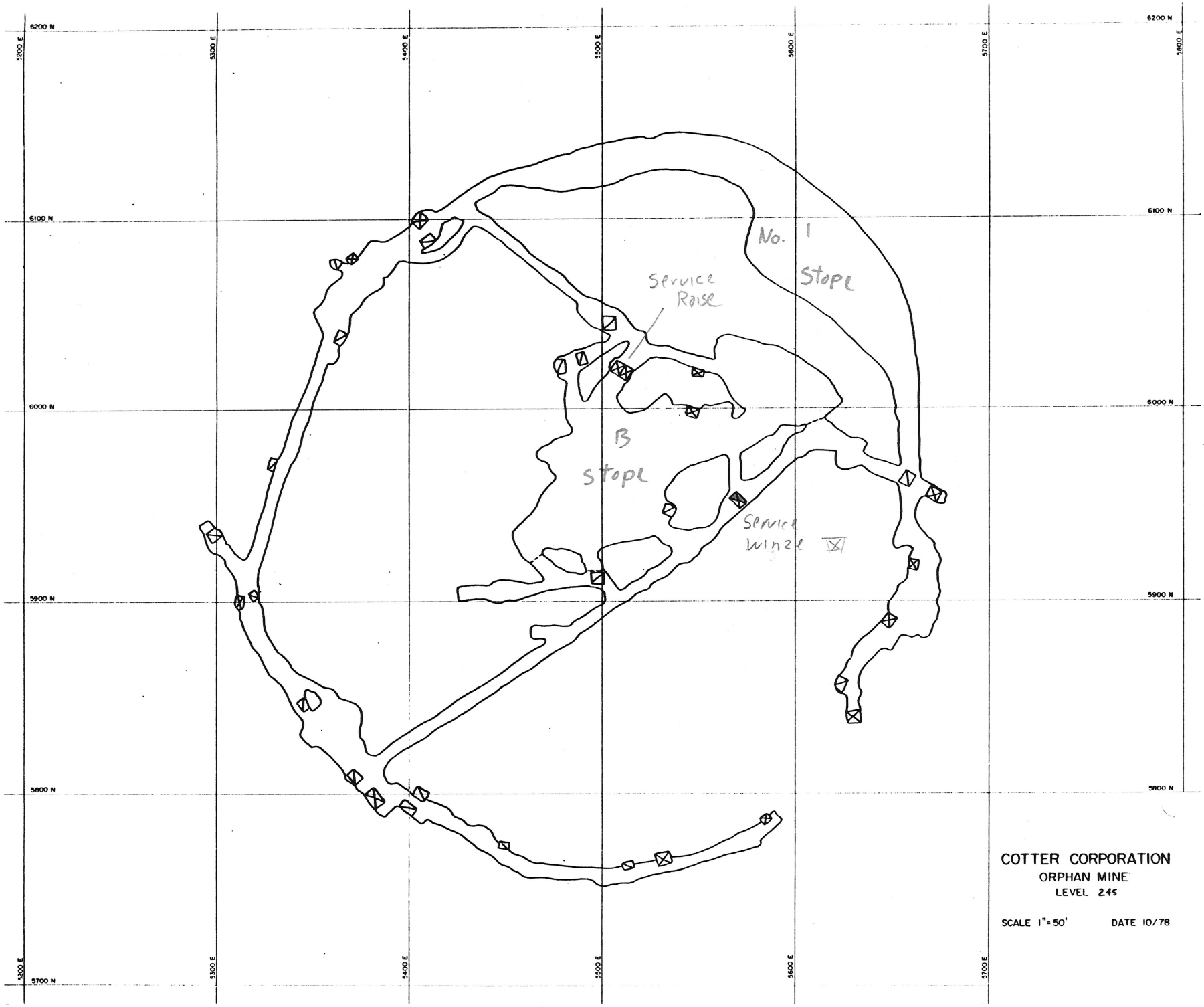
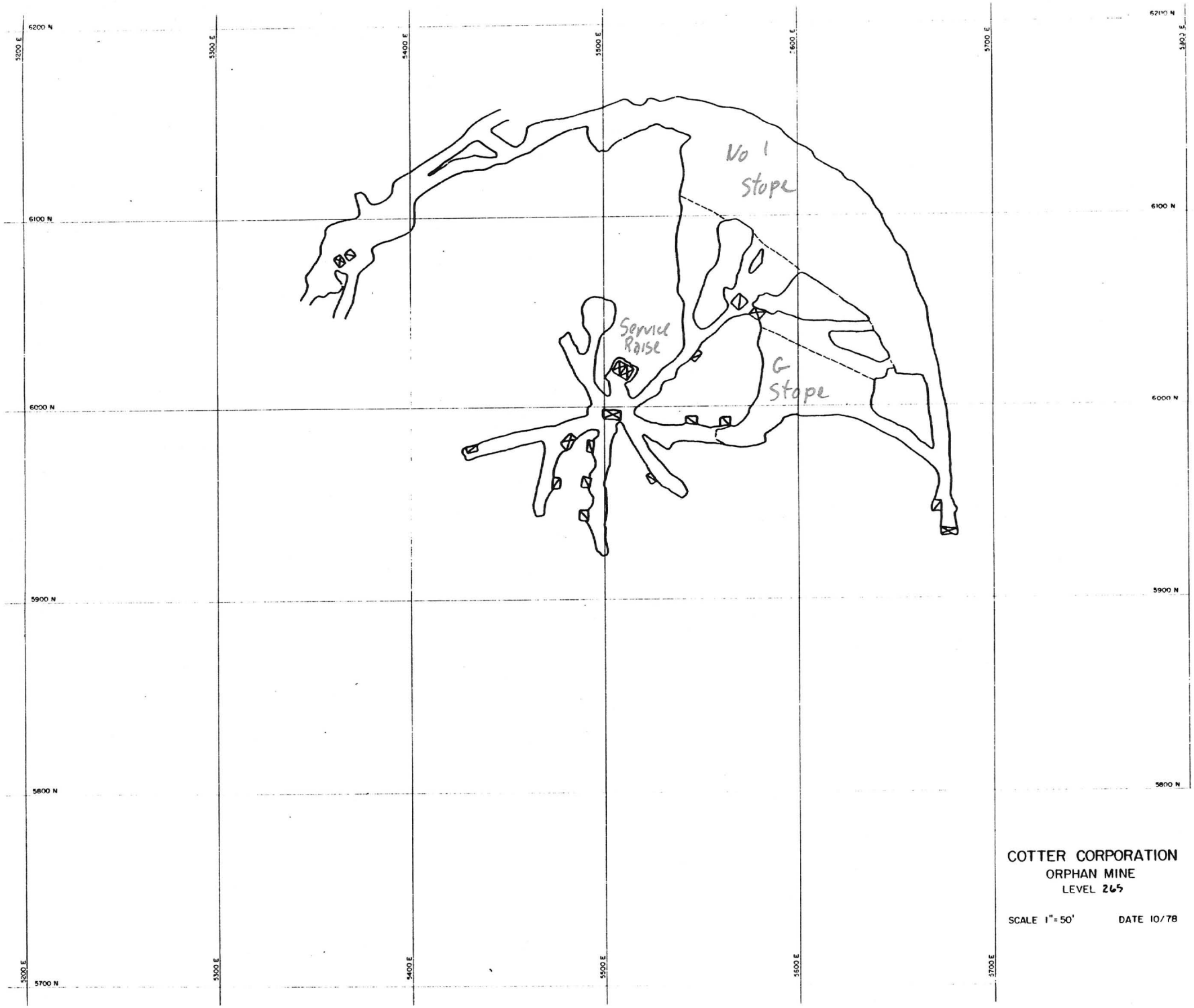


COTTER CORPORATION
ORPHAN MINE
LEVEL 24S

SCALE 1"=50' DATE 10/78

8



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ORPHAN MINE
LEVEL 265

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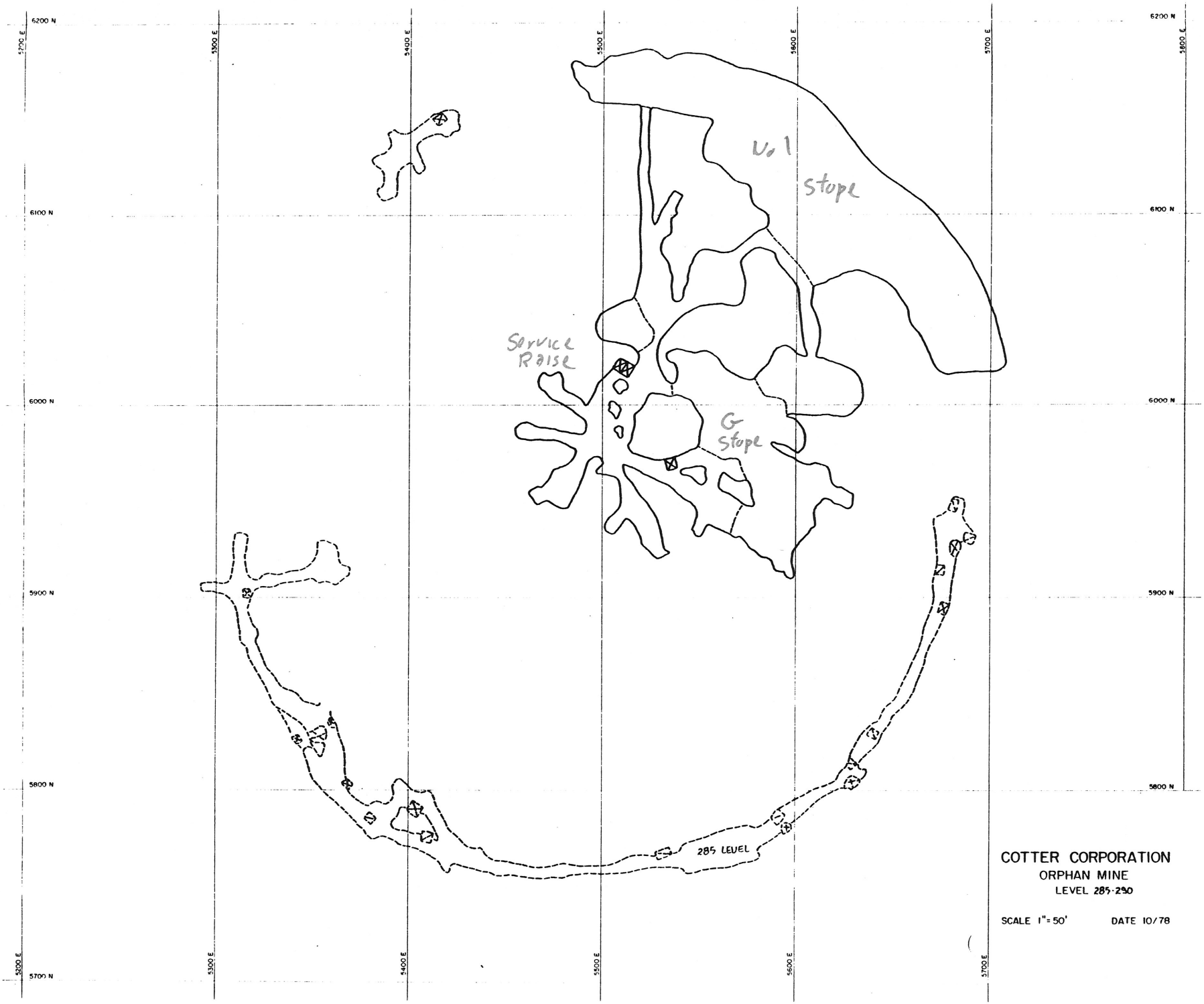

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ORPHAN MINE
LEVEL 285-290

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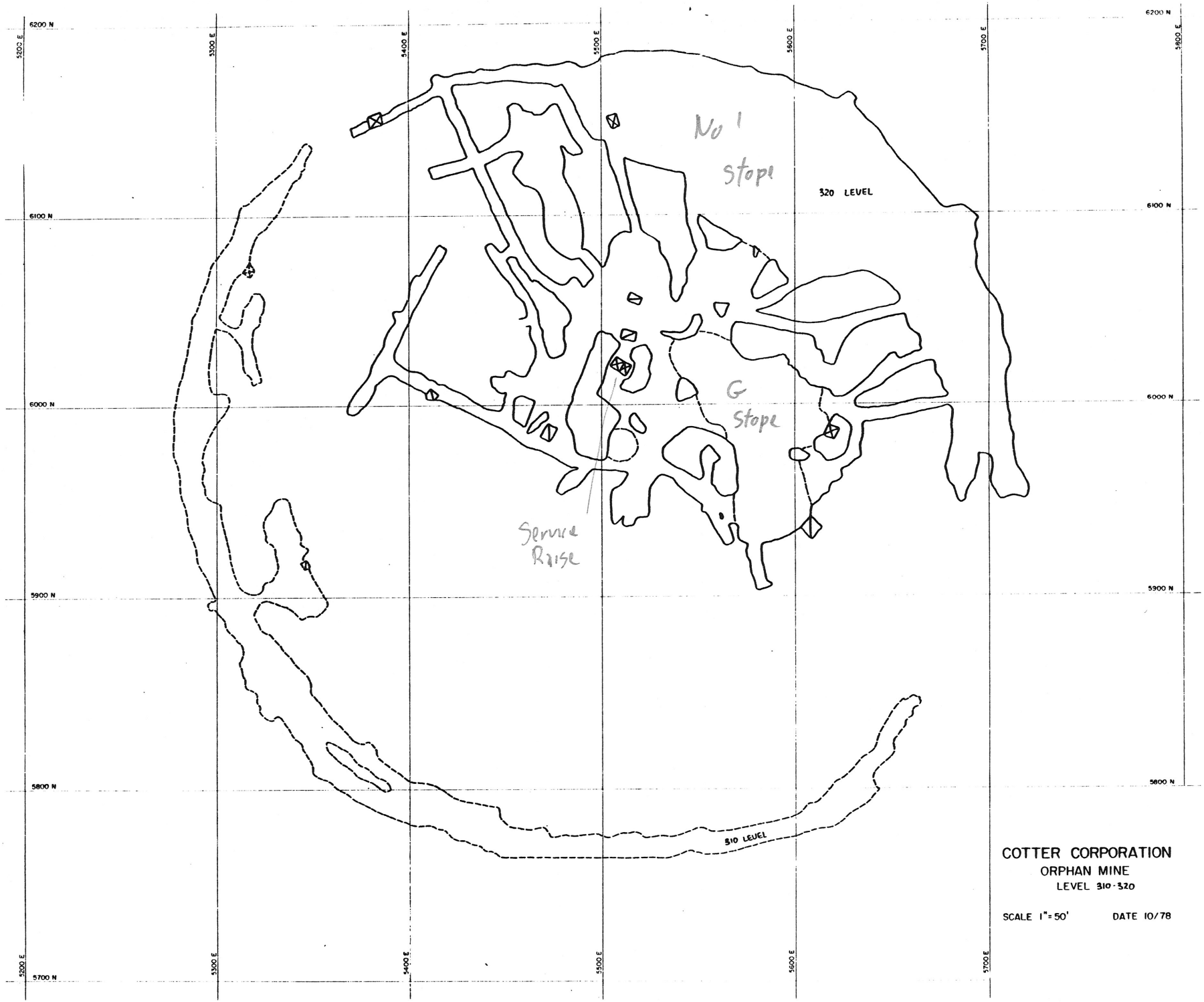

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ORPHAN MINE
LEVEL 310-320

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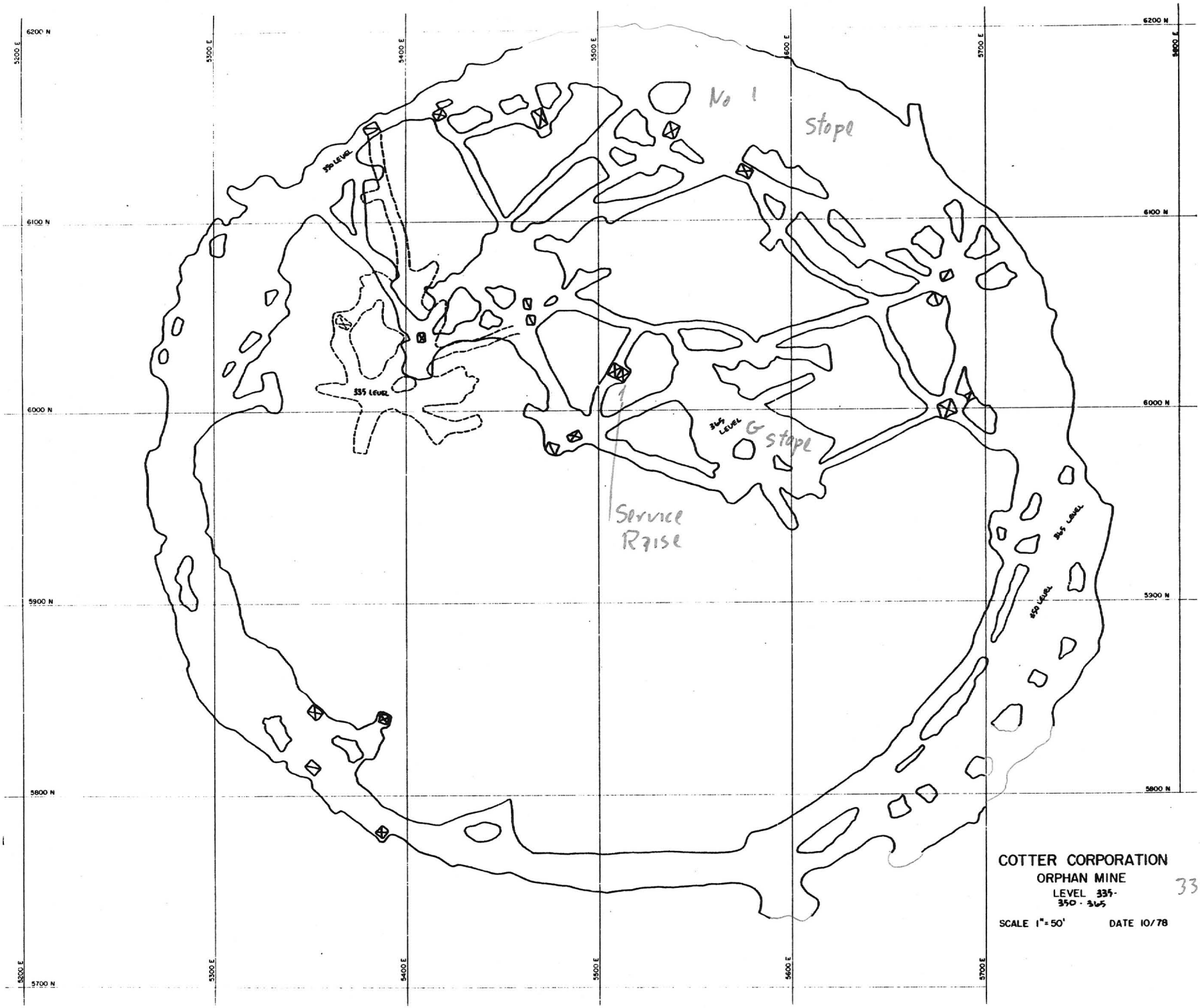
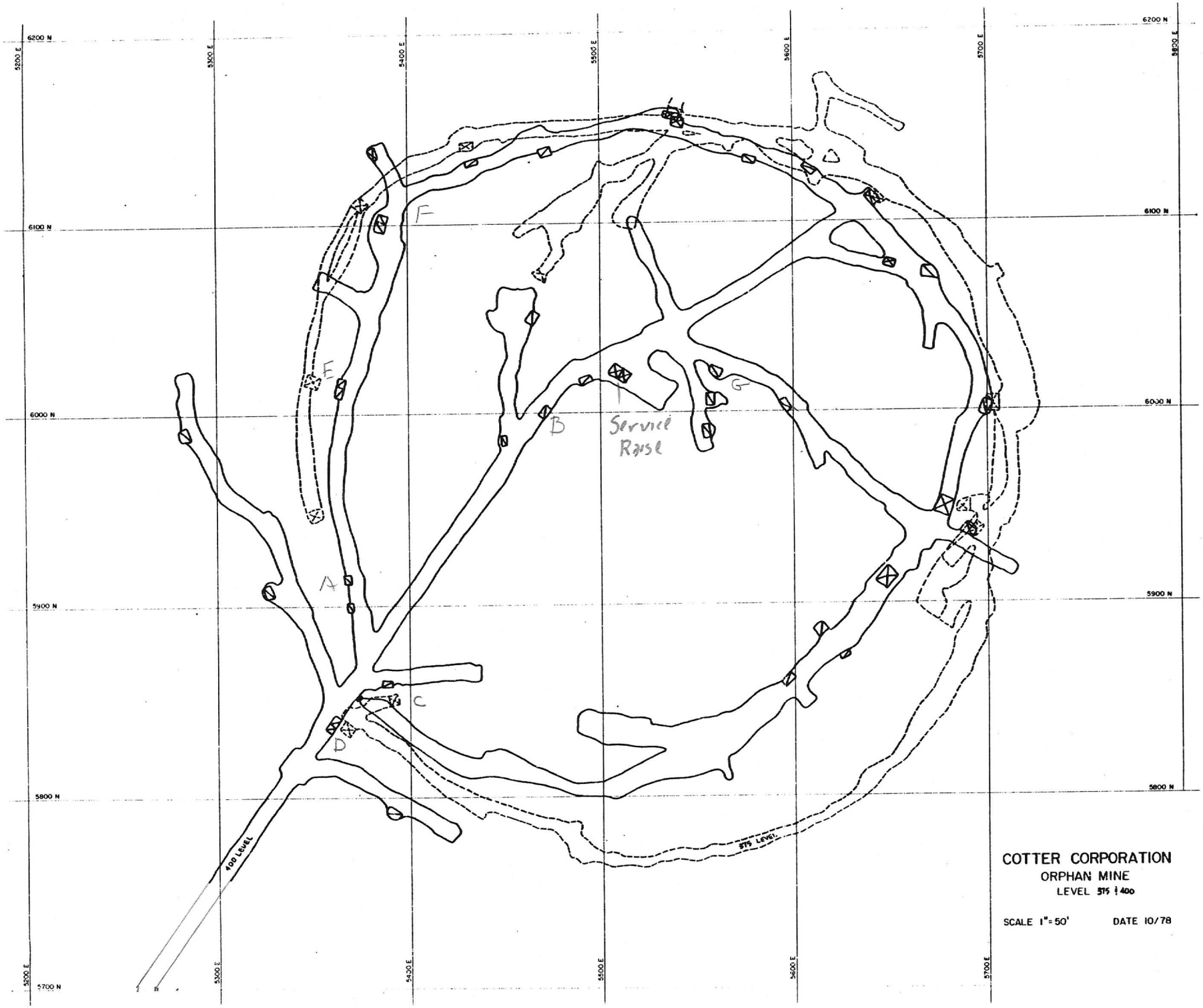


COTTER CORPORATION
ORPHAN MINE
LEVEL 335-
350 · 365

335, 350, 365

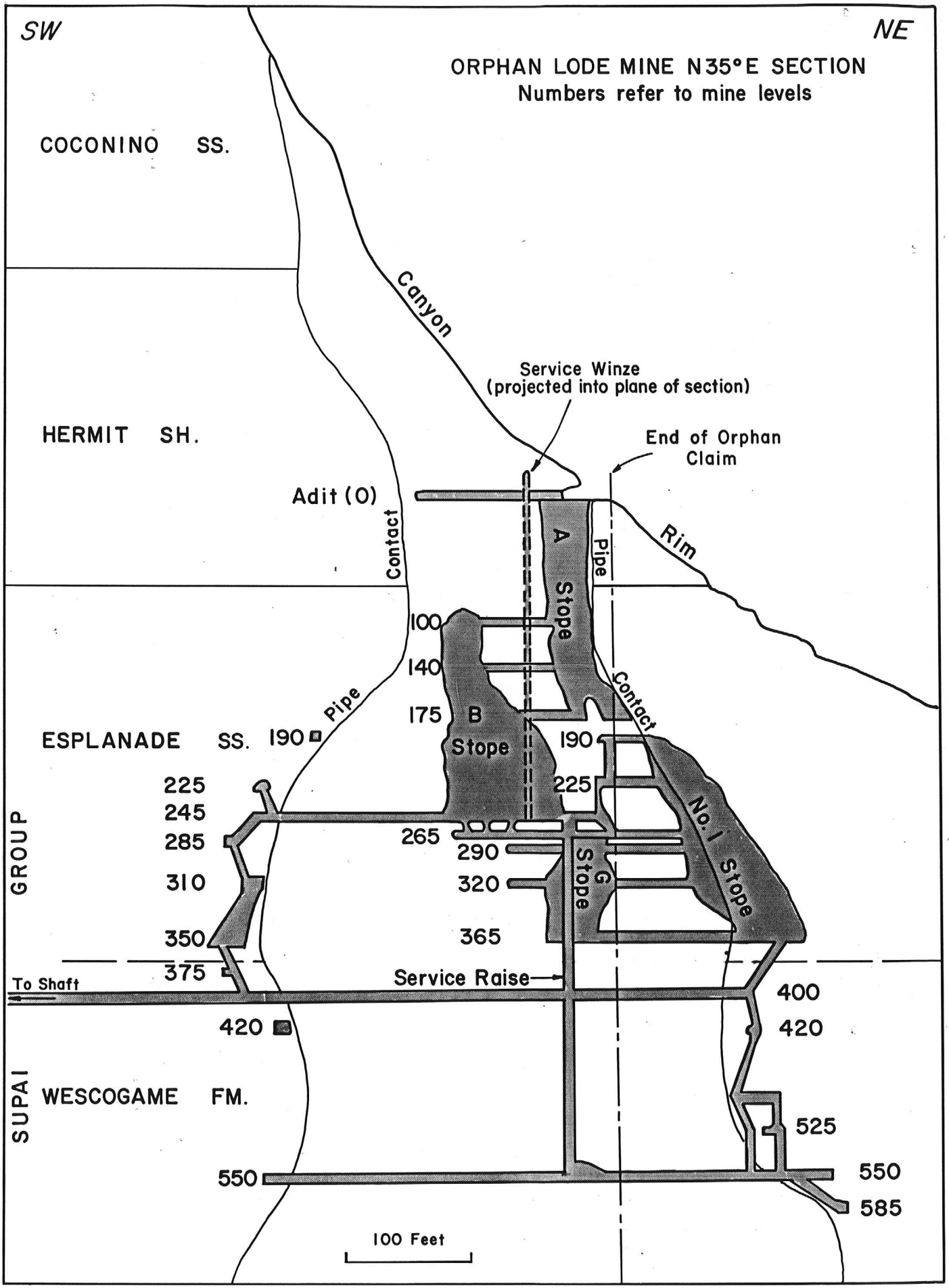
SCALE 1"=50' DATE 10/78

12



COTTER CORPORATION
ORPHAN MINE
LEVEL 575 & 400

SCALE 1"=50' DATE 10/78


SW
NE
ORPHAN LODE MINE N35°E SECTION
Numbers refer to mine levels
COCONINO SS.
HERMIT SH.
ESPLANADE SS.
SUPAI GROUP
WESCOGAME FM.
Canyon
Service Winze
(projected into plane of section)
End of Orphan Claim
Adit (O)
Contact
Pipe
Rim
A Stope
B Stope
G Stope
No. 1 Stope
100
140
175
190
225
245
265
285
290
310
320
350
365
375
400
420
525
550
585
To Shaft
Service Raise
100 Feet

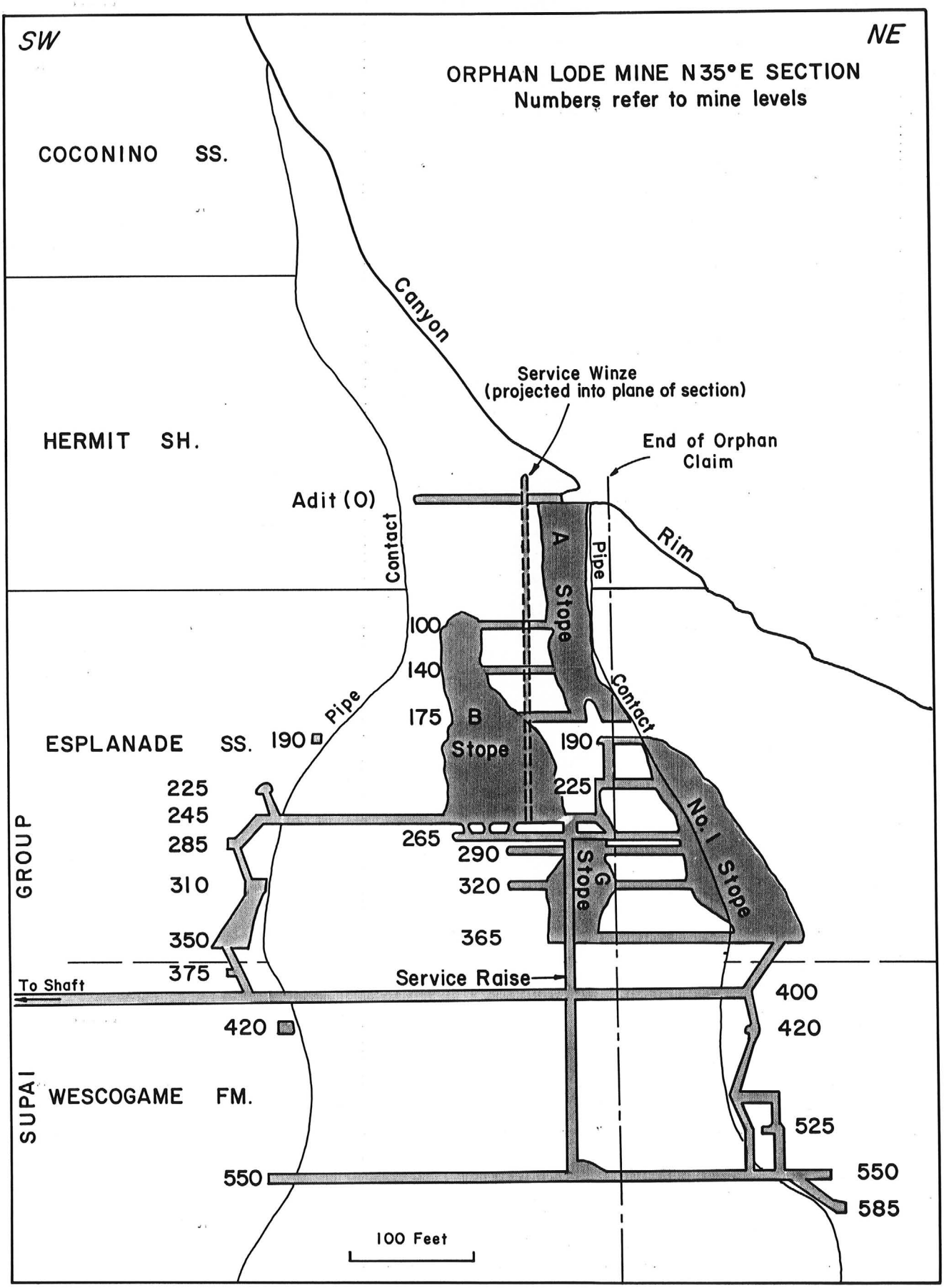


Figure 5. Cross Section, Orphan Lode Mine (Modified from Gornitz and Kerr, 1970)

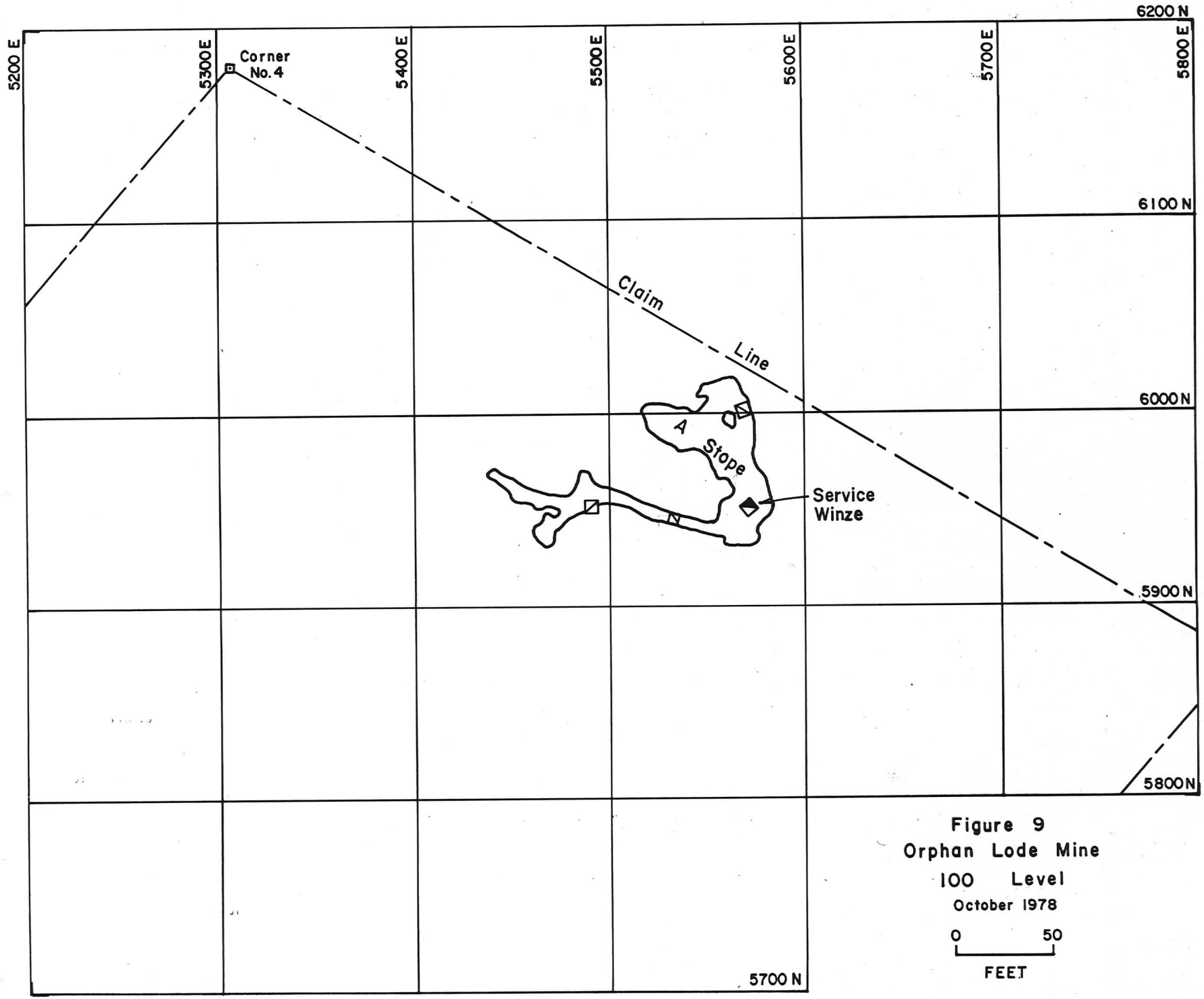


Figure 9
Orphan Lode Mine
100 Level
October 1978

0 50
FEET

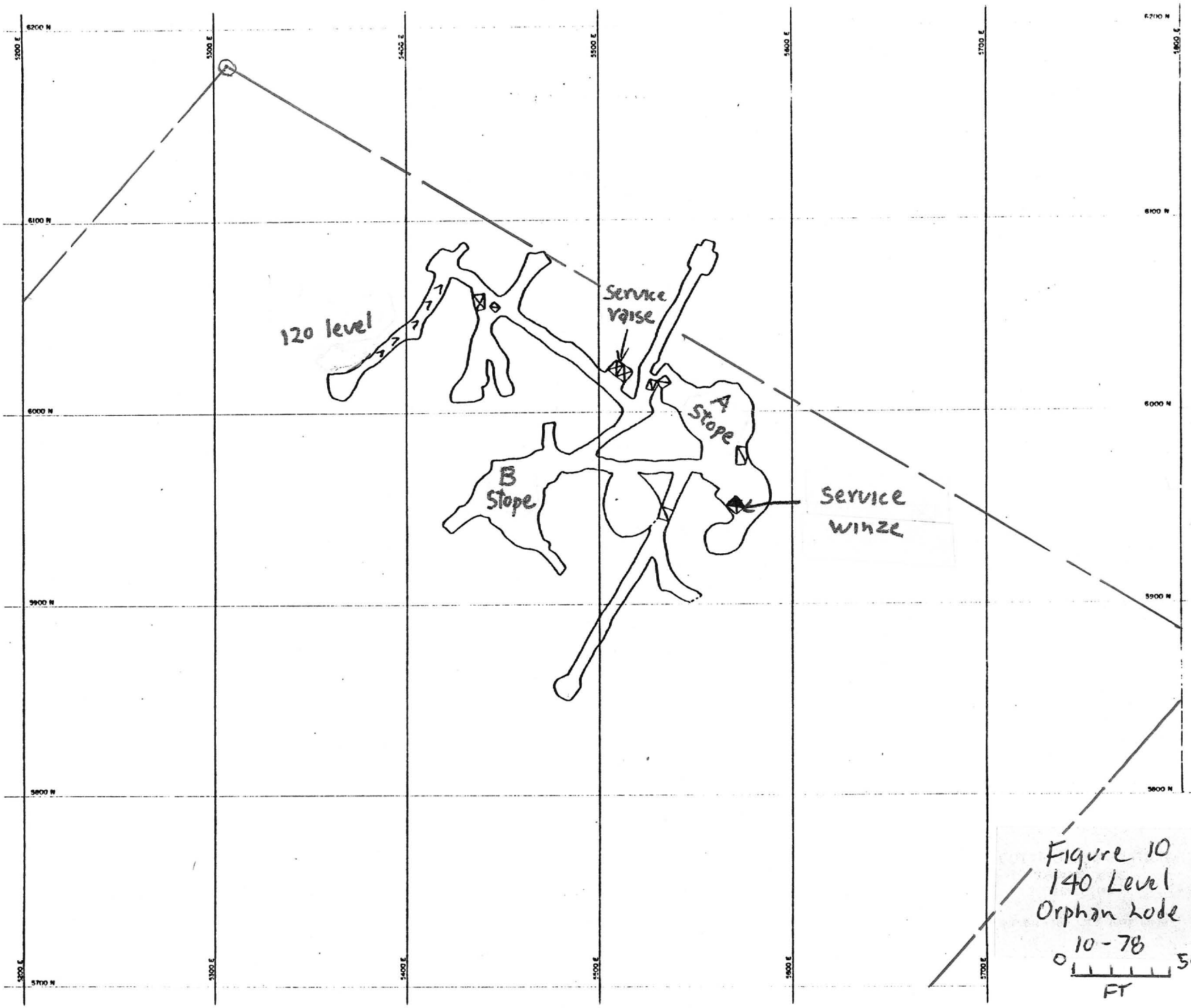


Figure 10
140 Level
Orphan Lode
10-78

AL

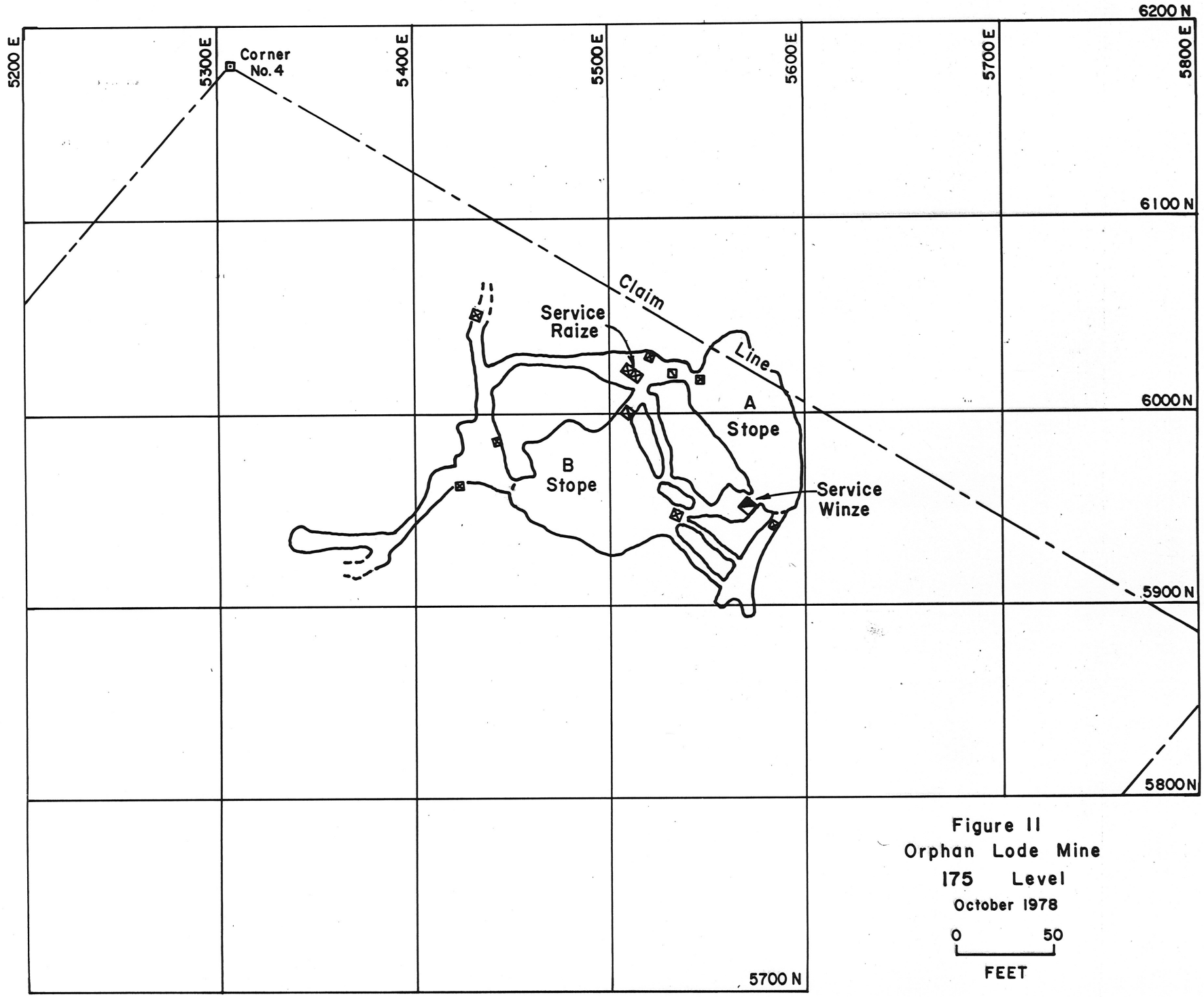


Figure 11
Orphan Lode Mine
175 Level
October 1978

0 50
FEET

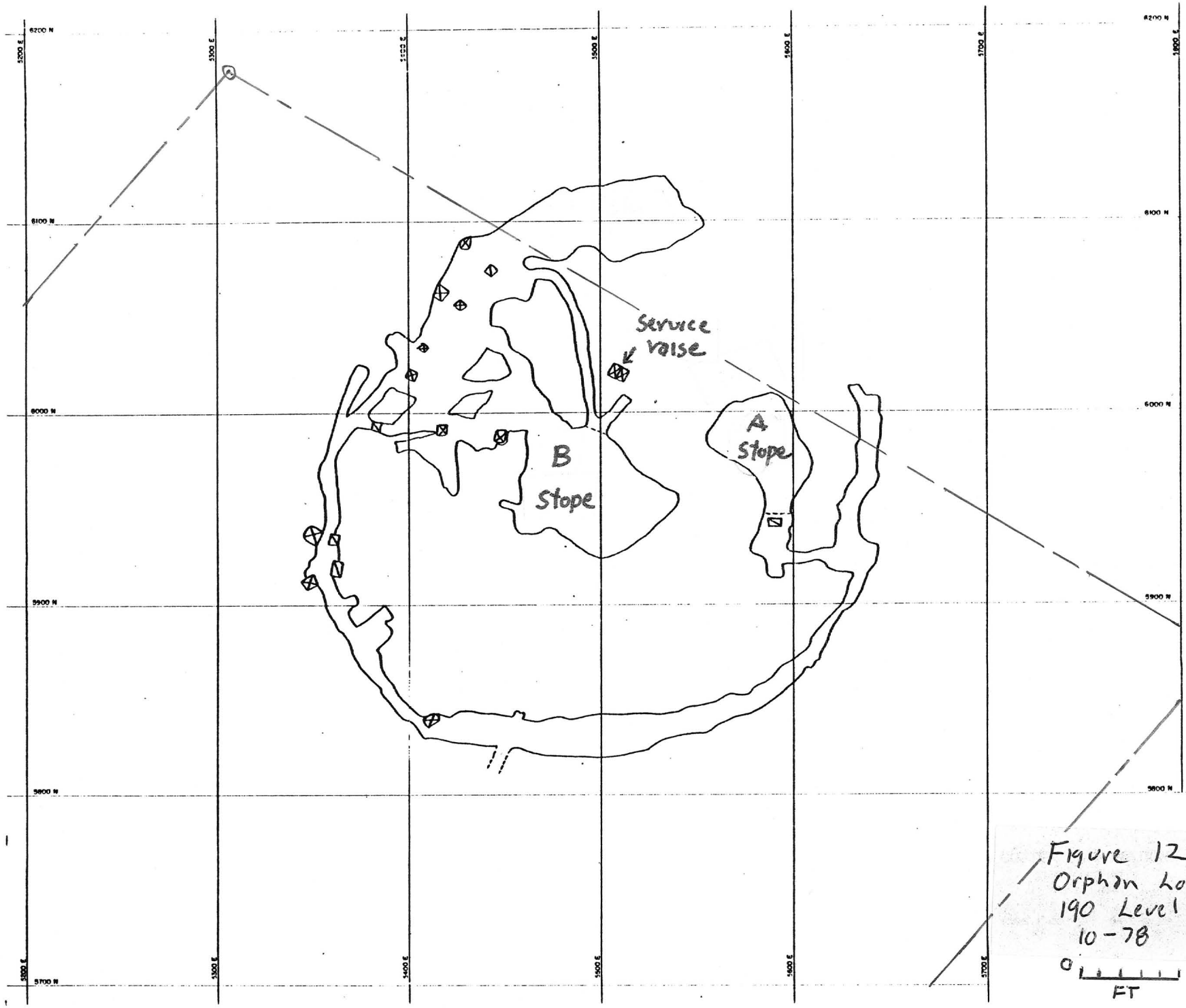


Figure 12
Orphan Lode
190 Level
10-78

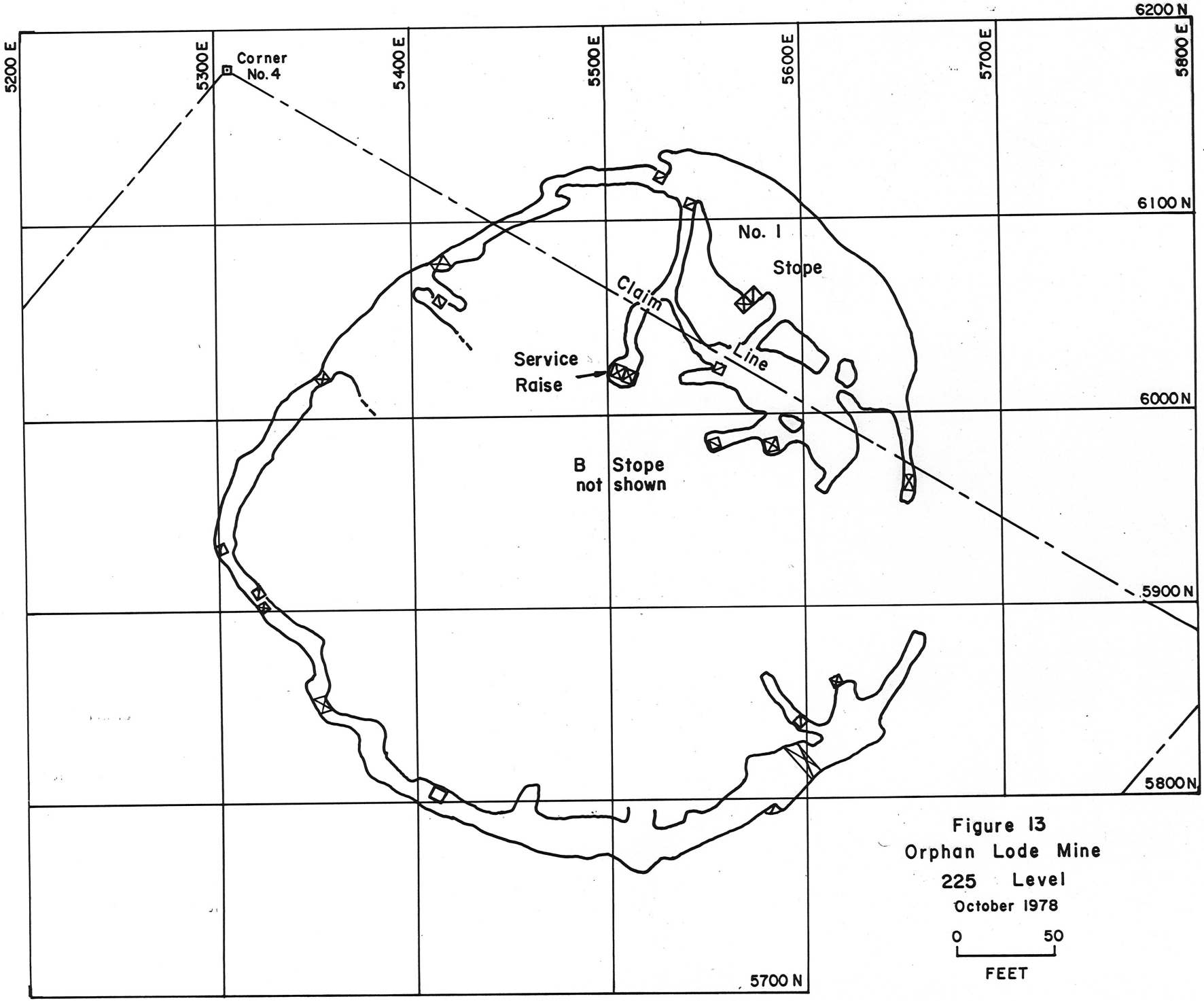


Figure 13
Orphan Lode Mine
225 Level
October 1978

0 50
FEET

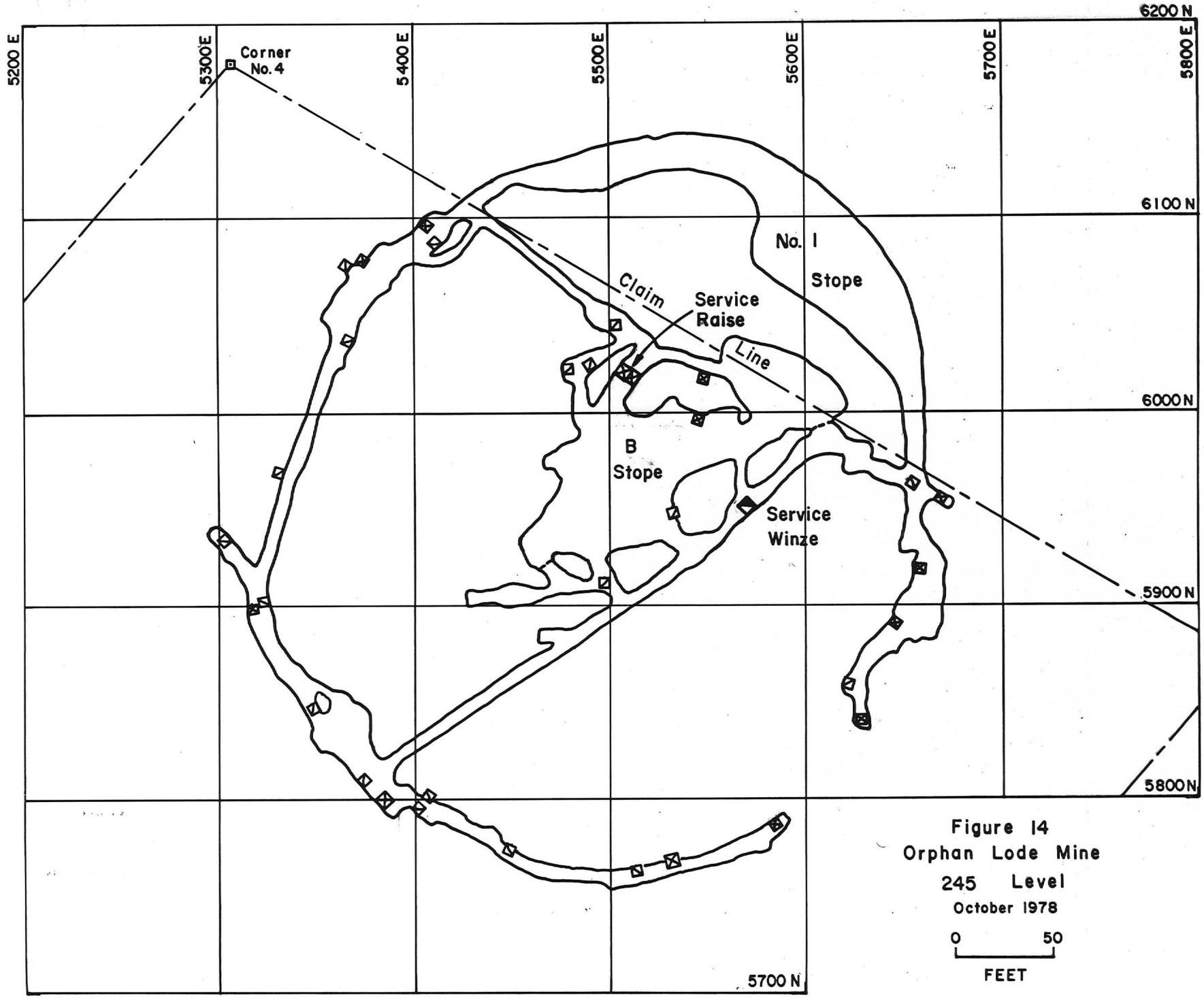


Figure 14
Orphan Lode Mine
245 Level
October 1978

0 50
FEET

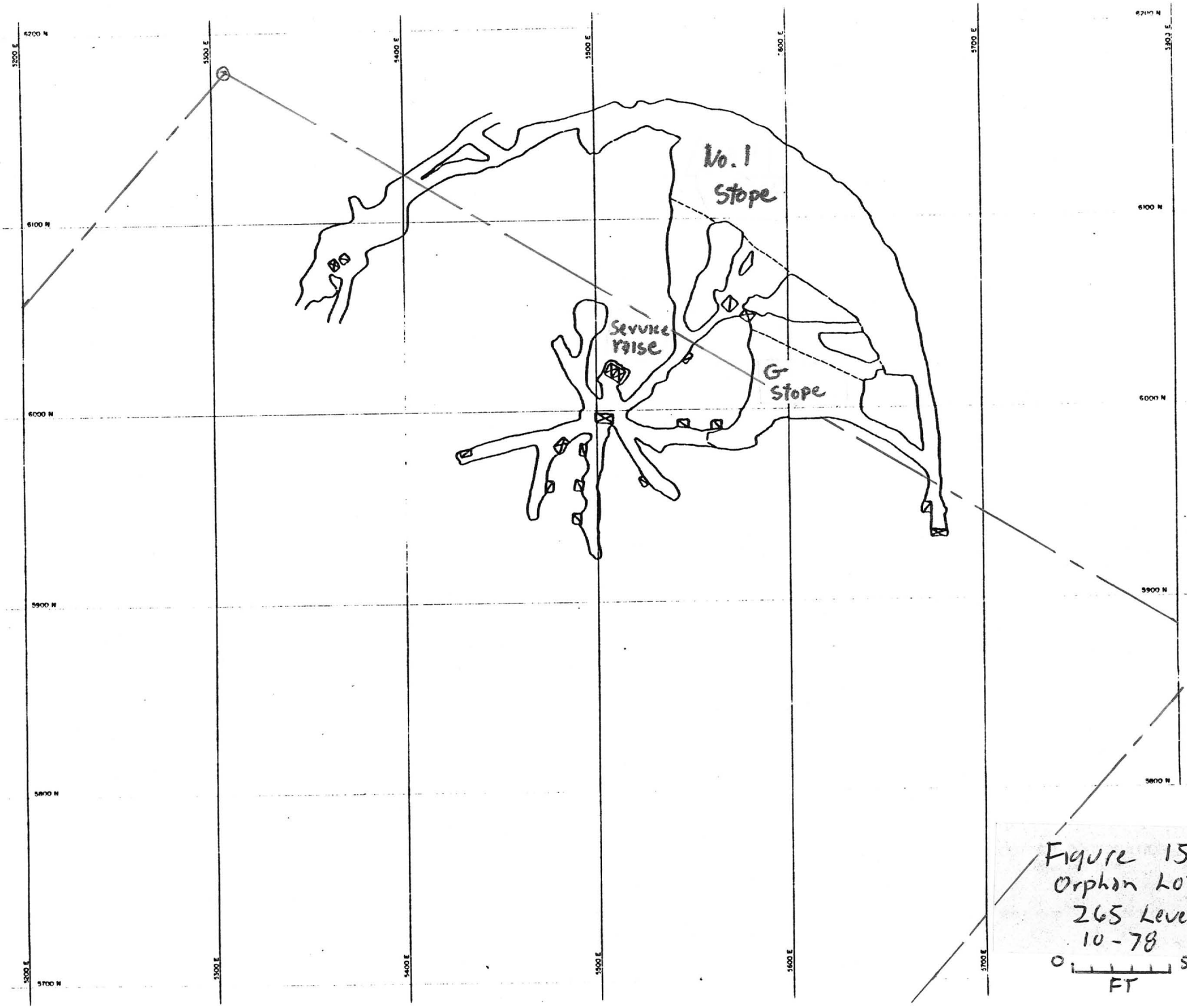


Figure 15
Orphan Lode
265 Level
10-78

0 50
FT

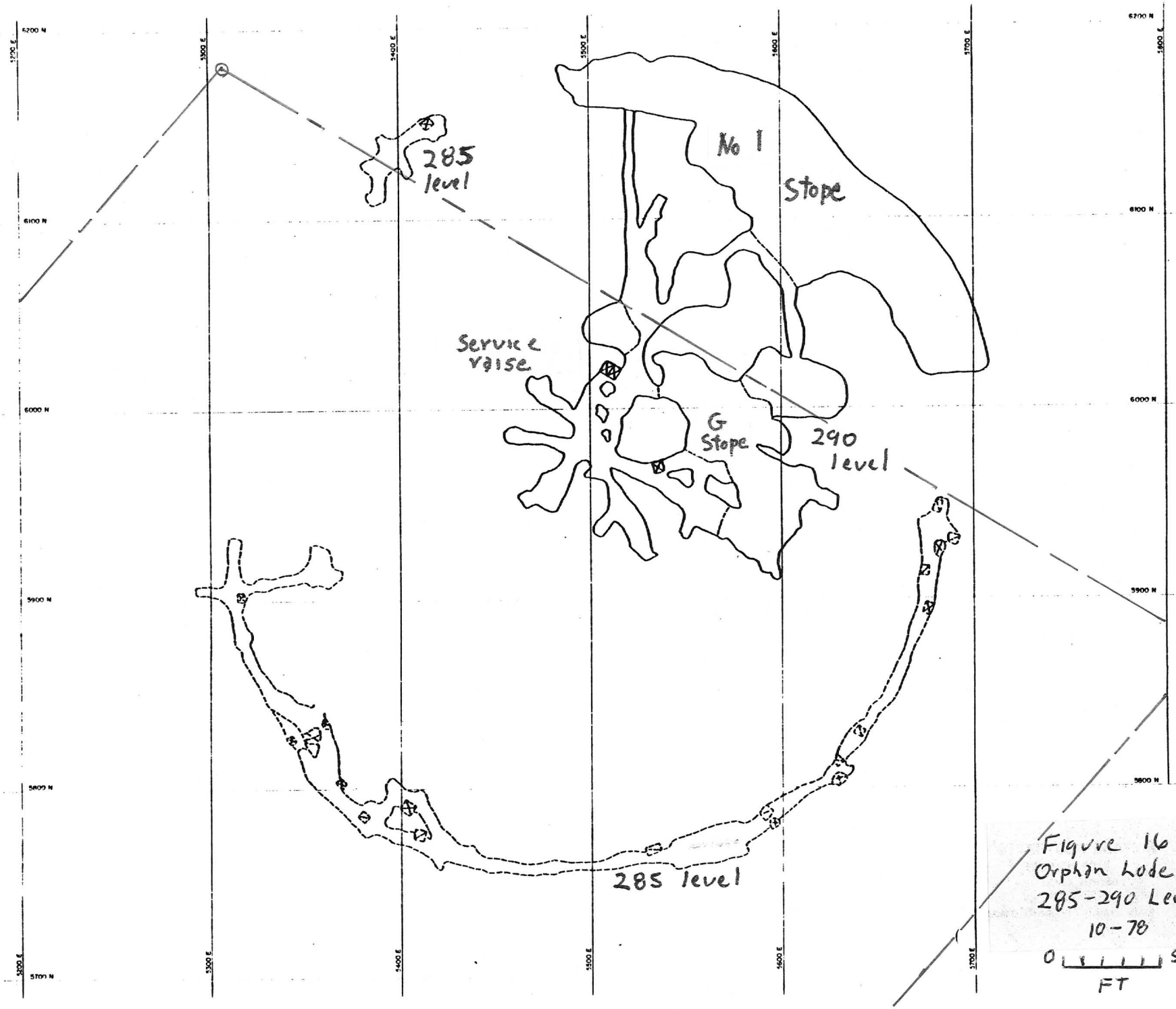


Figure 16
Orphan Lode
285-290 Levels
10-78

0 50
FT

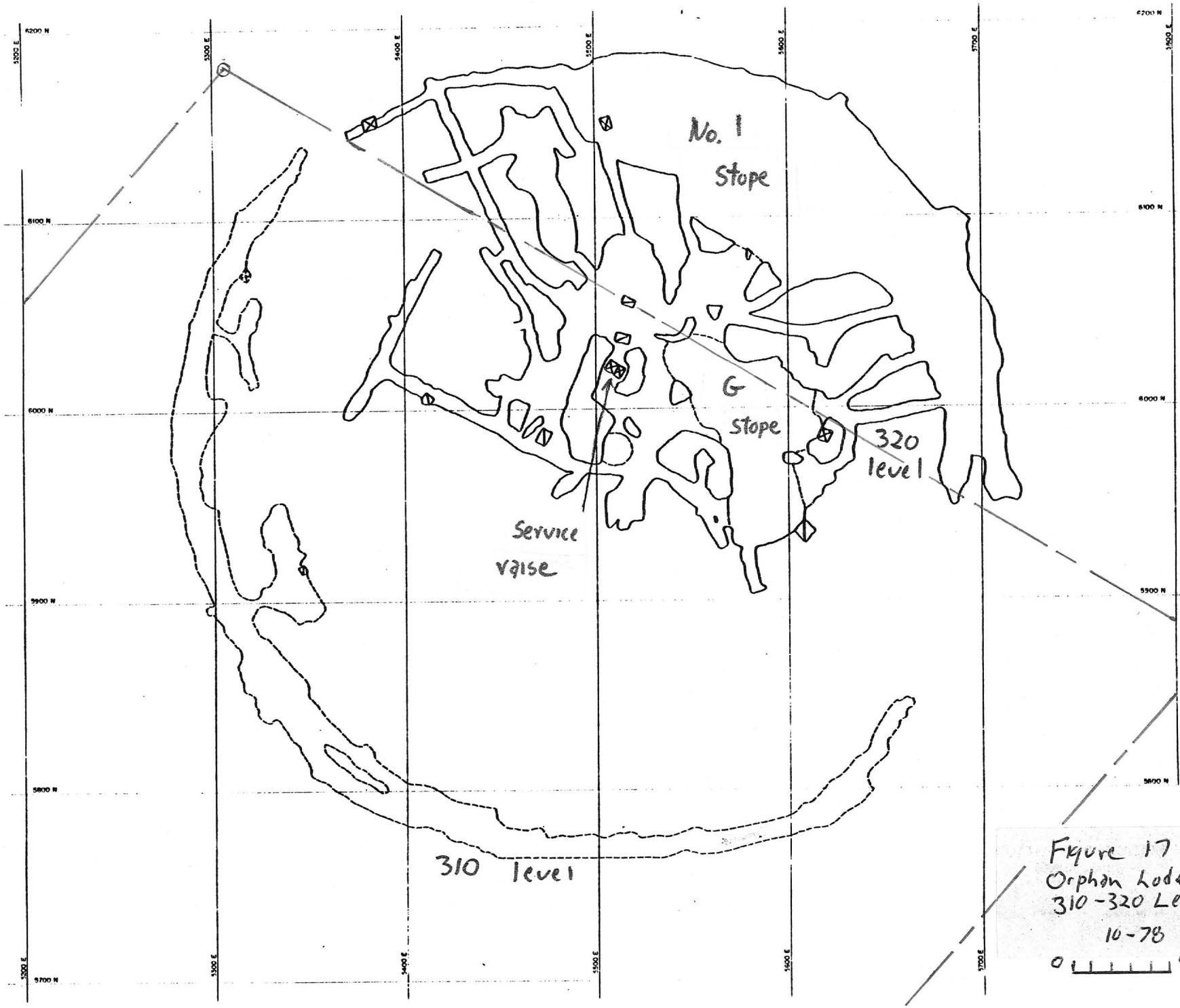


Figure 17
Orphan Lode
310-320 Levels
10-78
0 50

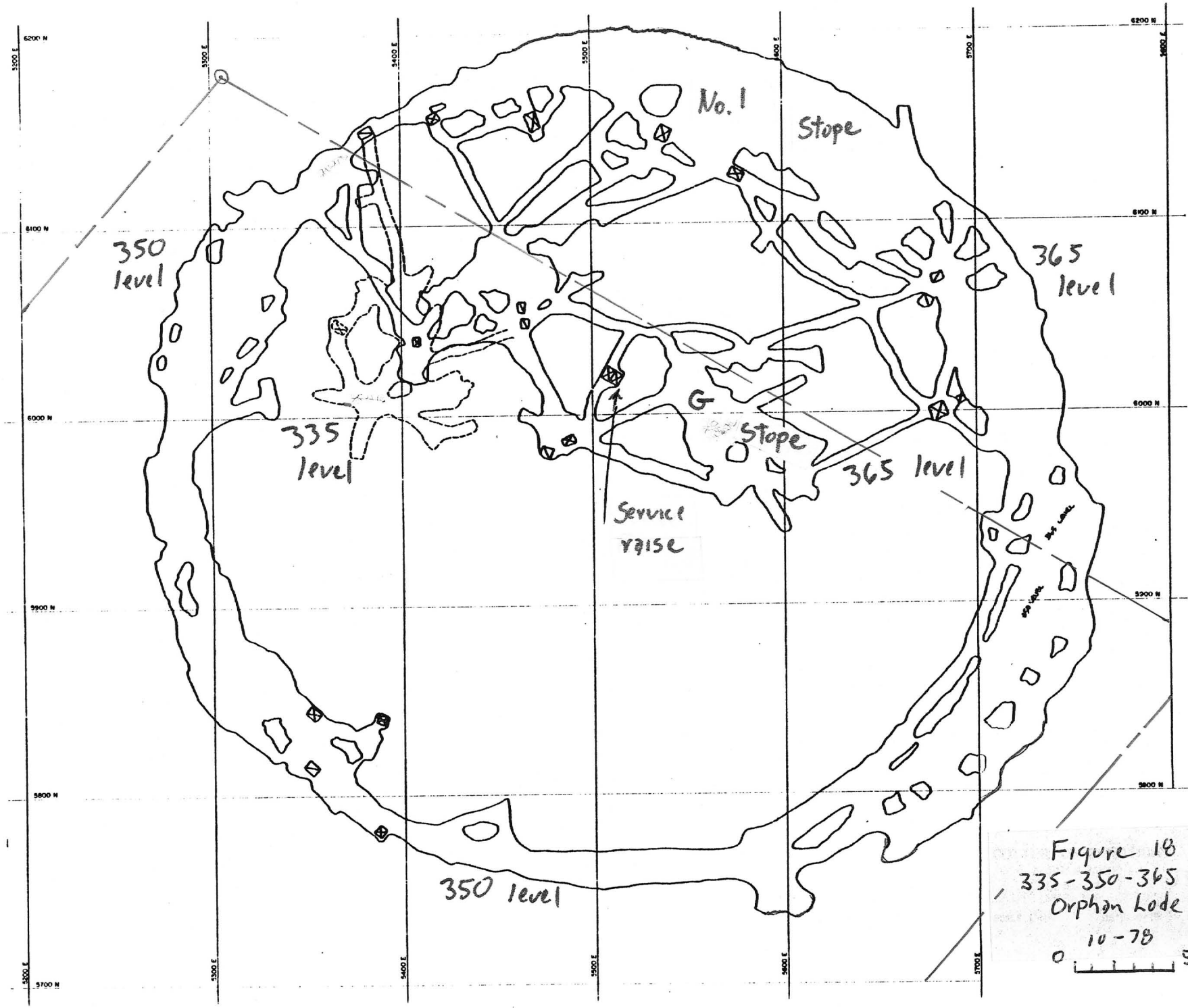


Figure 18
335-350-365 Levels
Orphan Lode
10-78
0 50

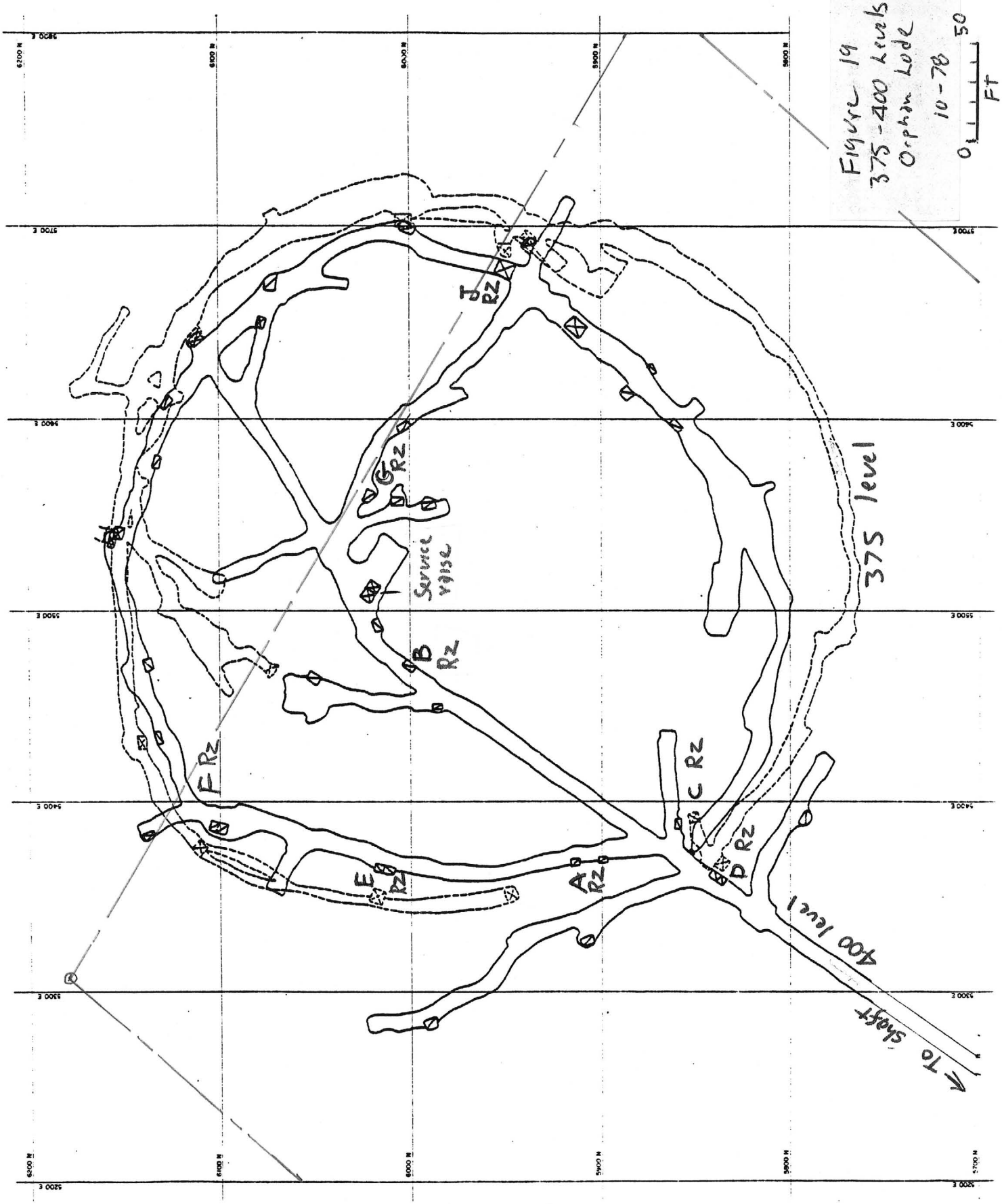


Figure 19
375-400 Levels
Orphan Lode
10-78
0
50
FT
375 level
400 level
To shaft
Service raise
A Rz
B Rz
C Rz
D Rz
E Rz
F Rz
G Rz
J Rz

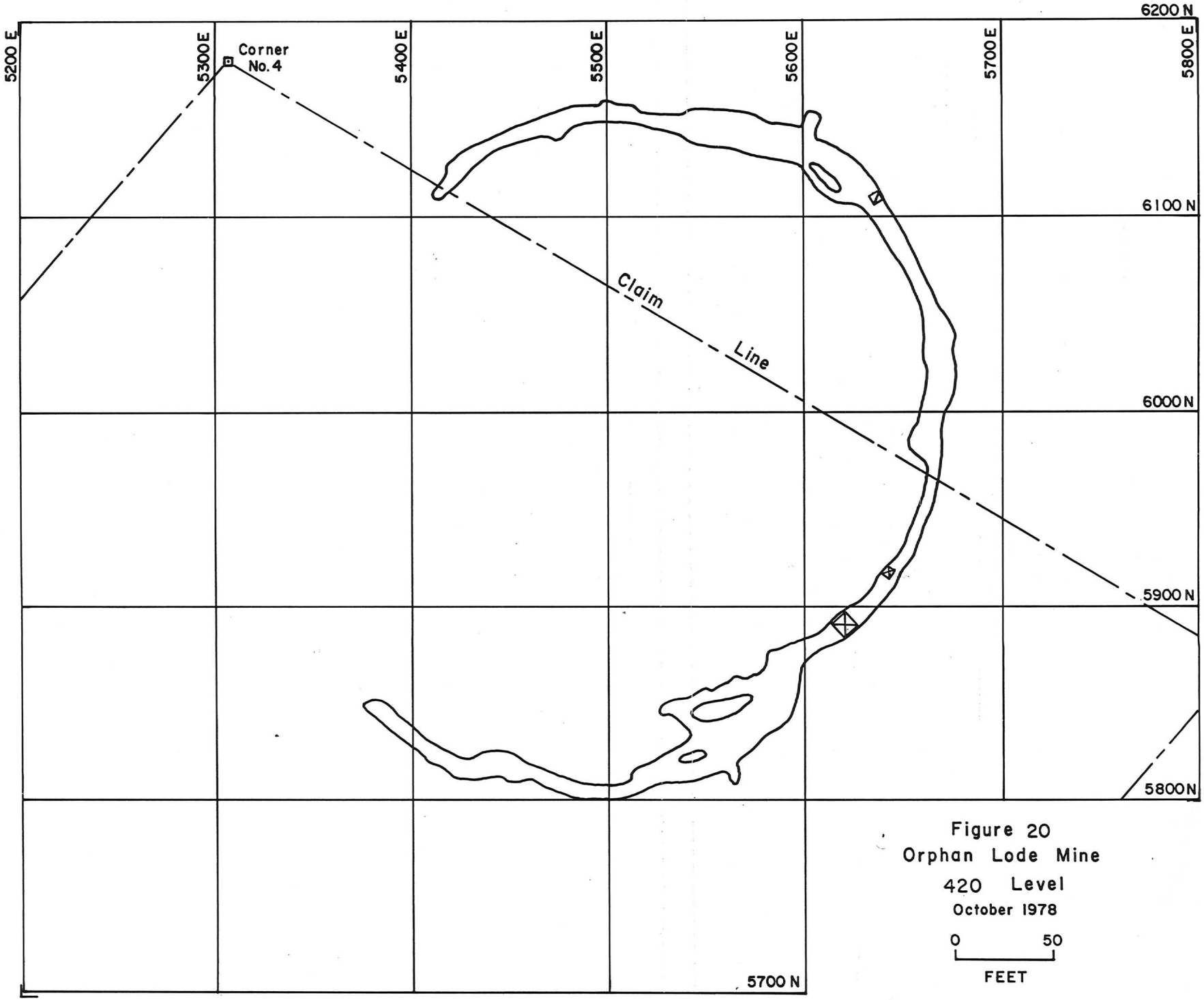


Figure 20
Orphan Lode Mine
420 Level
October 1978

0 50
FEET

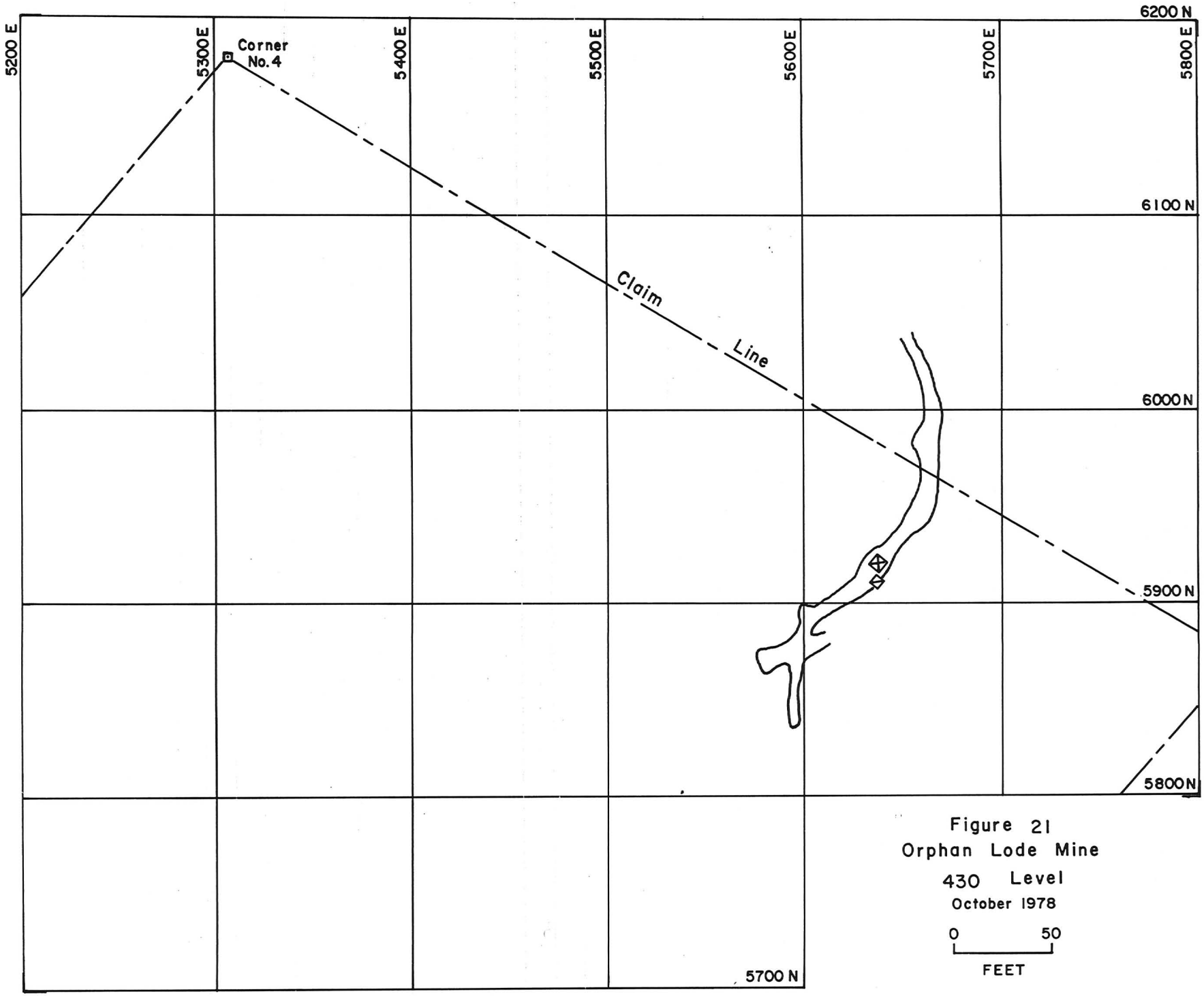


Figure 21
Orphan Lode Mine
430 Level
October 1978

0 50
FEET

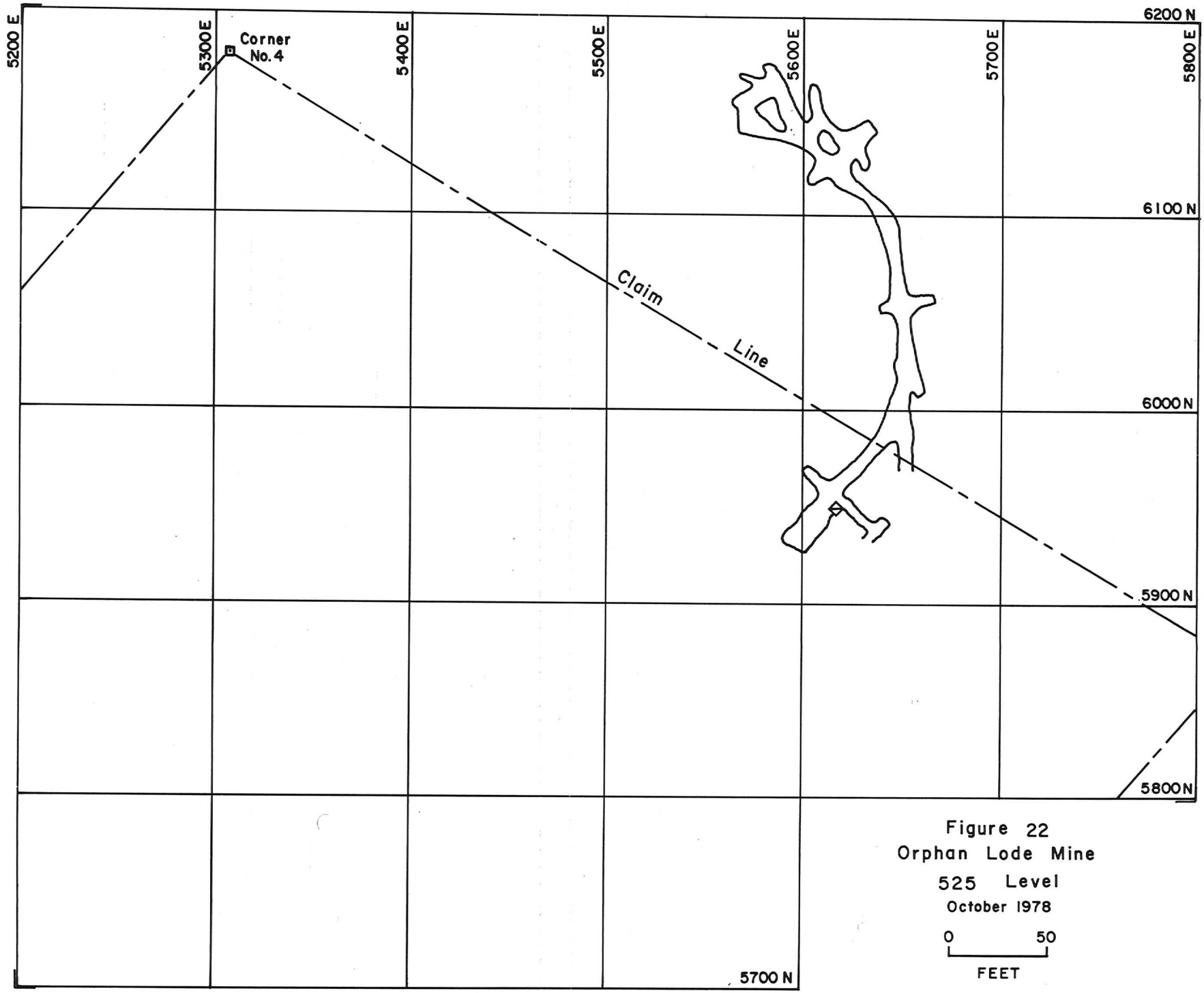


Figure 22
Orphan Lode Mine
525 Level
October 1978

0 50
FEET

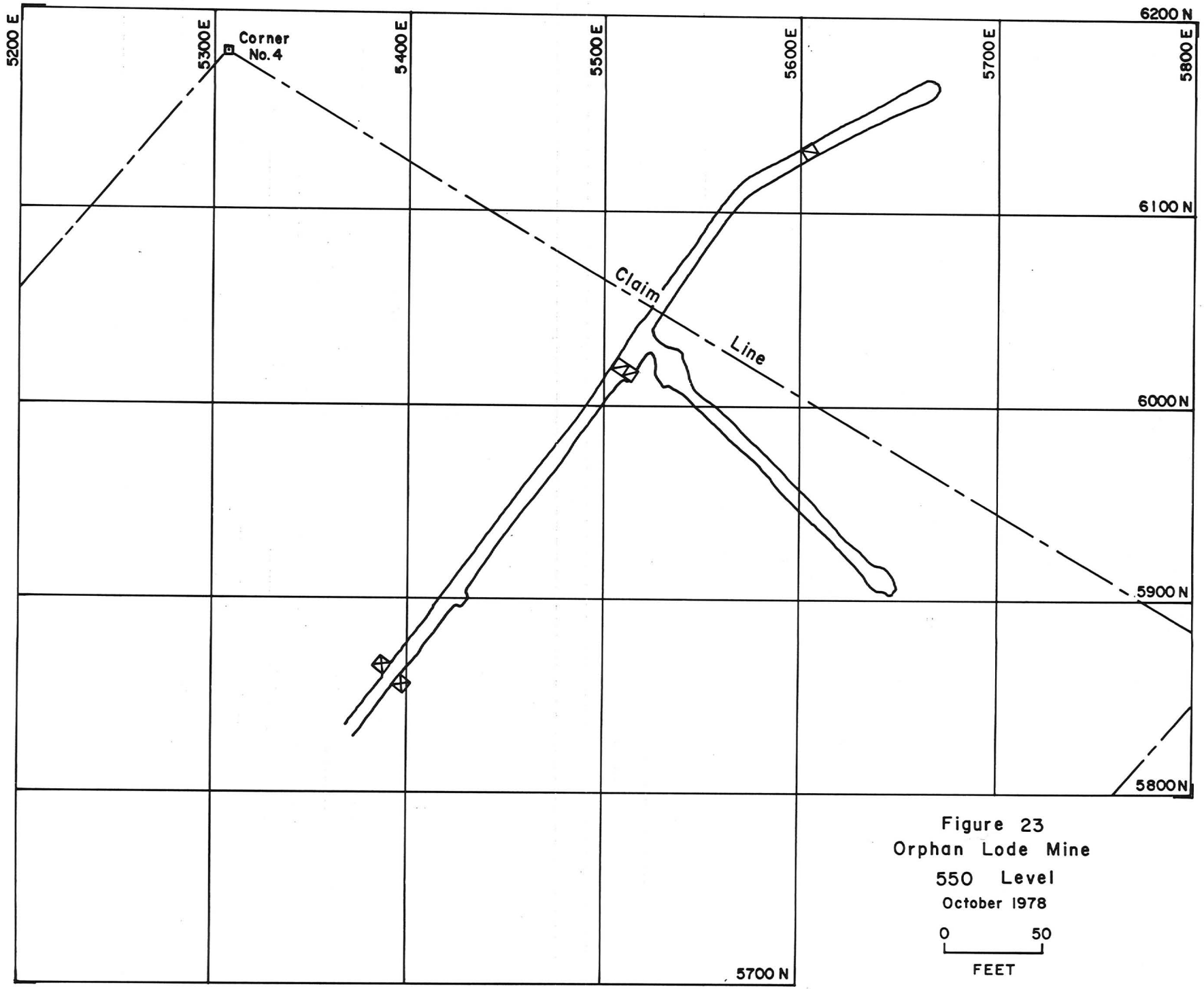


Figure 23
Orphan Lode Mine
550 Level
October 1978

0 50
FEET

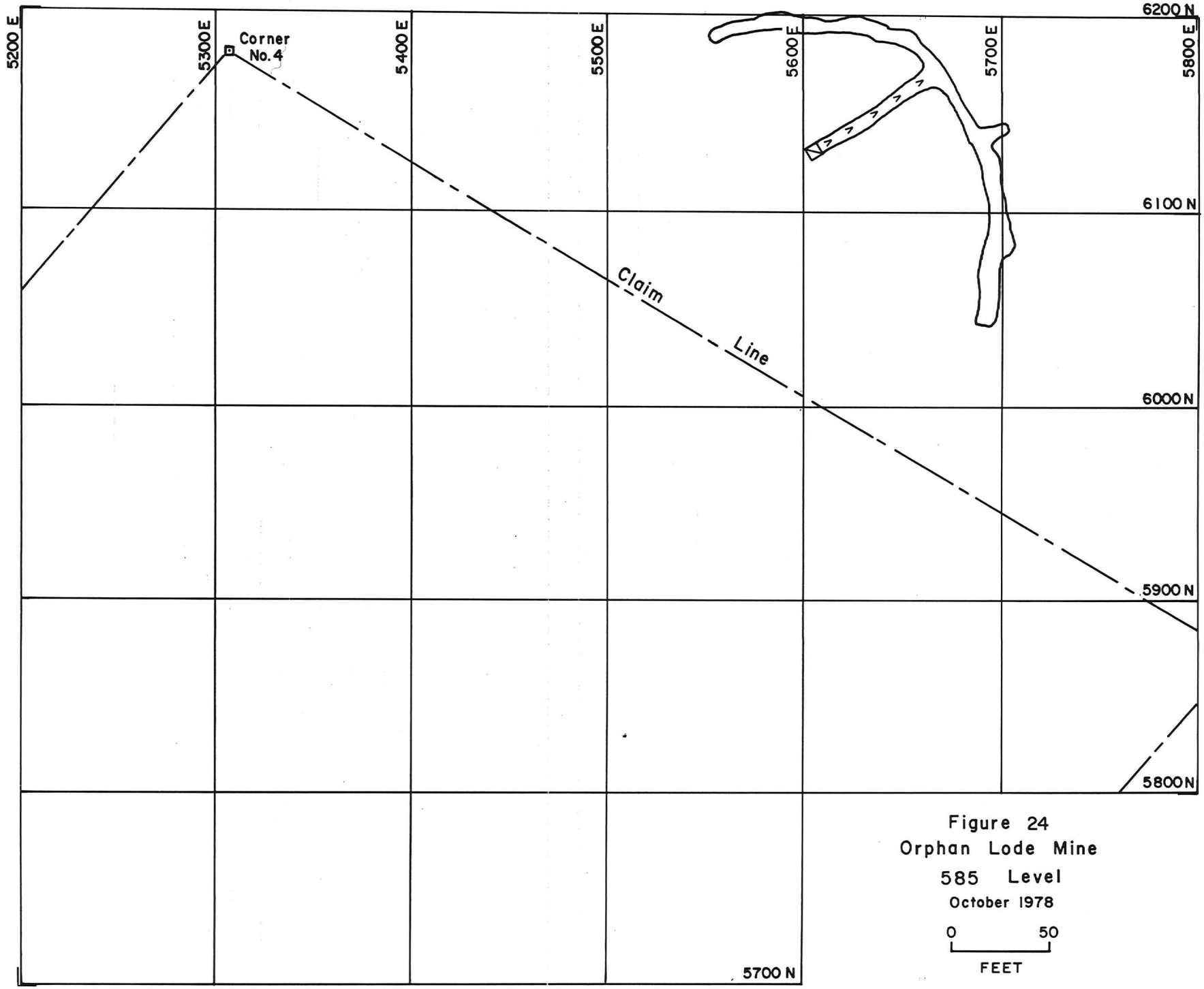
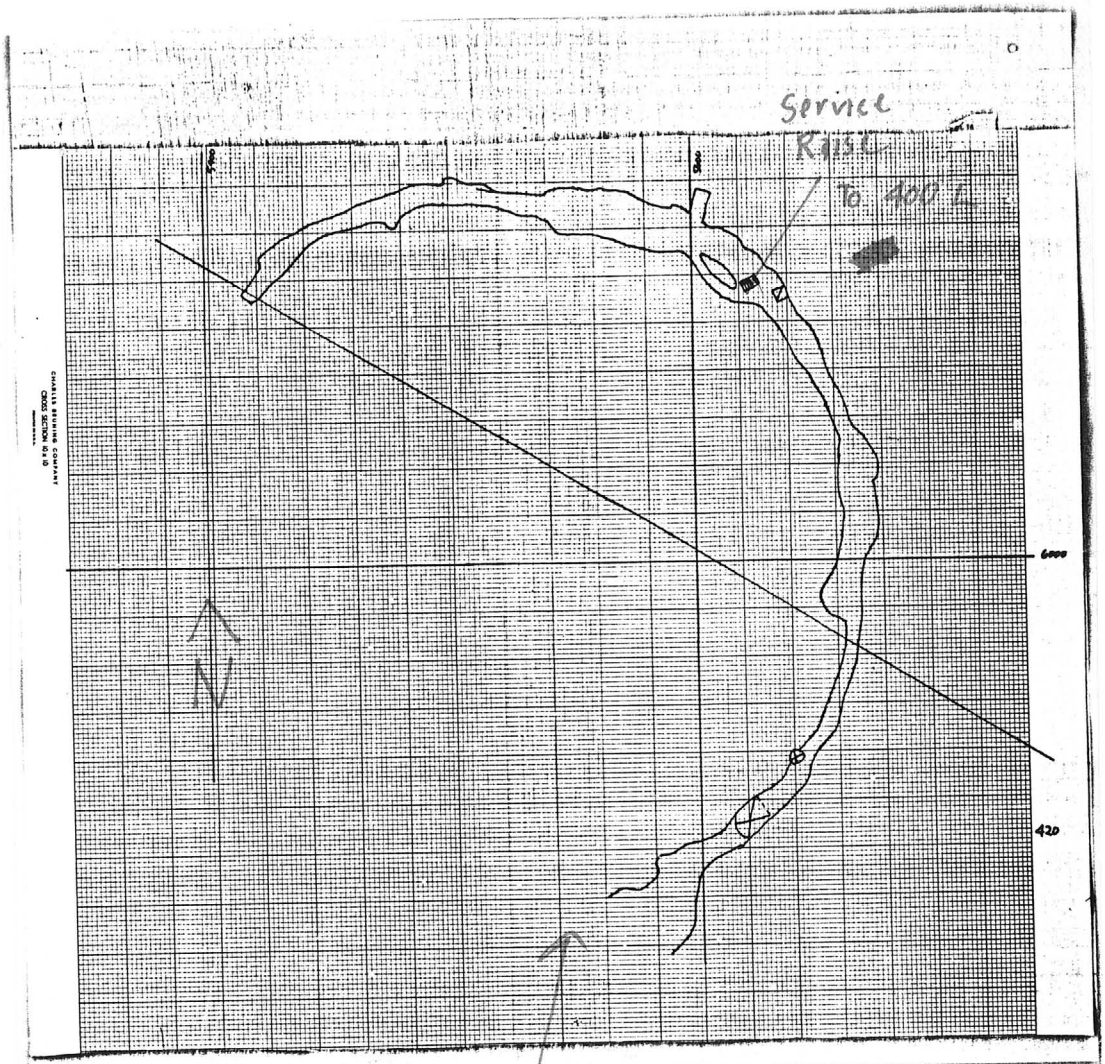


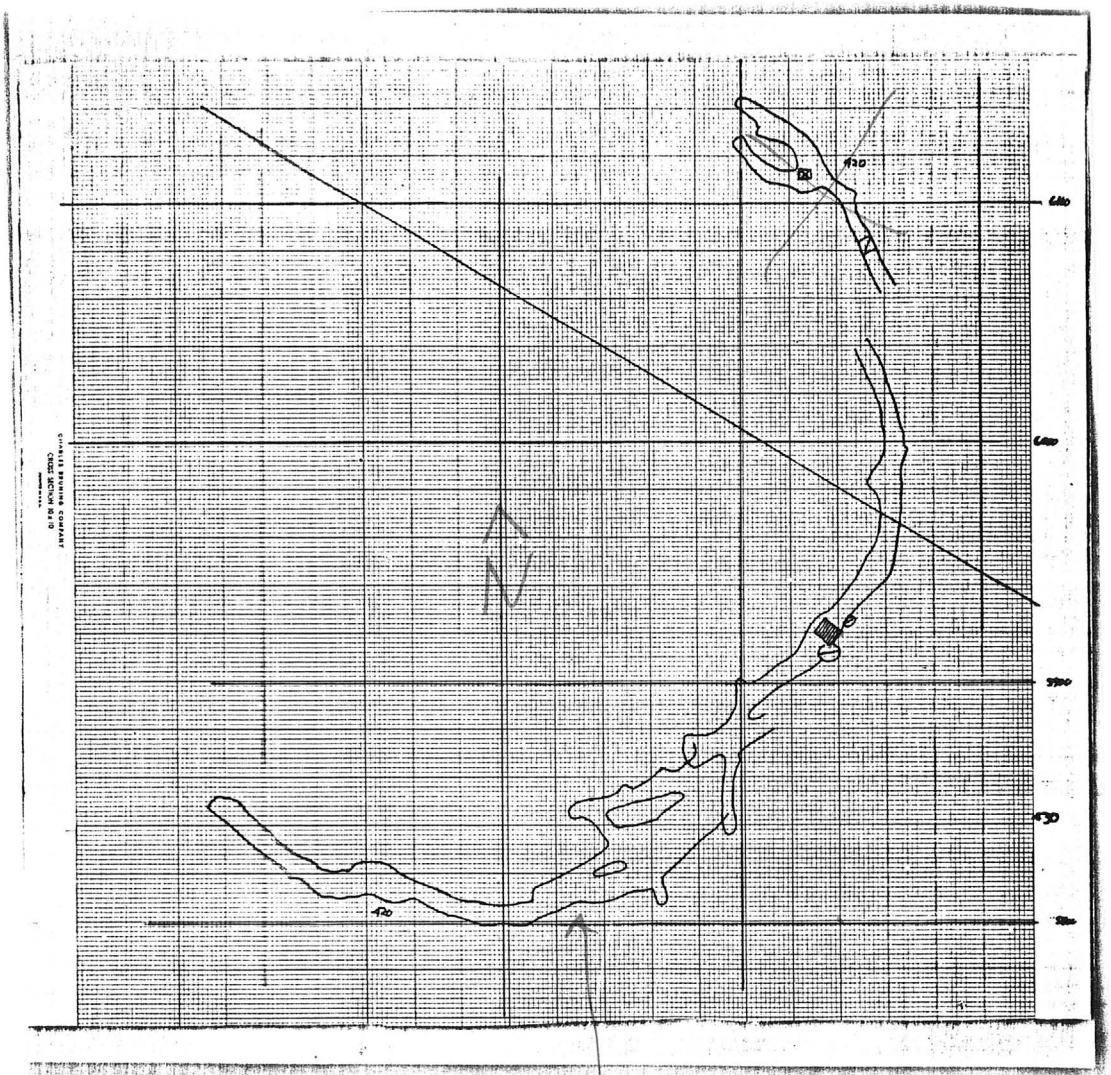
Figure 24
Orphan Lode Mine
585 Level
October 1978

0 50
FEET



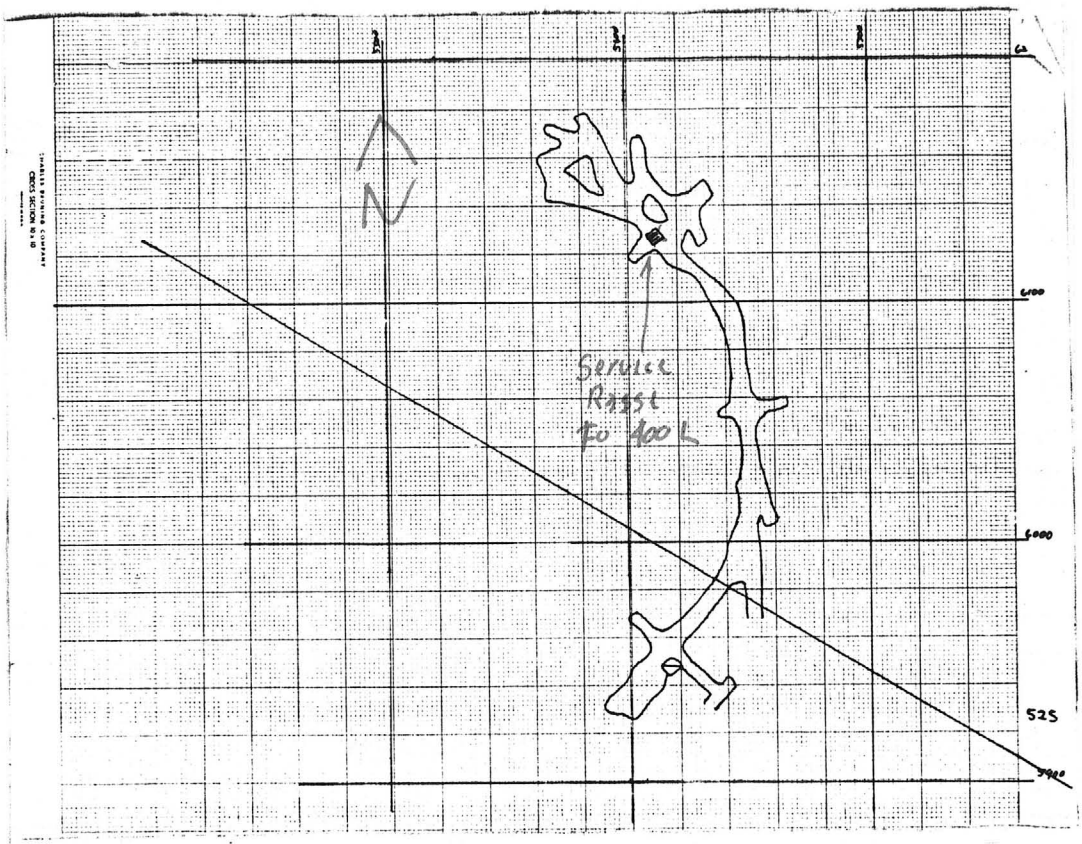
420 Level

add
from
430 Level map

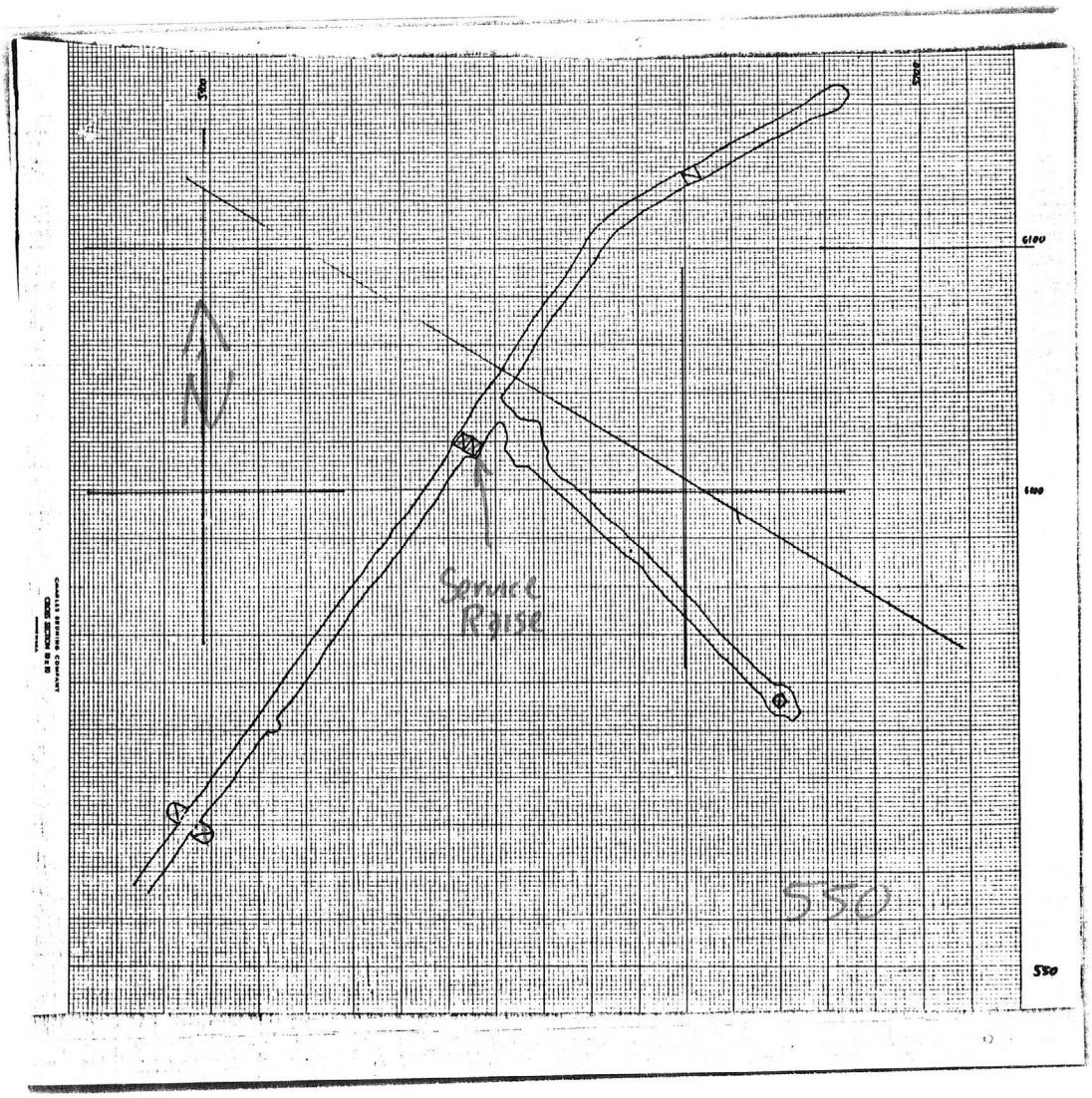


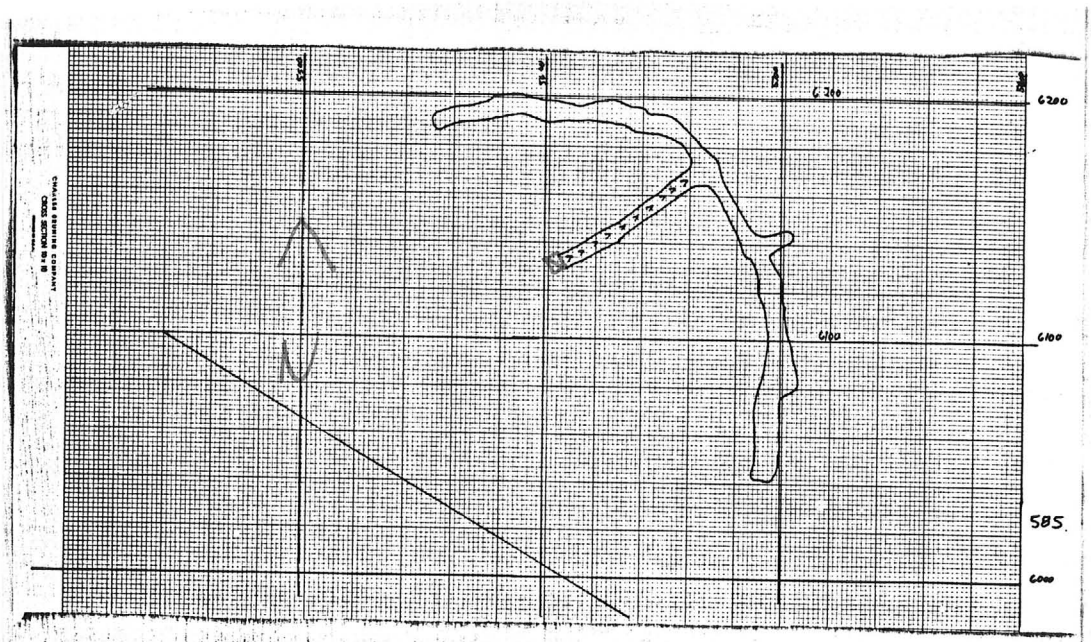
add to 420 level

430 Level

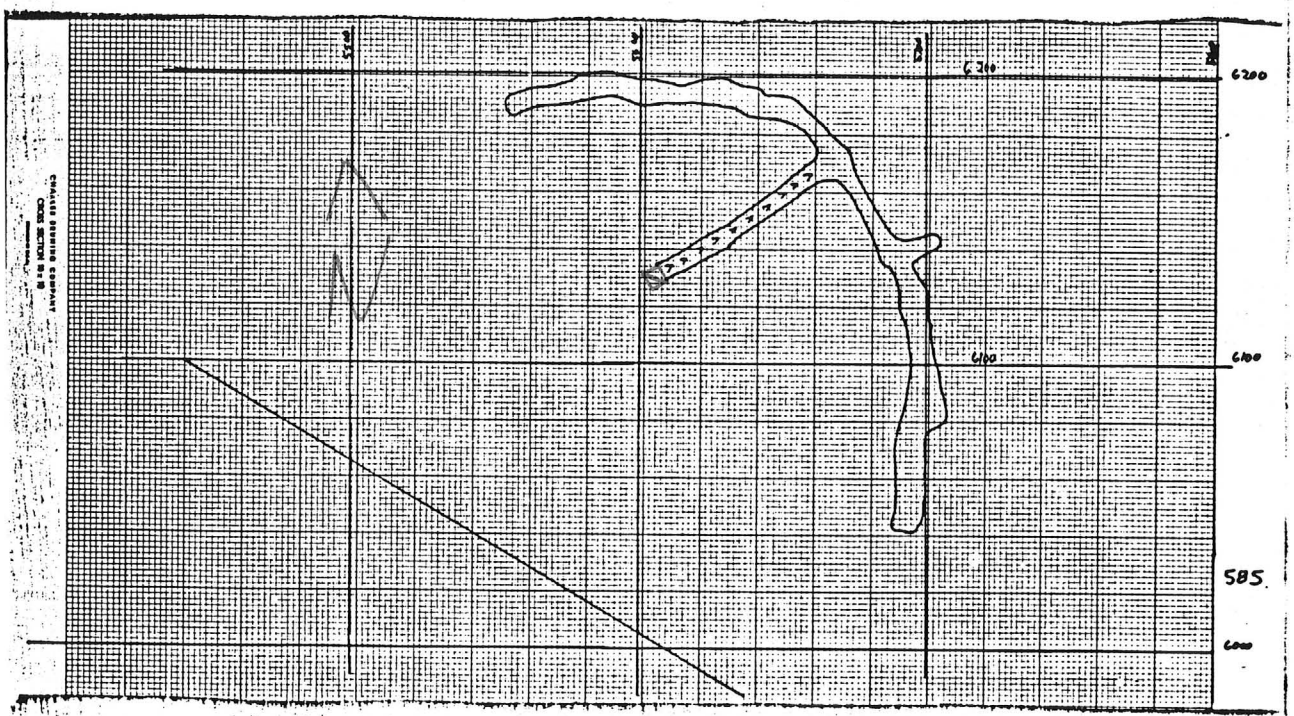


525 Level

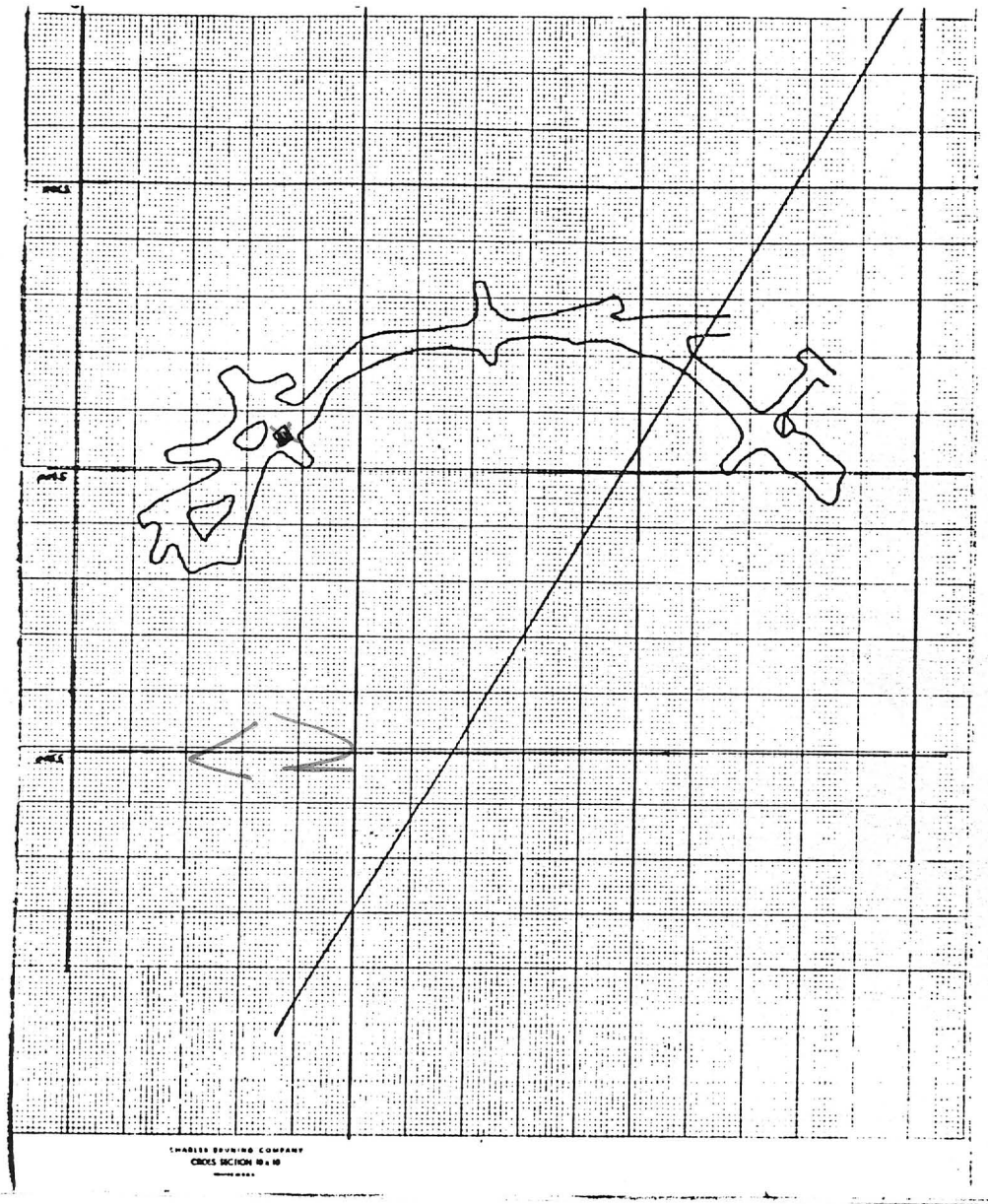

N
Sprint Raise
550



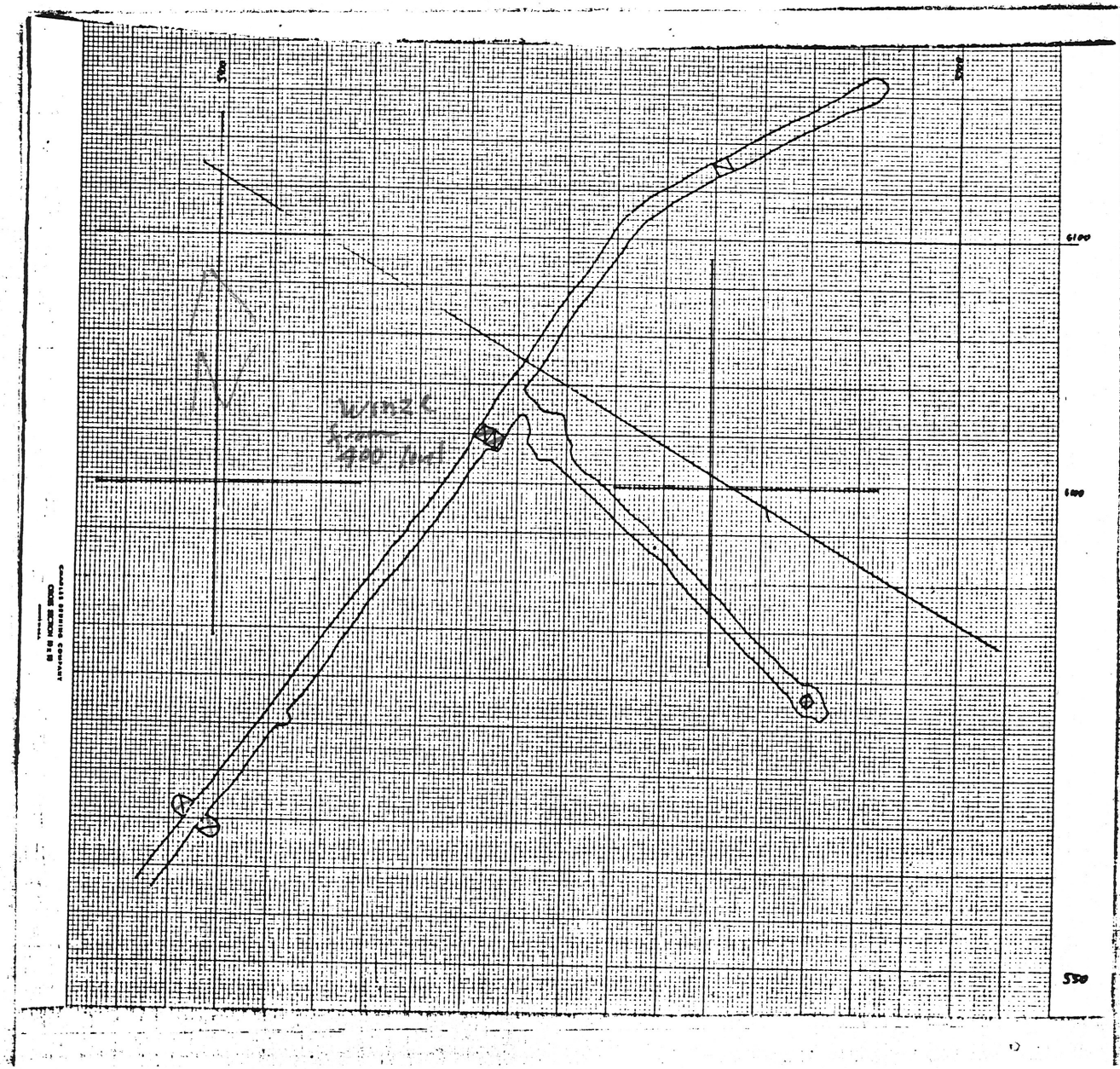
585 Level



585

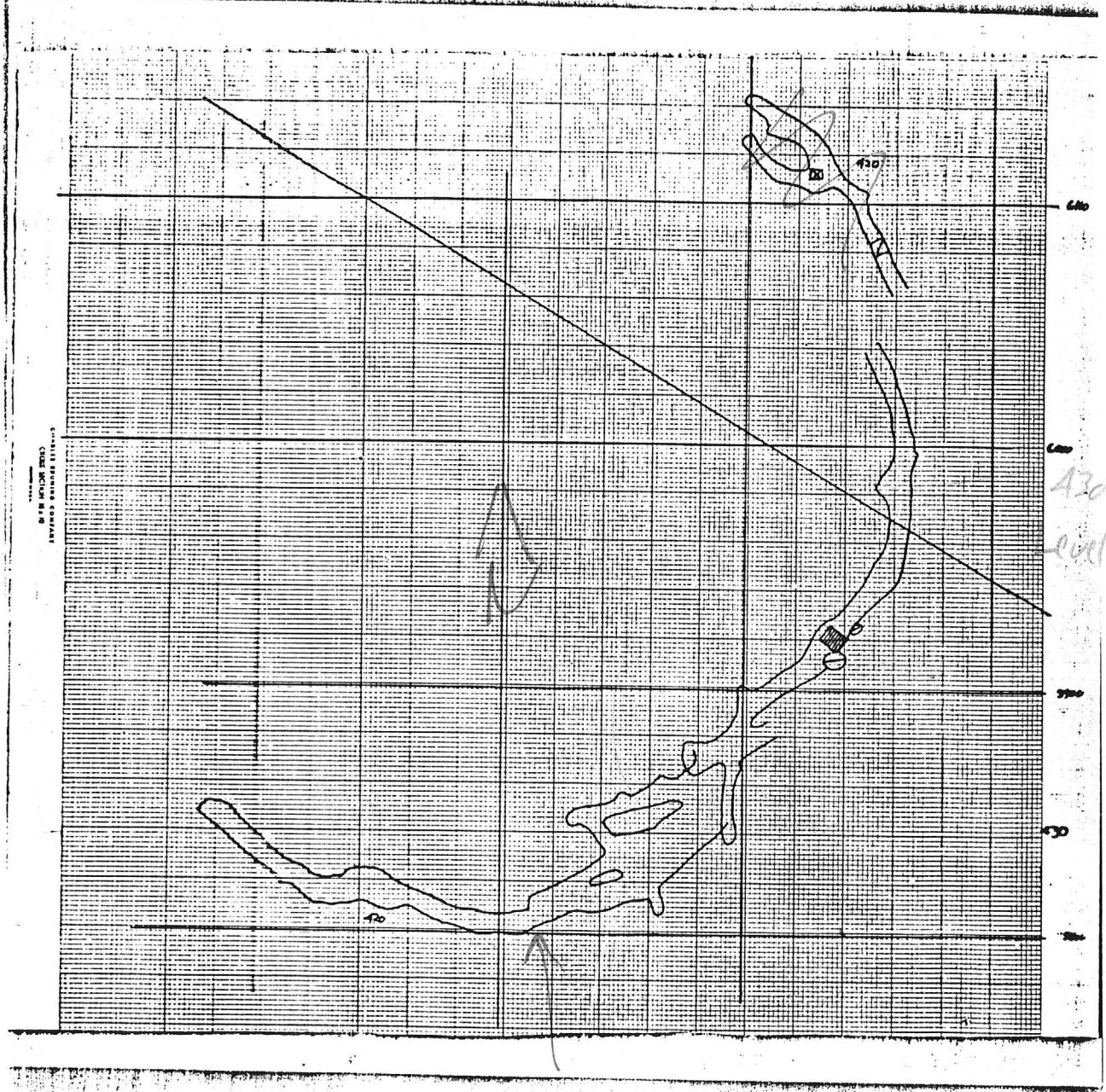


525

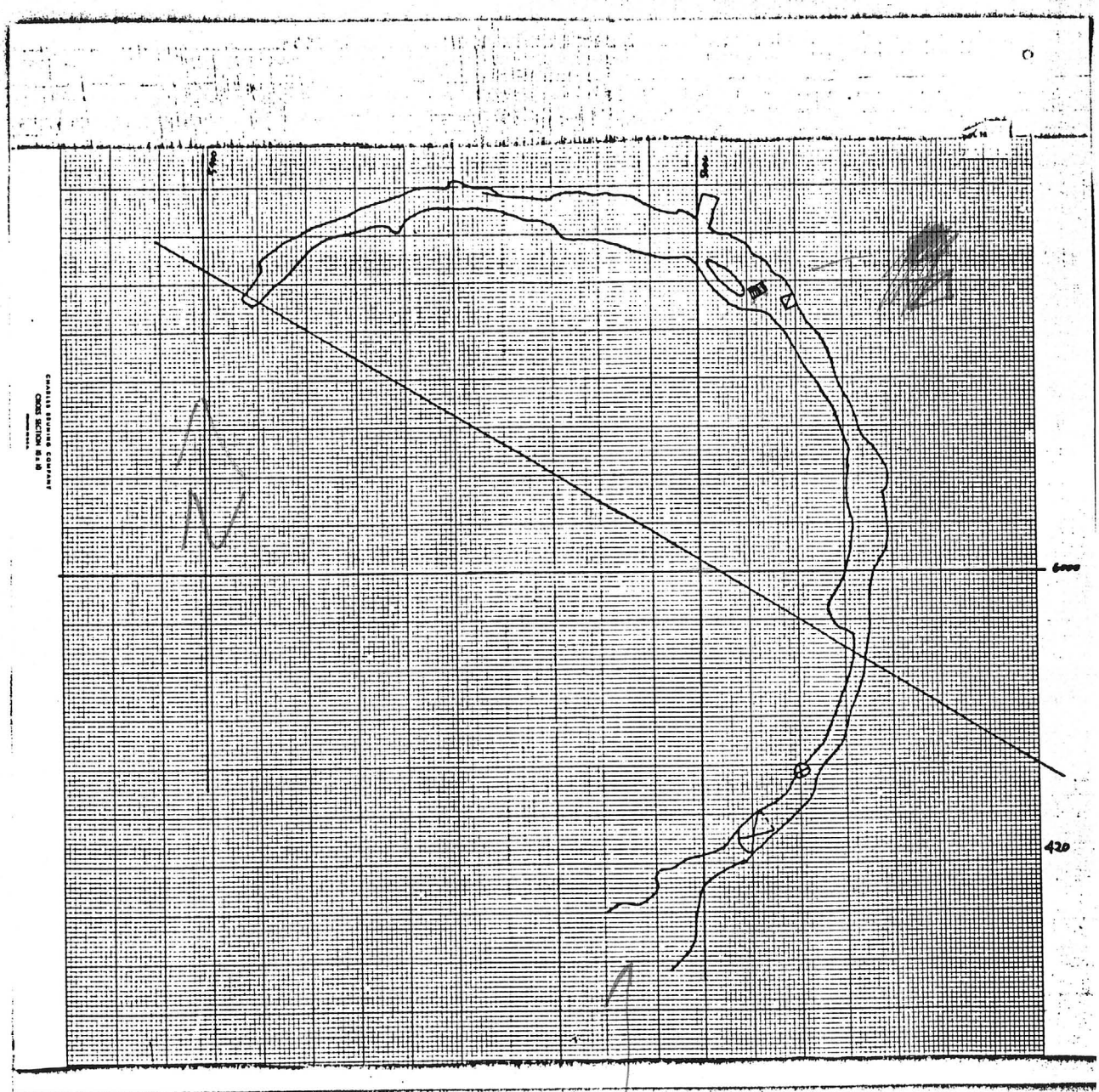


550

430



add to 420



420 Level

add from 430

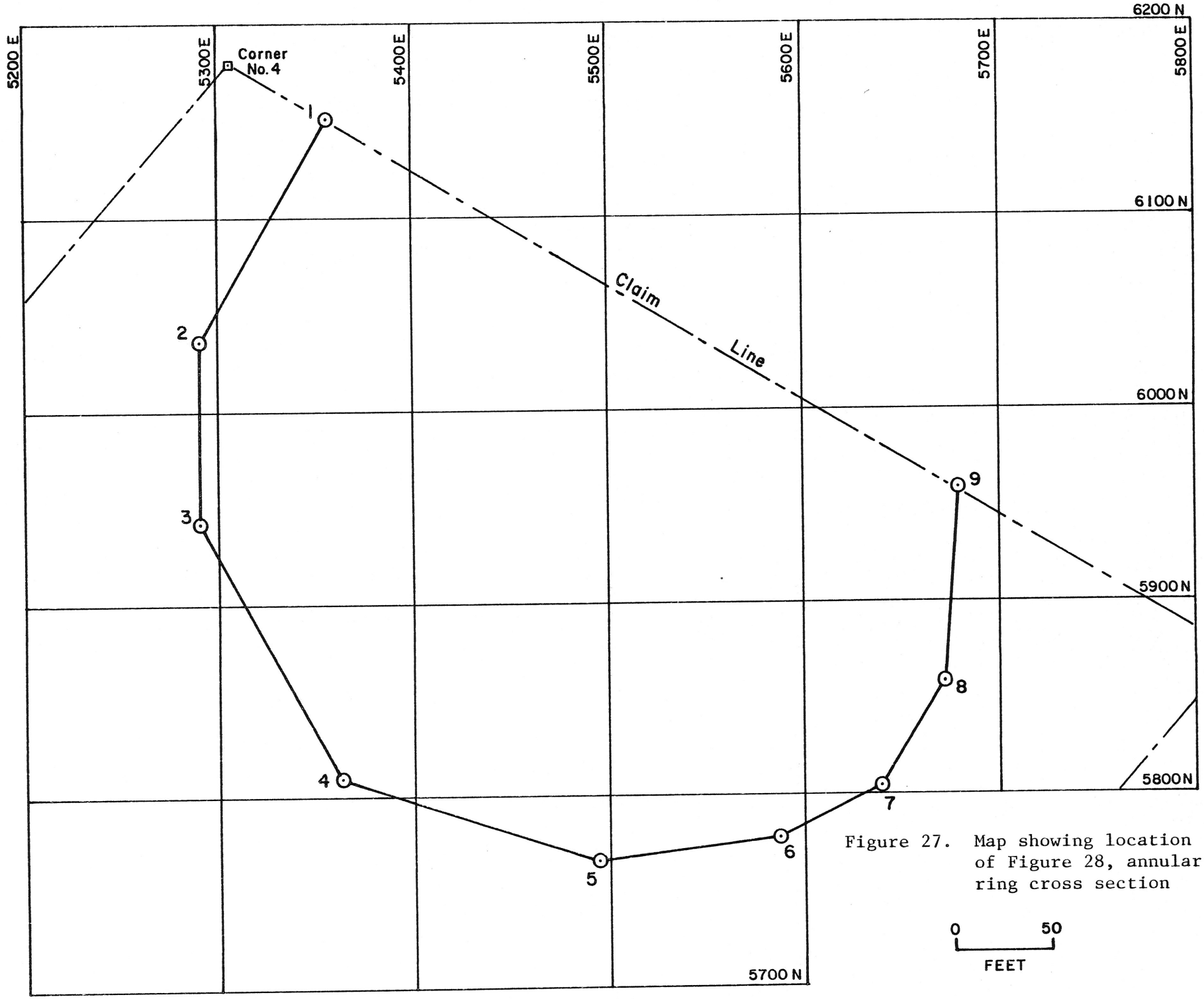
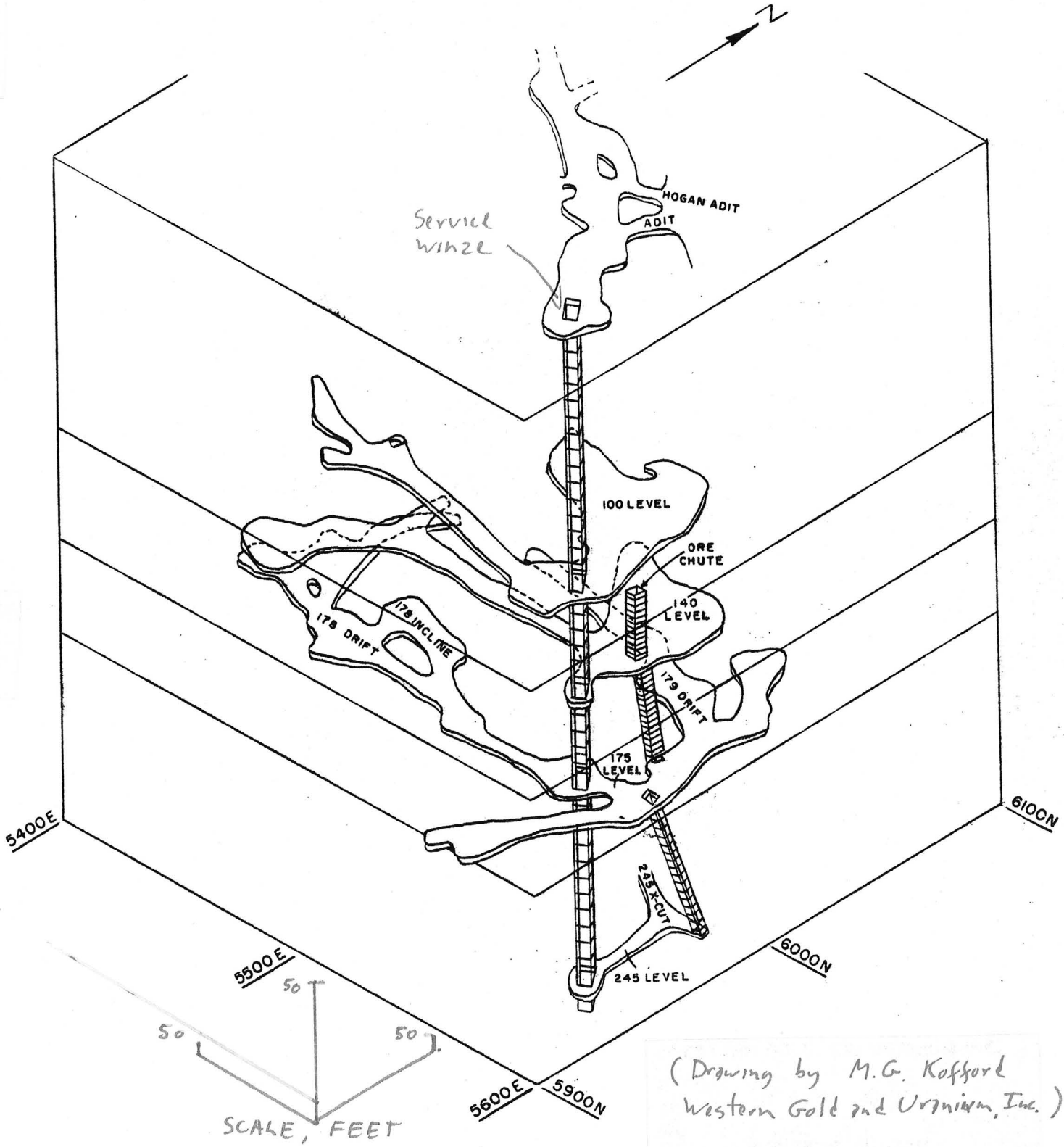


Figure 27. Map showing location of Figure 28, annular ring cross section



(Drawing by M.G. Koffard Western Gold and Uranium, Inc.)

Figure 6, Isometric drawing of Orphan Lode Mine, December 1958

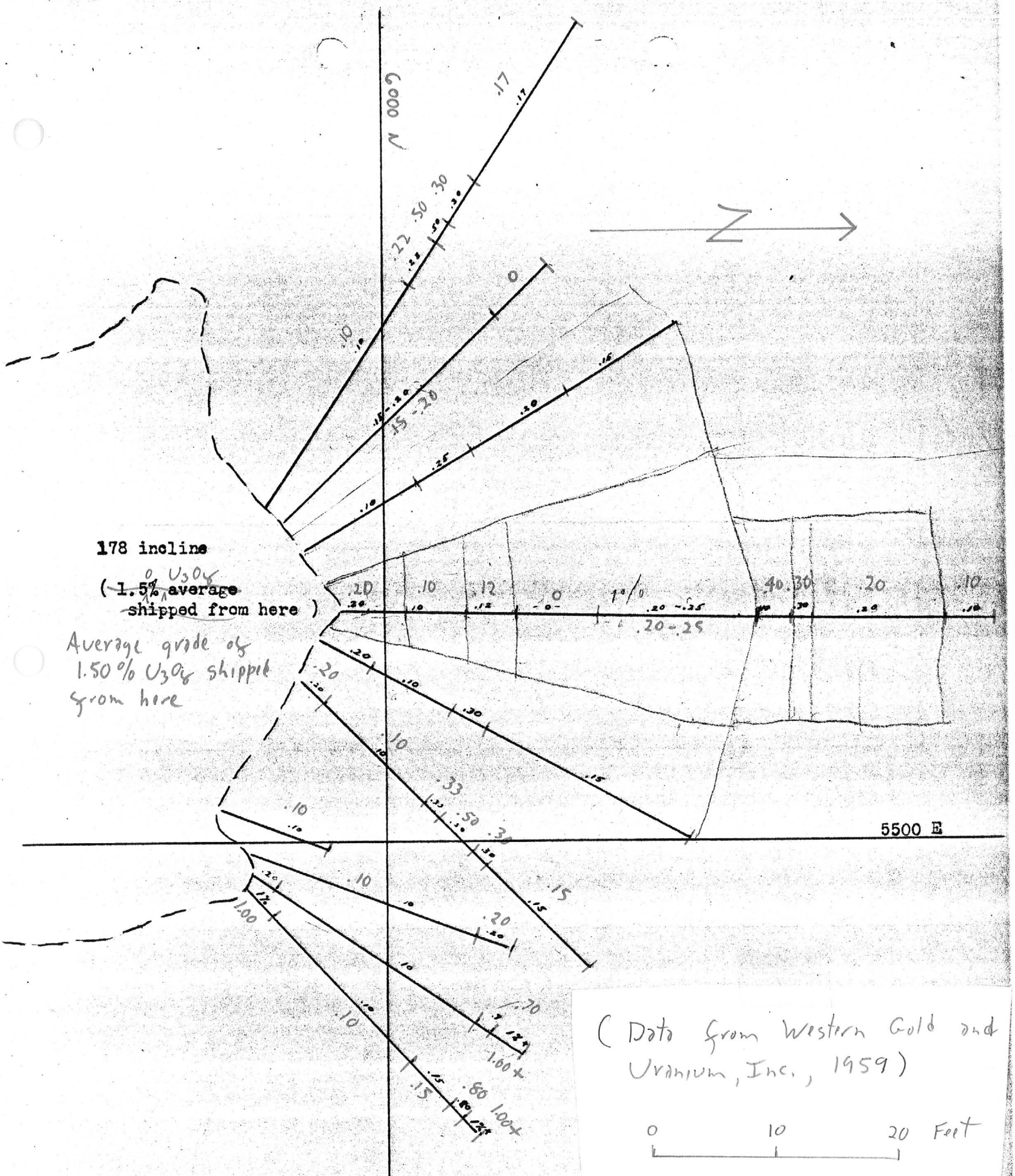


Figure 25, Results of longhole drilling in B zone showing grade distribution

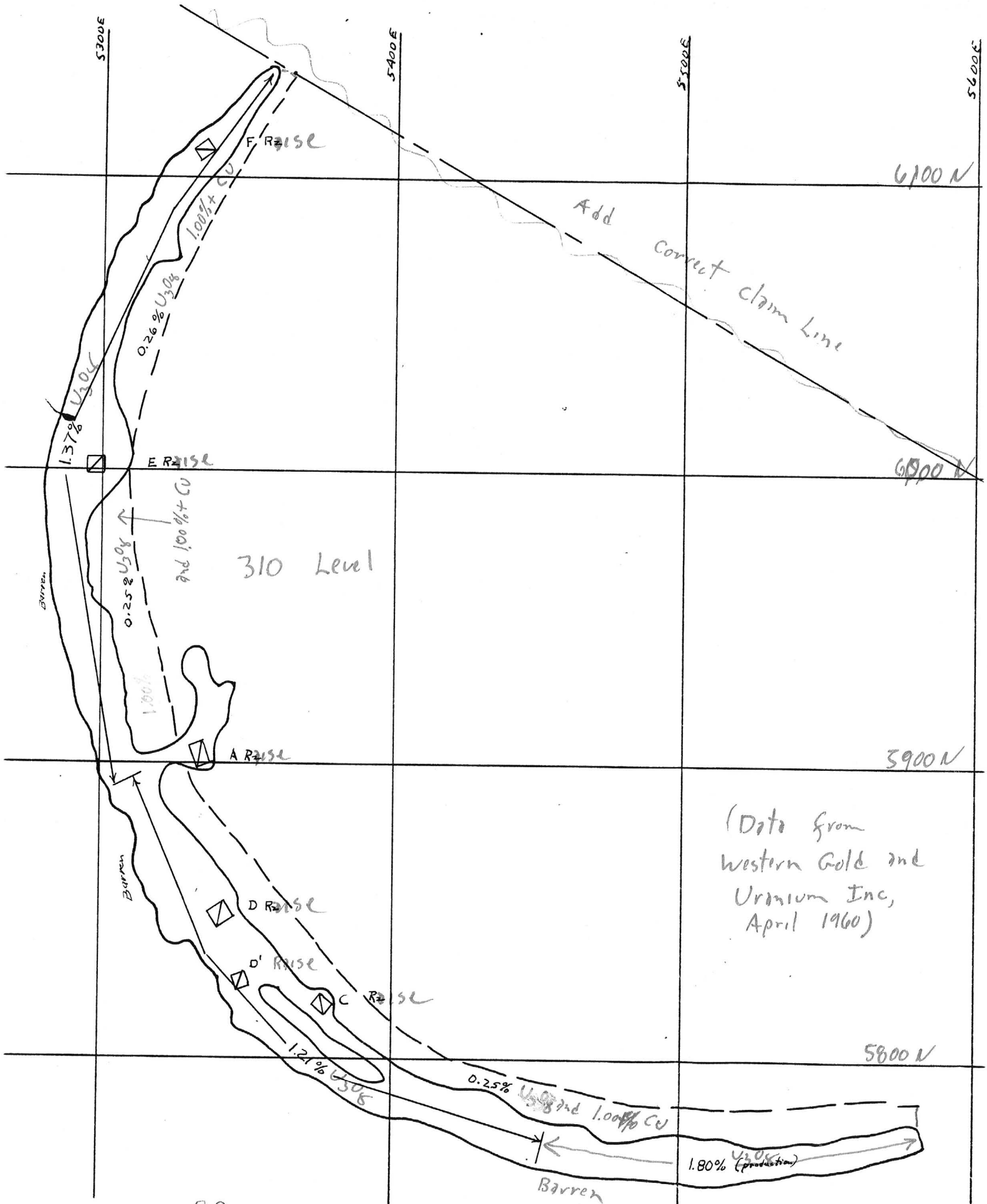
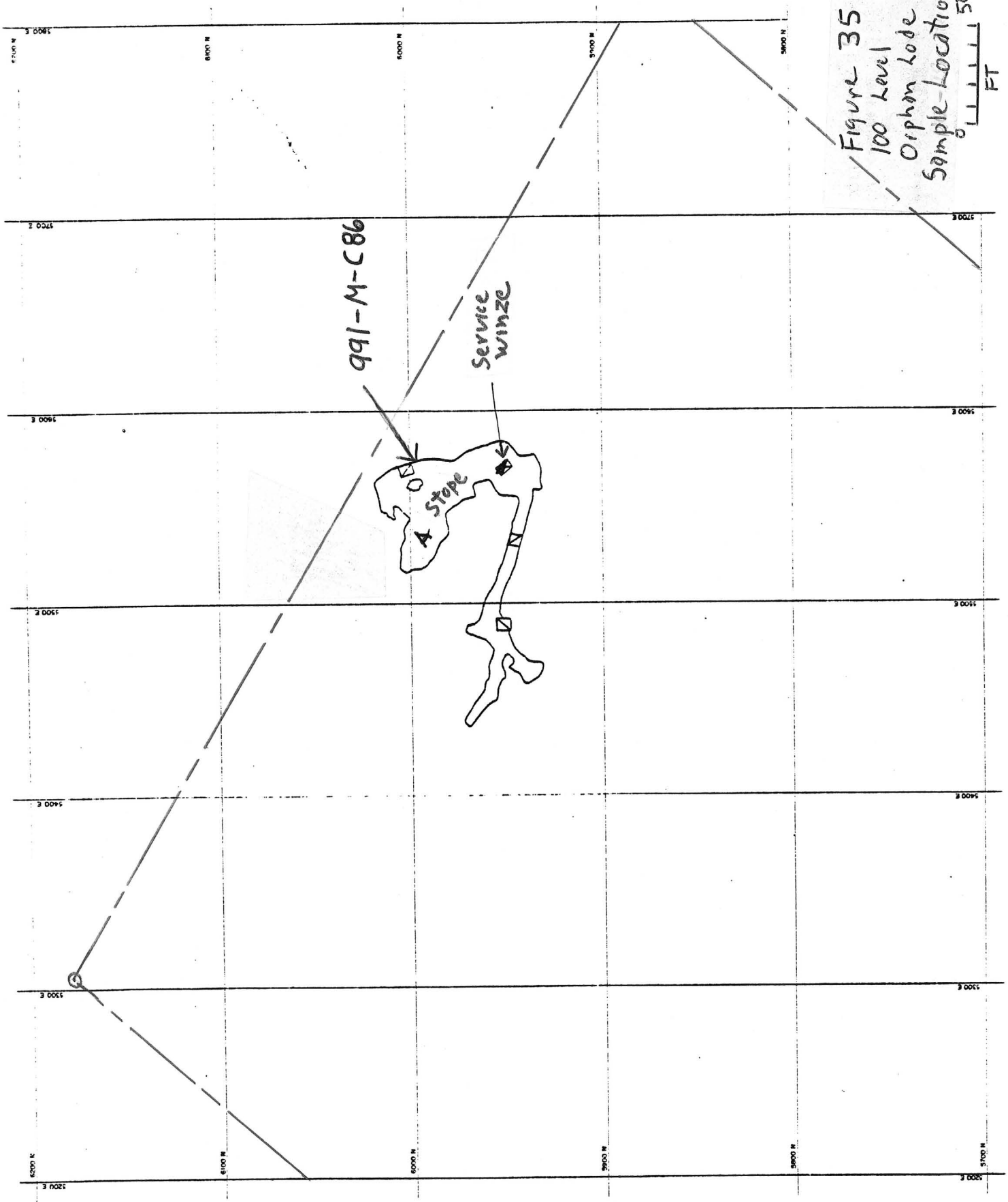


Figure 30, Map of annular ring zone on 310 level showing average uranium production grades, and reserves inferred from longhole drilling


991-M-C86
Service winze
A stope
Figure 35
100 Level
Orphan Lode
Sample Location
0
50
FT

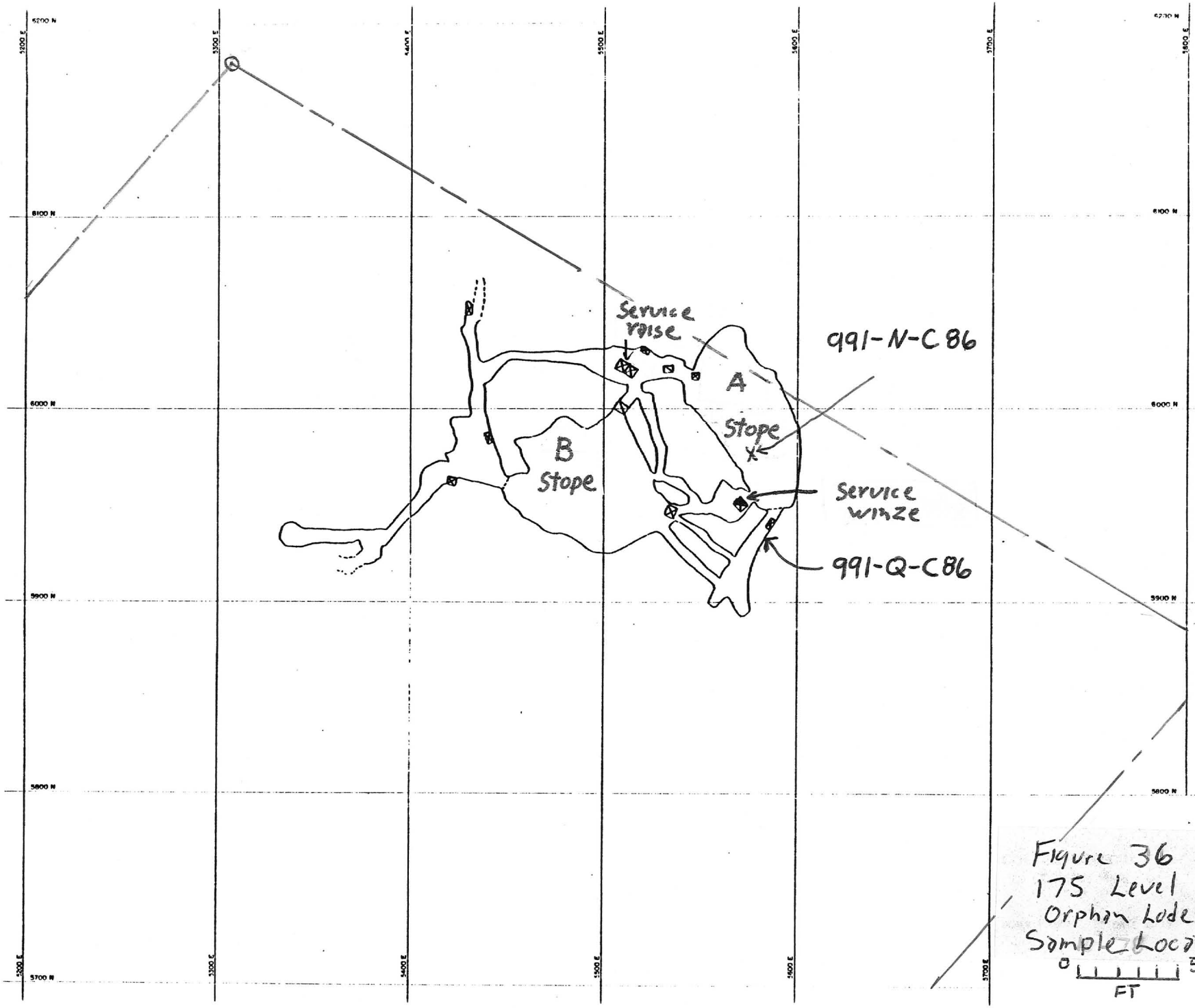


Figure 36
175 Level
Orphan Lode
Sample Locations

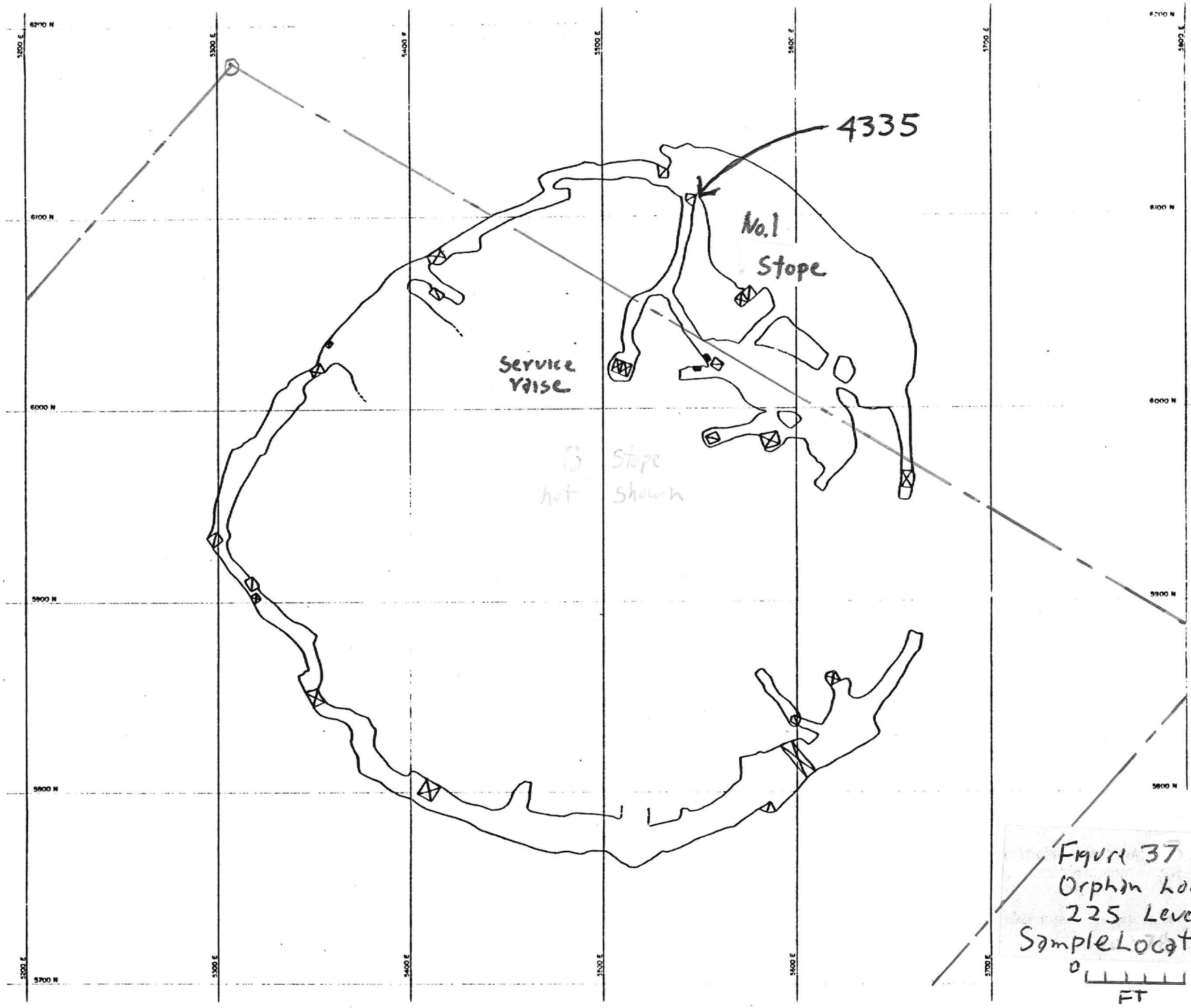


Figure 37
Orphan Lode
225 Level
Sample Location
0 50
FT

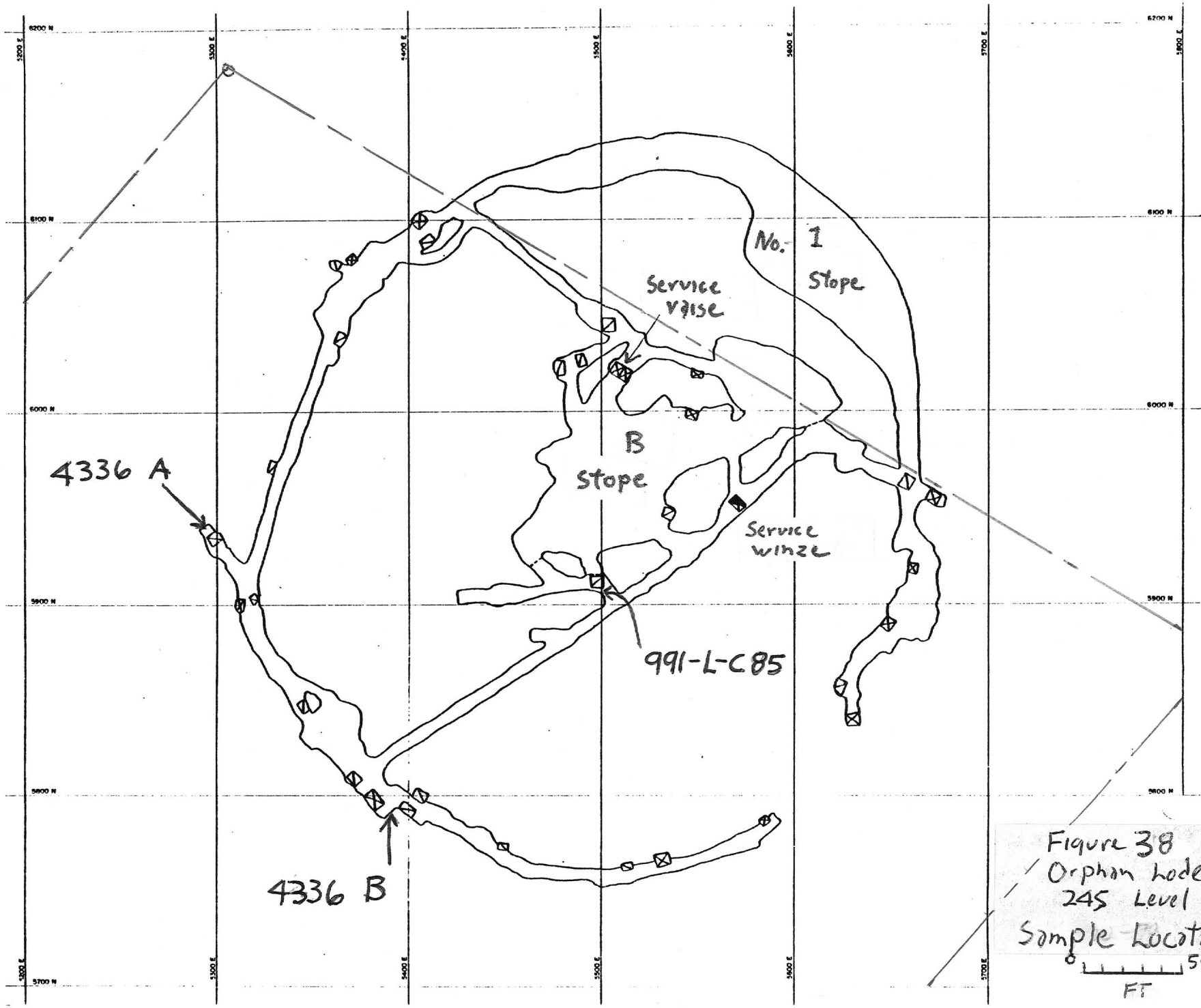


Figure 38
Orphan Lode
245 Level
Sample Locations

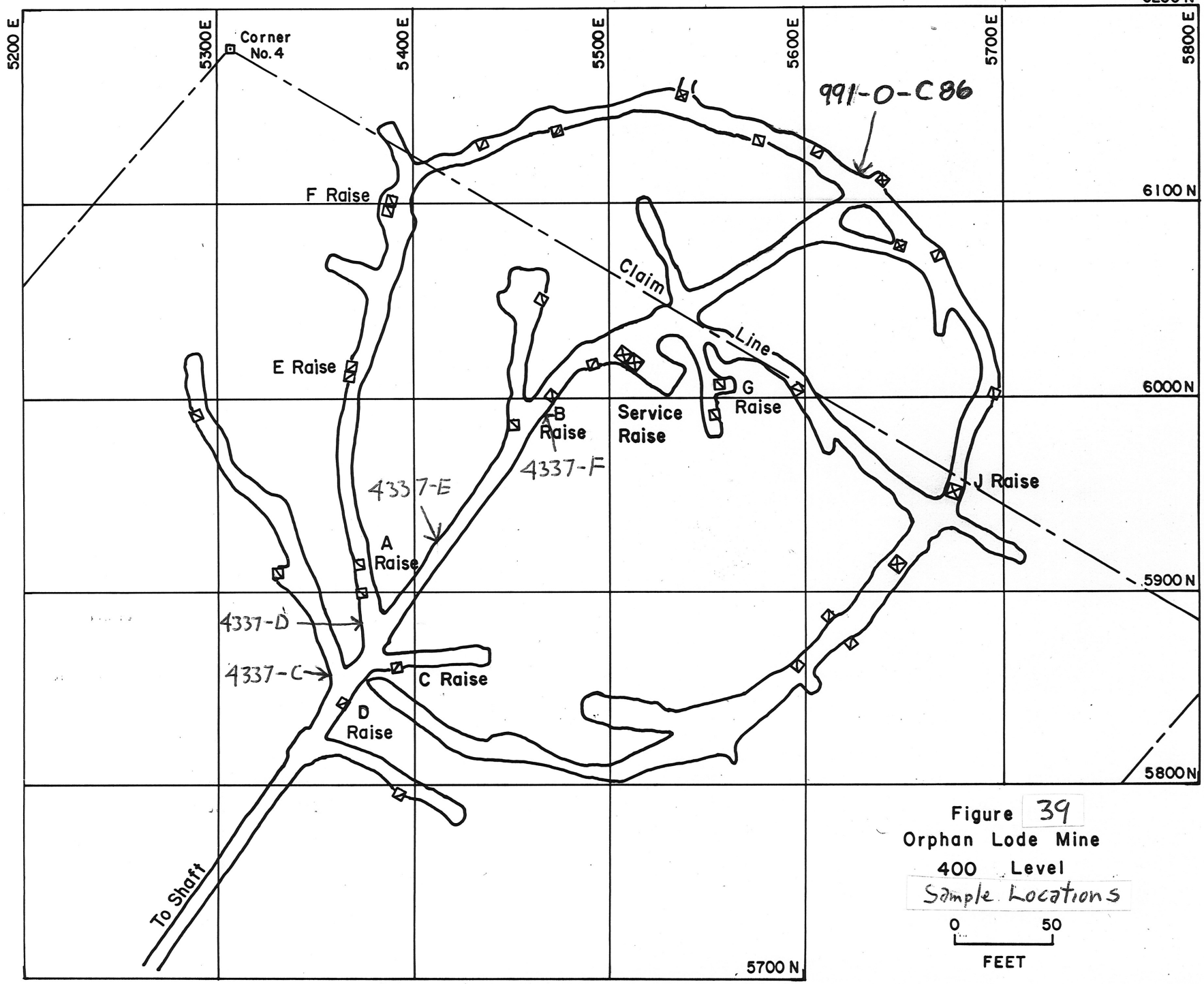


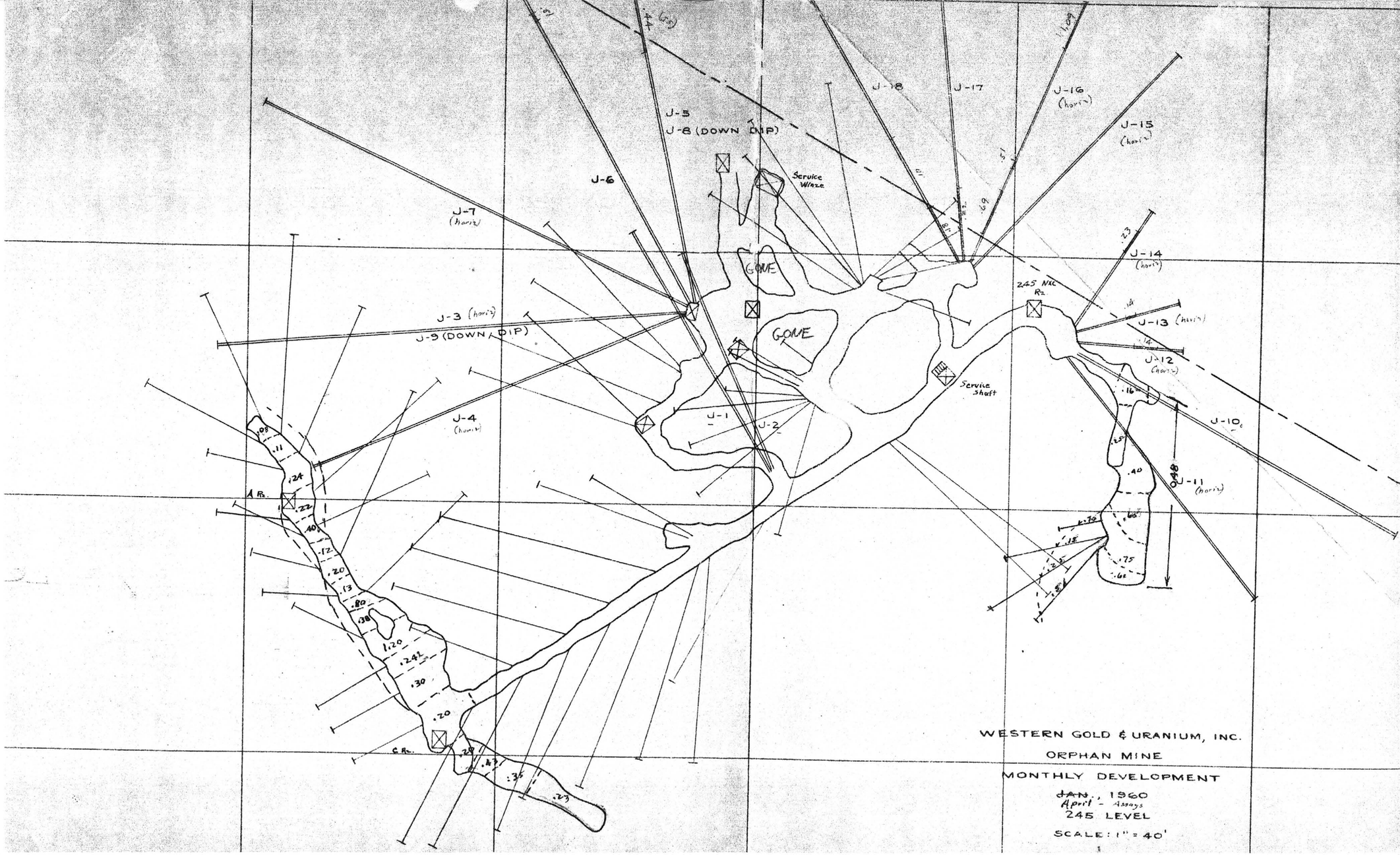
Figure 39
Orphan Lode Mine
400 Level
Sample Locations

0 50
FEET

A-35

7-10-99

CONTENTS



WESTERN GOLD & URANIUM, INC.

ORPHAN MINE

MONTHLY DEVELOPMENT

~~JAN.~~, 1960
April - Assays
245 LEVEL

SCALE: 1" = 40'

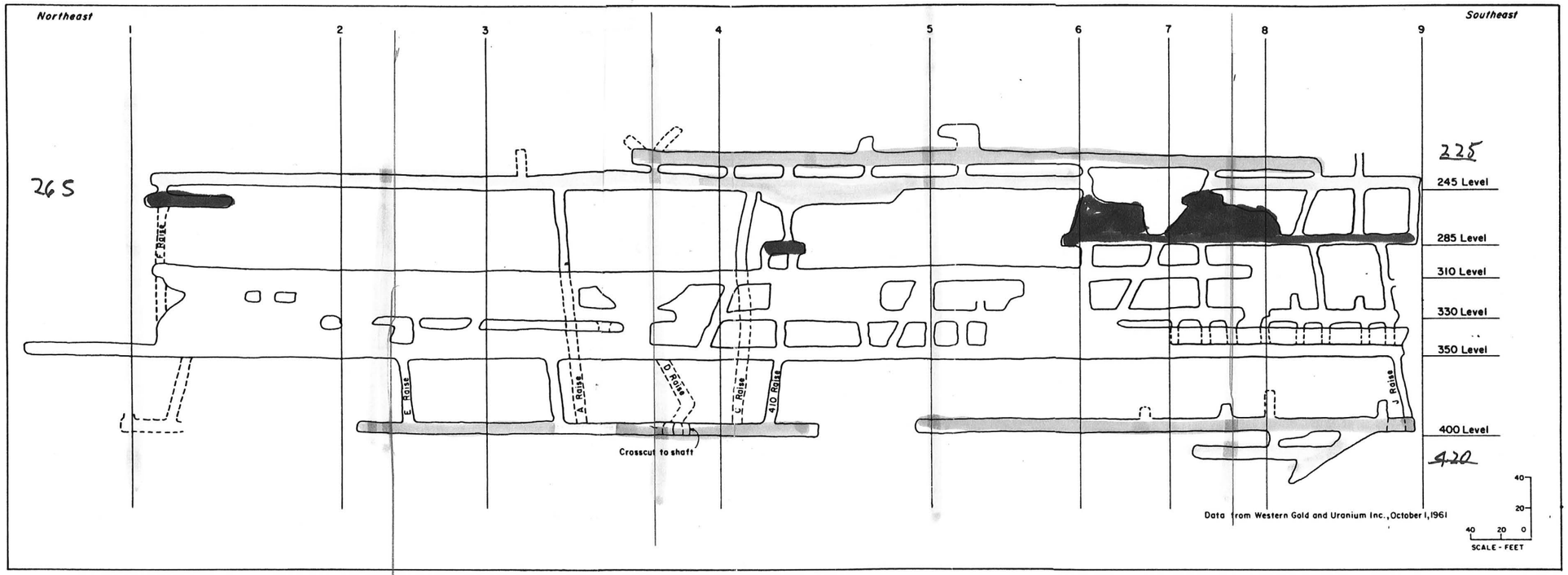


Figure 28. Vertical cross-section annular ring, Orphan Lode Mine, looking to the northeast
(See Figure 27 for location of section)

TABLE 3

Summary of exploration core holes with alphabetic prefixes, Orphan Lode Mine

Prefix	No. of Holes	Location	Year(s) Drilled	Results
A, B, D, E, F	25	100 ÷ 175 levels	1956 - 57	Located ore in upper part of pipe (A ÷ B zones).
G	10	Two stations in Park	1958	Defined the diameter of the pipe and located ore in annular ring and within lower part of pipe (G zone).
H	10	175 level	1958 - 59	Located ore in annular ring.
J	63	245 level	1959 - 61	Located ore in annular ring.
K	30	400 level	1959 - 61	Located ore in annular ring.
L	11	320 level	1959 - 61	Located ore in annular ring, and within pipe.
M	48	310 level	1960	Located ore within pipe and in annular ring.
N	64	350 level	1960	Located ore within pipe and in annular ring.
P	13	550 level	1961 - 62	Explored lower part of pipe, including Redwall Ls. and older sediments.
R	4	Adit level	1961	Explored pipe on, and above, adit level.

Maps showing the location of these core holes are not available.

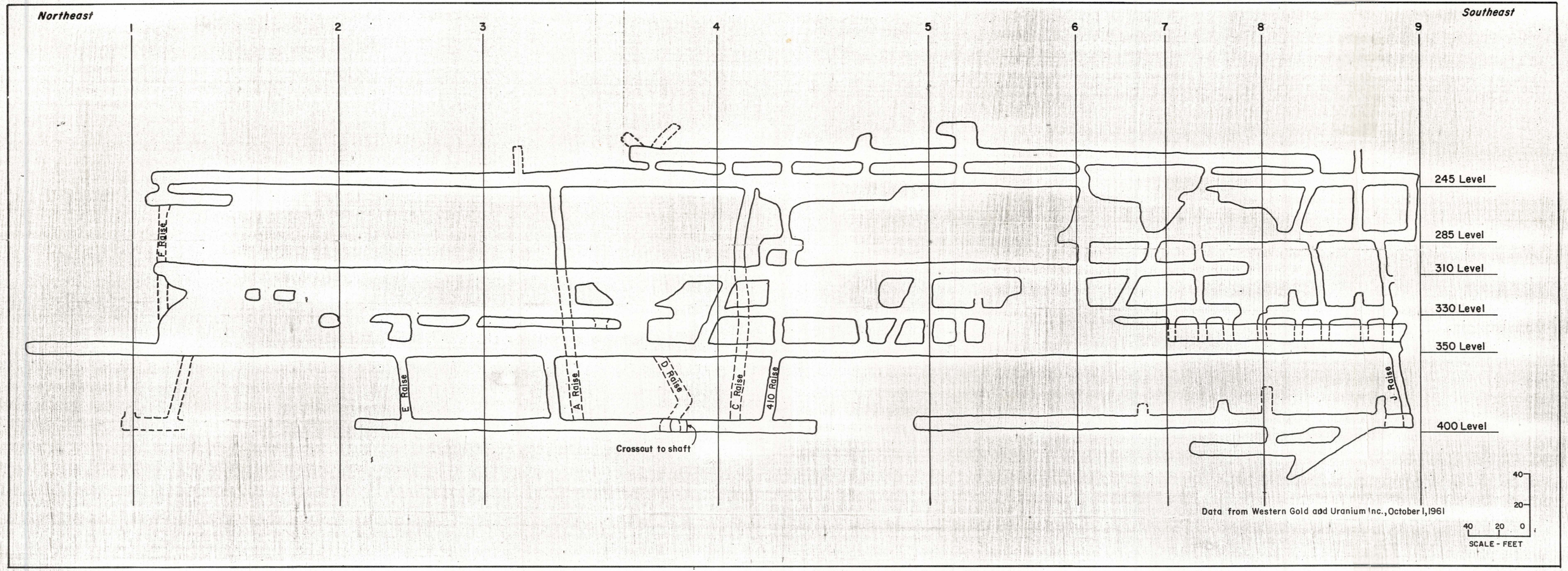


Figure 28. Vertical cross-section annular ring, Orphan Lode Mine, looking to the northeast

(See Figure 27 for location of section)