COPPER, GALLIUM, AND GERMANIUM ON SITLA LANDS IN THE SOUTHERN BEAVER DAM MOUNTAINS PROJECT AREA WASHINGTON COUNTY, UTAH

by
Taylor Boden and Ken Krahulec
Energy and Minerals Program

Utah Geological Survey
a division of
Utah Department of Natural Resources

Utah Trust Lands

The State of Utah School and Institutional Trust Lands Administration

State of Utah
School & Institutional
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Cover: Copper, gallium, and germanium ore rock (center) in the tailings from the upper shaft on the Apex mine. Gallium metal ingots (lower left) and synthetic crystals of gallium metal crystal (lower right), photographs courtesy of Recapture Metals Inc., Blanding Utah.

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EXECUTIVE SUMMARY

The Utah Geological Survey studied copper-gallium-germanium (Cu-Ga-Ge) potential on Utah School and Institutional Trust Lands Administration (SITLA) lands in the Beaver Dam Mountains of southwestern Washington County, Utah. The SITLA Cu-Ga-Ge project area is located near the Apex mine, which is used as a model in assessing mineralization in the area.

The Apex mine, in the Tutsagubet mining district, lies near the crest of the southern Beaver Dam Mountains in southwestern Washington County. The Apex mine exploited a Kipushi type Cu-Ga-Ge deposit in a steeply plunging, solution-collapse breccia pipe, hosted in the Pennsylvanian Callville Limestone and overlying Permian Pakoon Dolomite. The ore body has been developed to a depth of over 1400 ft, but the ore deposit probably bottoms in the heavily karstic Mississippian Redwall Limestone hundreds of feet below the deepest workings. Gallium and Ge are contained in goethite, jarosite, and hematite minerals in gossans that contain oxidized Cu minerals. The Apex mine still hosts an estimated 1 million ton Cu-Ga-Ge resource with an in-place value in excess of $1 billion at today's metal prices (March 2011); approximately two-thirds of this value is in Ge. A cluster of smaller, but similar, occurrences lie in an area of slightly more than 1 mi^2 near the Apex mine, but strong Ga-Ge geochemical anomalies are reported along a north-northwesterly trend up to 7 mi to the north-northwest of the Apex mine. Worldwide, other Kipushi type deposits include the Kipushi Cu-Zn ±Ga ±Ge deposit, Zaire; Tsumeb Cu-Pb-Zn ±Ga ±Ge deposit, Namibia; and the Ruby Creek and Kennicott Cu-Ag deposits in Alaska. These deposits are all important, large, high-grade deposits, each with several billions of dollars of copper alone, at today's prices.

SITLA lands, consisting primarily of sections 2, T. 43 S., R. 18 W., and 36, T. 42 S., R. 18 W., Salt Lake Base Line and Meridian (SLBM), were investigated due to their proximity to the Apex Cu-Ga-Ge deposit. The Apex deposit is located within a mile of SITLA lands and is used as a model in assessing the potential of other prospects in the project area. Despite the presence of Cu-Ga-Ge prospects (e.g., the Jesse mine in SITLA section 2, T. 43 S., R. 18 W.), little exploration potential is recognized on this tract because the mineralization is located within a post-mineral landslide block of Redwall Limestone. Unfortunately, this indicates that mineralization is confined to the slide block itself and does not extend downward into underlying rocks. Economic amounts of Ga-Ge are unlikely at the Jessie mine due to the limited size of the slide block and subsequent small tonnages of ore that could be present there, but this occurrence indicates mineralization may extend into the Redwall Limestone elsewhere. However, solution-collapse pipes can be "blind" (i.e., have no surface expressions even in premineral rocks). In recent exploration for "blind" Cu-U solution-collapse breccia pipes in the Arizona Strip, just south of the Utah border, airborne vertical-time-domain electromagnetic (VTEM) surveys have been used successfully to define targets for drilling. SITLA section 36, T. 42 S., R. 18 W., SLBM, lies on the mineralized north-northwest trend, is underlain by favorable host strata, and is just north of the Apex mine, so this tract contains excellent exploration potential despite the lack of mineralization at the surface.

INTRODUCTION

Project Background

This report presents results of a study of copper (Cu), gallium (Ga), and germanium

(Ge) resources on Utah School and Institutional Trust Lands Administration (SITLA) lands in the southern Beaver Dam Mountains of Washington County, Utah. The Utah Geological Survey (UGS) investigated the Cu-Ga-Ge resources at the request of Thomas B. Faddies, SITLA, Assistant Director-Hard Rock and Industrial Minerals. This study is part of an ongoing Memorandum of Understanding between the UGS and SITLA to evaluate the mineral resources of SITLA lands in Utah. Information for the report comes from the published literature, unpublished company reports, the UGS's Utah Mineral Occurrence System files, field investigations, and laboratory analysis of samples collected from in and around the SITLA project area.

UGS Energy and Minerals Program geological staff visited the project area in late 2010 to examine SITLA lands for Cu-Ga-Ge potential. Tutsagubet mining district mines and prospects in and around the SITLA project area were examined and sampled to evaluate the area's Cu-Ga-Ge deposits. The Apex mine Cu-Ga-Ge deposit, located in the project area and within a mile of SITLA lands, was the first deposit in the world to be mined primarily for Ga-Ge, and is used as a model in assessing the potential of Cu-Ga-Ge prospects in the project area.

Project Area

The SITLA Cu-Ga-Ge project area (figure 1) is located in the Tutsagubet mining district of the southern Beaver Dam Mountains in southwestern Washington County. For the purposes of this study, SITLA lands, consisting of section 2, T. 43 S., R. 18 W. and section 36, T. 42 S., R. 18 W., Salt Lake Base Line and Meridian (SLBM), were given the highest priority for investigation due to their proximity to the Apex Cu-Ga-Ge deposit. The majority of land in the project area is federally owned and administered by the Bureau of Land Management (BLM), with a lesser amount held by SITLA and privately owned (plate 1). The project area encompasses approximately 9 mi^2 on the U.S. Geological Survey's Jarvis Peak 7.5-minute topographic quadrangle, and may be reached by road from St. George by traveling west a distance of about 25 mi on U.S. Highway 91. The Shivwits Paiute Indian Reservation is located less than 2 mi to the north, and the Beaver Dam Mountains Wilderness Study Area is located about 2 mi to the southeast. Access to the interior of the project area is via dirt roads that range from good to poor. Mines and prospects in the project area lie at elevations between 5000 and 6000 ft. The project area topography is moderately to extremely rugged, consisting mostly of steep limestone slopes, cliff areas, and dry washes. Karst features such as caves, dissolution cavities, and brecciated limestone are common in some areas (figure 2). The study area is covered by sparse to dense high desert vegetation, having large areas burned by a wildfire in 2006.

GALLIUM AND GERMANIUM

Gallium and Ge are both relatively rare, weakly chalcophile elements, and semi-metals. The current world's Ga and Ge supply comes entirely as a byproduct from the recovery of other metals. Gallium and Ge are currently of particular interest due to the heavy U.S. reliance on imports of these metals and their prominent use in military applications.

Gallium

Occurrence

Gallium is present in the earth's continental crust at an average concentration of 15 parts per million (ppm). Gallium is

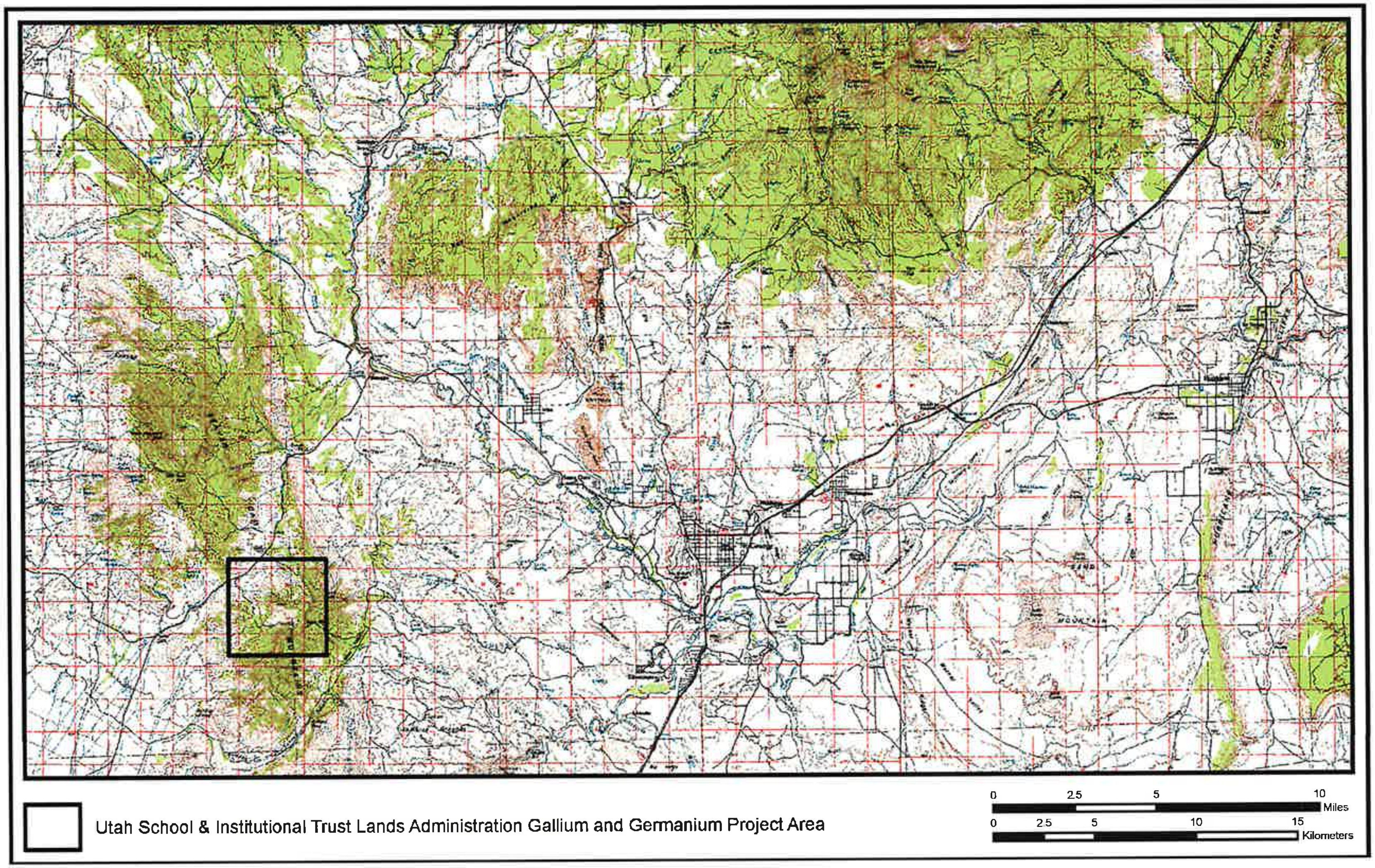

Figure 1. SITLA Washington County gallium and germanium project area location map.

Figure 2. Dissolution cavity and brecciated limestone karst structures common in the Redwall Limestone in the project area.

about as abundant in the earth's crust as lead (Pb); however, it typically does not concentrate in sulfide mineral deposits as strongly Pb. Gallium is chemically similar to aluminum (Al) in many respects and can substitute for Al in trace amounts in many minerals. Most highly aluminous rocks and minerals and some zinc (Zn) minerals contain detectable amounts of Ga (Petkof, 1985). The aluminum ore bauxite may average 50 ppm Ga, and can contain up to 100 ppm. Sphalerite from Pb deposits in the tri-state area of Kansas, Missouri, and Oklahoma ranges from 10 to 200 ppm Ga and averages 50 ppm. The Cu, Fe, and Ga sulfide mineral germanite [$Cu_{26}Fe_4Ge_4S_{32}$], found in the Republic of Namibia in southern Africa, can contain up to 1.85% Ga. Gallium is also found in some coals, though rarely in amounts exceeding 100 ppm.

Gallium is a silvery white semi-metal, having a melting point of just 85.6° F, so it will literally melt in your hand, and a boiling point of 4357.4° F (Petkof, 1985). Its atomic number is 31 and atomic weight 69.72. Gallium is used in semiconductors when alloyed with other elements, especially As forming Ga arsenide (Petkof, 1985).

Market

Approximately 99% of domestic Ga consumption in 2010 was in the form of Ga arsenide (GaAs) and Ga nitride (GaN) for use in electronic components (U.S. Geological Survey, 2011a). Analog integrated circuits (microchips) are the largest application (64%) for Ga. Semiconducting GaAs is used in integrated circuits of cellular telephones, high-performance computers, compact radar and microwave devices utilized by the military, and other electronic devices. Optoelectronic applications consume about 35% of Ga in areas such as aerospace, industrial equipment, medical equipment, and telecommunications. Optoelectronic devices use semiconducting GaN in the manufacturing of laser diodes and light-emitting diodes (LEDs). The remaining 1% of Ga demand is in specialty alloys, research and development, pharmaceuticals, and other applications. Gallium sold for roughly $300 per pound in 2010 (U.S. Geological Survey, 2011a). The world Ga market is small, roughly $70 million per year, which corresponds to about 234,000 pounds, or 117 short tons.

Industry

Gallium is found in very small concentrations in ores of other metals, and primary Ga is mostly produced as a byproduct from the treatment of bauxite Al ore. The remainder of Ga produced is as a byproduct from Zn refining (U.S. Geological

Survey, 2011a). Only a small percentage of the Ga present in bauxite and Zn ores is currently economically recoverable.

In 2010, no domestic primary Ga was recovered; however, one company (Recapture Metals Inc.) in Blanding[1], Utah recovered and refined Ga from impure Ga metal and scrap, and one company in Oklahoma refined Ga from impure Ga metal (U.S. Geological Survey, 2010a). Import sources between 2005 and 2008 consisted of Germany, 26%; Canada, 23%; China, 17%; Ukraine, 12%; and other, 22%. World primary Ga production in 2010 was estimated to be 117 tons, and was produced mainly by China, Germany, Kazakhstan, and Ukraine (U.S. Geological Survey, 2011a).

Germanium

Occurrence

Germanium is present in the earth's continental crust at an average concentration of 1.5 ppm (Butterman and Jorgenson, 2005). Germanium is found concentrated in several diverse geological environments, mostly as a minor constituent of some base-metal sulfide ores, but also in coal deposits. However, Ge occurs in low concentrations even in these deposits, and Ge-containing ores are not currently mined for the contained Ge. Primary Ge minerals are usually formed at low to intermediate temperatures in sulfide mineralization processes, and secondary minerals form from supergene oxidation of sulfide ore deposits. Germanium is usually found in the Zn sulfide minerals sphalerite and wurtzite, where it can reach concentrations of several hundred ppm. To a lesser extent, it can be found in the Cu sulfide minerals chalcopyrite, enargite, bornite, and tennantite. From Cu deposits in Tsumeb, Namibia and Kipushi, Zaire, primary Ge content can range from 6.2% to 10.9% in germanite, 4.6% to 9.2% in renierite [$Cu_{6.5}Zn_{5.5}Ge_{1.5}As_{0.5}Fe_4S_{16}$], and 6.4% in argyrodite [Ag_8GeS_6] (Butterman and Jorgenson, 2005). Butterman and Jorgenson (2005) report average Ga concentration in coal deposits at just 3.7 times earth crustal abundance levels of 5.5 ppm.

Germanium is a grayish white semi-metal, having a melting point of 1719° F and a boiling point of 5125° F (Butterman and Jorgenson, 2005). Its atomic number is 32 and atomic weight 72.59. Germanium has a metallic luster, is hard and brittle, having a Mohs hardness of 6, and has the same covalently bonded, cubic structure as diamond. It is a semiconductor that has electrical properties between those of a metal and an insulator. Germanium is optically transparent to near-infrared radiation in the wavelength range of 1800 to 23,000 nanometers (Butterman and Jorgenson, 2005). It is also easily machinable, relatively strong, able to withstand exposure to chemicals and moisture, and is resistant to atmospheric oxidation.

Market

Estimated domestic Ge consumption in 2009 consisted of infrared optics, 30%; fiber-optic systems, 25%; polymerization catalysts, 25%; electronics and solar electric applications, 15%; and other (phosphors, metallurgy, and chemotherapy), 5% (U.S. Geological Survey, 2011b). Germanium lenses and window blanks are used by the U.S. military for various infrared applications such as thermal weapon sights, infrared night-vision systems, and other thermal imaging systems. In fiber-optic systems in the telecommunications industry, Ge is added

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[1] Recapture Metals Inc., a subsidiary of Neo Material Technologies Inc., recycles GaAs scrap through a thermal decomposition plant a couple of mile east of Blanding. The Recapture Metals plant produces between 13,000 and 27,000 pounds of nearly pure Ga per year, making it the second largest Ga operation in the U.S. (Hal Palmer, March 2011, oral communication).

in small amounts to the silica glass core of optical fibers to increase the refractive index, and prevent signal loss while not absorbing light. Germanium substrates are favored for use in satellite photovoltaic solar cells. Recent development of a Ge-substrate, high-efficiency solar cell, converting 41.6% of sunlight into electricity, could allow typical industrial solar panels and other photovoltaic devices to generate more electrical power[2]. Germanium sold for about $425 per pound in 2010 (U.S. Geological Survey, 2011b). The world Ge market is also small, roughly $112 million per year, which corresponds to about 264,000 pounds, or 132 short tons.

Industry

Germanium, like Ga, is found in very small concentrations in ores of other metals, and Ge is primarily produced as a byproduct from the treatment of Zn ore. Smaller amounts of Ge are produced from Cu refining and extraction from fly ash at coal-burning power plants. Zinc ore from the Middle Tennessee mining complex can contain as much as 400 ppm Ge. Secondary Ge production contributes significantly to the Ge supply, producing approximately 30% of the total Ge consumed worldwide from recycled materials. Over 60% of the Ge used in the manufacturing of optical devices is routinely recycled, and Ge scrap is now also routinely recovered from the window blanks in decommissioned tanks and other military vehicles. Significant amounts of the Ge supplied to the current world markets comes from various government stockpiles, especially from China and states once belonging to the former Soviet Union. Currently, China produces about 67% of the Ge produced globally (U.S. Geological Survey, 2011b).

In 2008, primary Ge was recovered from Zn concentrates produced at two domestic Zn mines, and Ge compounds and metal were produced at two domestic refineries. Germanium-containing Zn concentrates were produced by Teck Cominco (now Teck Resources Limited) at its Red Dog Zn-Pb open pit mine in Alaska (U.S. Geological Survey, 2011b). Most of the concentrate produced at the mine was shipped to the company's processing plant at Trail, British Columbia, the world's largest Pb-Zn smelting and refining complex and producer of Ge (very roughly 90,000 pounds GeO_2 per year). In 2006, the most recent year for which records are found, Trail's Ge production was 73,200 pounds. Cumulative U.S. imports of Ge between 2005 and 2008 consisted of about 547,800 pounds, which came from Belgium, 36%; China, 34%; Russia, 17%; Germany, 10%; and other, 3%. The total world production in 2010 was an estimated 132 tons (U.S. Geological Survey, 2011b).

HISTORY OF THE PROJECT AREA

Previous Work

The SITLA Washington County Ga-Ge project area has been under investigation since Cu mineralization was discovered at the Apex deposit in 1872. Because the Apex deposit is used as a model in assessing mineralization in the project area, a review of the literature pertaining to that deposit is essential. Gaylon Hansen's discovery of significant Ga-Ge concentrations at the Apex mine in the late 1950s resulted from his routine use of then new multi-element spectrographic analysis. His recognition of the anomalous Ga-Ge mineralization at the Apex Cu mine led to many studies of the deposit. Numerous unpublished studies of the Apex mine have been performed by the various companies that have tried to develop the deposit. Some unpublished company reports were available to the UGS, but many remain unavailable. Important published

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[2] Sylarus Technologies, of St. George, Utah, is a U.S.-owned, supplier of Ge substrates to the solar photovoltaic and electronics industries.

studies on the Ga-Ge occurrence at the Apex mine and the associated geology of the Beaver Dam Mountains include Kinkel (1951), Bernstein (1986), Dutrizac and others (1986), Hintze (1986), Wenrich and others (1987), Petersen and others (1988), Hammond (1991), and Biek and others (2009).

Apex Mine

The Apex mine is located in the Tutsagubet mining district in the central part of the Beaver Dam Mountains, in southwestern Washington County, Utah. Copper, Pb, Zn, and Ag ores have been mined from both the east and west sides of the mountain range. The Apex mine, located on the east flank of the southern Beaver Dam Mountains, was the most significant producer in the Tutsagubet district. District ores are associated with northwest-trending faults, fissures, and breccias in Paleozoic limestones. Prospects were initially located in the area in the 1870s, but the mining district was not organized until June 1883. Early hand-sorted ore shipments from the Apex mine to the rail head at distant Milford for transport to Swansea, Wales, ran 54.2% Cu and 140 ppm Ag (Butler and others, 1920). Even into the 1930s, ore shipments contained 31% Cu (Cook, 1960). The district was worked intermittently from 1884 to 1962, mostly producing Cu and/or Pb ore when the market was favorable. Perry and McCarthy (1977) report total production from the district from prior to 1887 to 1976 to be 15,864,689 pounds of Cu, 949,733 pounds of Pb, 22,009 pounds of Zn, 182,659 ounces of Ag, and 52.13 ounces of Au.

The Apex mine, discovered in 1872, has been known by several names including the Utah-Eastern, Pen, Dixie, and Dixie-Apex mine. The mine is located in the NW¼SW¼SW¼ section 6, T. 43 S., R. 17 W., SLBM, and at an elevation of about 5500 ft. The mine produced small tonnages of very high grade Cu ore estimated to average about 26% Cu. The ore occurs in an irregular, steeply plunging, branching, chimney-like body (or bodies) about 200 to 350 ft long and 15 to 50 ft wide in plan view.

The mine was initially accessed by the Upper Adit on the 250 ft level (250 ft below the discovery pit) and then by a vertical internal winze (Main Shaft) in the footwall of the ore body. Later, the 500 ft level adit was driven with major levels off the Main Shaft (vertical) on the 630 ft level, 750 ft level, 900 ft level, 1100 ft level, 1330 ft level, and finally the 1400 ft level. The old inclined shaft in the ore body itself caved in 1905, and about this time the mine maps were lost in a fire (Kinkel, 1951). The primary land position at the Apex mine consists of a block of about 22 patented mining and 9 unpatented claims dating back to 1906 (table 1).

The following section is taken from the Hansen and others (1999) summary report. The presence of Ga-Ge was initially detected at the Apex mine by Gaylon Hansen in 1958, while prospecting for beryllium. Hansen held

Table 1. History of property ownership in the Apex mine area.

Property	Company	Office	Filed	Closed	Claims
Malachite	PPM PURE METALS*	Germany	1906	Current	9
Malachite	TECK COMINCO AMERICAN INC.	Spokane, WA	1906	Current	9
Eldorado	PAUL LAMOREAUX	Parowan, UT	1972	1994	14
Apex Dixie	PIONEER EXPLORATION	Midvale, UT	1986	1996	860
Dix-Apex	APEX MINERALS UT INC. (Gaylon Hansen)	Salt Lake City, UT	1995	1999	160
LVA	ZACHARY HENDERSON	Reno, NV	2010	Current	75

*PPM Pure Metals was formed from the merger of the non-ferrous metallurgical companies Penarroyo S.A. (France) and Preussag AG (Germany).

a series of purchase options on the property from 1964 to 1982, when his rights were sold to Musto Explorations, Ltd. of Vancouver, Canada. Musto proceeded to develop the mine and build a $28 million, 90-ton-per-day Ga-Ge mill/hydrometallurgical plant/refinery, located near the main paved roadway on the Piute Indian Reservation about 6.5 mi north-northeast of the mine. Production began in October 1985, making the Apex mine the world's first primary producer of Ga-Ge. However, the property only operated briefly due to metallurgical problems caused by the unexpectedly high carbonate content of the ore. Bulk metallurgical samples of the ore (dump?) suggested a lime content of 2 to 4%, but run-of-mine production averaged closer to 10 to 18%. This resulted in much higher than anticipated acid consumption making the initial acid digestion step uneconomical.

Hecla Mining Company purchased the property in 1989 for $5.5 million, were able to solve the metallurgical problems, produced Cu and Ge for about four months in 1990, but put the property on standby in 1991 because of a collapse of metal prices due to deep discounting by European producers. It is estimated that Hecla produced some 80,000 pounds of Cu-cathode during this period, but it is unclear if Ge was sold. Hecla continued to successfully run the mill/refinery to recover Co and W from electronic and industrial scrap. The Apex mine and this recycling operation were then purchased by the OM Group, Inc., and then in 1996, Cominco, Ltd./Preussag AG purchased the mine for $1 million. In 2005, the International Royalty Corporation purchased a 3% gross overriding royalty on the property. The current registered owner of the property is Teck Cominco American Inc./ Penarroyo (table 1). Teck, as mentioned previously, is the world's largest producer of Ge from their Trail, BC Pb-Zn smelting complex.

The Apex mine was developed to a depth of approximately 1400 ft where the ore was still thoroughly oxidized. Nearly all of the Cu-rich ore was removed from the mine by previous operators, leaving behind the Fe-rich minerals that contain the majority of the Ga-Ge. Production details are sketchy from the Apex mine, but are very crudely estimated at about 30,000 tons prior to 1963. Musto produced another 10,270 tons from the Apex mine in 1986 yielding 1645 pounds of Ga, 5634 pounds of Ge, and 224,800 pounds of Cu. The mine had a rated annual output of approximately 22,000 pounds Ga and 42,000 pounds Ge (Musto Explorations Ltd. annual report, 1987). Hecla operated the property briefly in 1990, yielding a similar production total to Musto's 1986 operation. Production during the Musto-Hecla period is believed to have been by an underground block cut and fill operation.

The Apex mine site has been partially reclaimed and the mill has been partially dismantled. The property suffered from metallurgical problems caused by an unanticipated high carbonate content of the ore. The current mine owners show no interest in reviving the operation. Mineral resources at the Apex mine are roughly 1 million tons averaging 0.033% Ga, 0.087% Ge, 1.8% Cu, and 41 ppm Ag (table 2). At current metal prices (March 2011) this in place resource is valued at in excess of $1 billion ($1110/ton) with roughly two-thirds of this amount in Ge. This resource could supply the entire world market for Ga for approximately 2.8 years and for Ge for 6.6 years.

Historically, the mine has also been a popular mineral collecting locality due to the deep oxidation of the complex Cu-As-Pb-Zn ore. In addition to the colorful Cu minerals azurite, malachite, chrysocolla, and brochantite, the mine was well known for the As minerals conichalcite and aurichalcite (Wenrich and others, 1987).

Table 2. Tonnage and grade for typical Kipushi type Cu±Pb±Zn deposits. Units in parts per million (ppm), and percent (%).

Deposit	Location	Type	Tons	Cu (%)	Ga (%)	Ge (%)	Pb (%)	Zn (%)	Ag (ppm)	Reference
Apex	Utah	Production	30,000 e	26.0			1.0		30.0	Butler and others, 1920; U.S. Bureau of Mines records (1916-1963)
Apex	Utah	Production^{r}	10,270	1.1	0.008	0.027				Burgin, 1987
Apex	Utah	Reserve	230,200	1.6	0.046	0.105				Hecla Mining Company, 1989
Apex	Utah	Resource^{1}	1,000,000 e	1.8	0.033	0.087	0.8	2.2	41.0	Hansen and others, 1999
Kennecott	Alaska	Production	4,800,000	12.5					70.0	Long and others, 1998
Ruby Creek	Alaska	Resource	90,000,000 e	1.2					95.0	Trueman, 1998
Tsumeb	Nambia	Production	33,000,000 e	4.0	^{P}	^{P}	9.0	3.2		Trueman, 1998
Kipushi	Zaire	Prod. & Res.	77,000,000	4.8	^{P}	^{P}	0.5	8.8		Trueman, 1998

^{e} Estimated.

^{r} Recovered metals.

^{P} These metals have been produced, but the grade is not reported.

^{1} Between the 170 ft and 1400 ft levels; including the above reserve.

GEOLOGIC OVERVIEW

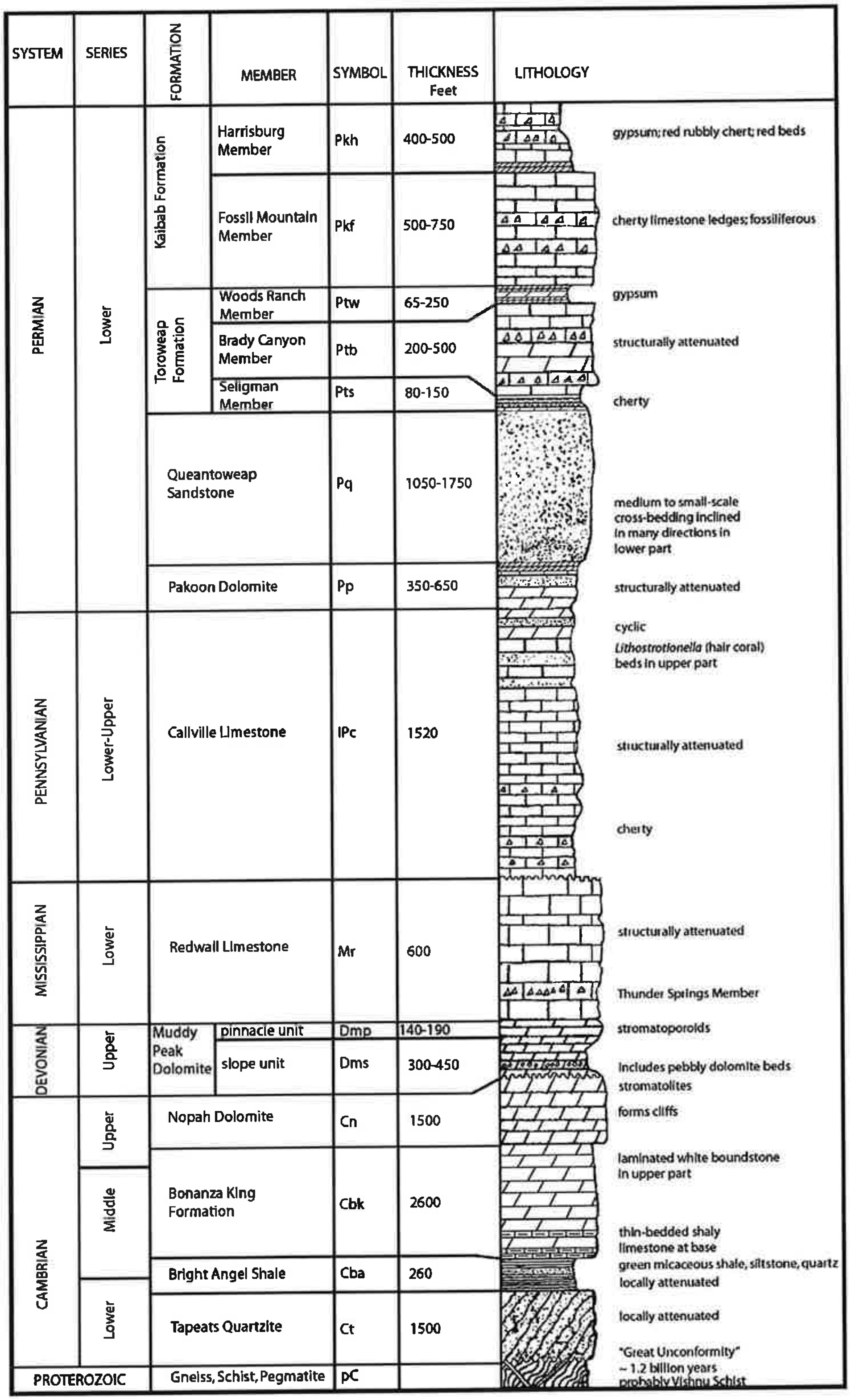
Geologic Setting

Stratigraphy

The SITLA Washington County Ga-Ge project area is located in the Beaver Dam Mountains where more than a 6-mi-thick sequence of strata is exposed. The stratigraphic sequence (figure 3) has been described by Hintze (1986) and Biek and others (2009), and consists of a relatively thin complex of Proterozoic rocks, and over 13,000 ft of Paleozoic strata, 12,000 ft of Mesozoic strata, and about 7000 ft of Cenozoic stratified volcanic and sedimentary rocks.

Proterozoic rocks crop out on the west side of the Beaver Dam Mountains in a continuous belt about 8 mi long and 4 mi wide, and are located about 3 mi northwest of the SITLA project area. The Proterozoic complex of rocks consists of gneiss, schist, and pegmatite that form the core of the Beaver Dam Mountains anticline. Dark-gray dioritic gneiss predominantly composed of amphibole is the most extensively exposed Proterozoic rock type, followed by predominantly mica and amphibole schist, pink granitic K-feldspar pegmatite, and less common white orthoclase pegmatite (Hintze, 1986). The pink granitic pegmatite dikes and sills are widespread and intrude the gneiss, schist, and white pegmatite.

Paleozoic strata in the Beaver Dam Mountains are mostly composed of marine carbonates, and lower Paleozoic strata generally thicken westward from the range and thin to the east. Cambrian rocks in the SITLA project area, from oldest to youngest, consist of the Tapeats Quartzite, Bright Angle Shale, Bonanza King Formation, and Nopah Dolomite (plate 2). The Cambrian Tapeats Quartzite is separated from the underlying Proterozoic complex by a marked unconformity. Tapeats Quartzite consists of reddish-orange to orange, thin- to very thick-



SYSTEM	SERIES	FORMATION	MEMBER	SYMBOL	THICKNESS Feet
PERMIAN	Lower	Kaibab Formation	Harrisburg Member	Pkh	400-500
			Fossil Mountain Member	Pkf	500-750
		Toroweap Formation	Woods Ranch Member	Ptw	65-250
			Brady Canyon Member	Ptb	200-500
			Seligman Member	Pts	80-150
		Queantoweap Sandstone		Pq	1050-1750
		Pakoon Dolomite		Pp	350-650
PENNSYLVANIAN	Lower-Upper	Callville Limestone		IPc	1520
MISSISSIPPIAN	Lower	Redwall Limestone		Mr	600
DEVONIAN	Upper	Muddy Peak Dolomite	pinnacle unit	Dmp	140-190
			slope unit	Dms	300-450
CAMBRIAN	Upper	Nopah Dolomite		Cn	1500
	Middle	Bonanza King Formation		Cbk	2600
		Bright Angel Shale		Cba	260
	Lower	Tapeats Quartzite		Ct	1500
PROTEROZOIC		Gneiss, Schist, Pegmatite		pC	

Figure 3. Simplified lithologic column of the Paleozoic section of the Jarvis Peak area, Beaver Dam Mountains; modified from Hayden and others (2005) with data from Hammond (1991).

bedded quartzite, having a few thin layers of quartz-pebble conglomerate and sandstone. The Tapeats Quartzite attains a maximum thickness of approximately 1200 ft and variations in thickness are believed to be caused by brittle tectonic attenuation faulting (Hintze, 1986). The Bright Angel Shale is mostly recessive, thinly bedded, micaceous siltstone, shale, and quartzite, having a measured thickness of 250 ft that locally thins or disappears due to tectonic attenuation faulting along bedding surfaces. The upper and lower Bright Angel Shale contacts are gradational with adjacent formations. The Bonanza King Formation consists mainly of medium- to light-brownish-gray, fine- to medium-grained, medium- to thick-bedded dolomite. The lower part of the formation also includes some bluish-gray, silty, limestone beds, and an olive-gray, slope-forming, shaly limestone. The formation has a measured thickness of about 2500 ft, but is heavily faulted and brecciated, and complete stratigraphic sections are rarely observable (Hintze, 1986). The Nopah Dolomite lies conformably above the Bonanza King Formation and consists of light-brownish gray, medium- to fine- grained, thick-bedded to massive dolomite, having algal stromatolites in its upper part. The Nopah Dolomite has a measured thickness of approximately 1300 ft, having variations in thickness likely due to tectonic attenuation and brecciation (Hintze, 1986).

Ordovician and Silurian deposits are missing from the Beaver Dam Mountains, and the Devonian is represented by the Muddy Peak Dolomite. The Muddy Peak Dolomite is divided into the Slope member in the lower part and Pinnacle member in the upper part (plate 2; Hintze, 1986). The lower Slope member is mainly a silty, fine-grained, light olive-gray to pale yellowish gray, thin- to medium-bedded dolomite, having a measured thickness of 520 ft. The upper Pinnacle member consists mostly of medium-gray, medium-crystalline, massive dolomite that contains sandy laminae and scattered chert nodules, and has a measured thickness of 160 ft. The Black Warrior mine (plate 2) developed a limonitic deposit in brecciated dolomite in the Pinnacle member.

The Redwall Limestone (plate 2) is generally divided in descending order into the Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members; however, in the Beaver Dam Mountains it is undivided (Hintze, 1986). The Redwall is a cliff-forming fossiliferous limestone that is typically medium- to dark-gray, thick-bedded, and locally cherty (Thunder Springs Member?). The Redwall Limestone has deformed plastically and faulting is usually hard to identify, but Hintze (1986) obtained a measured thickness of 850 ft near Horse Canyon. The contact between the resistant Redwall and overlying Callville Limestone is marked by a shallowing in slope angle. The majority of the mines and prospects in the SITLA project area occur in the Redwall Limestone (plate 2). In northern Arizona, numerous solution-collapse breccia pipes, similar to the breccia pipe that hosts the Apex ore deposit, begin in the Redwall Limestone and affect overlying strata (Wenrich, 1985).

The Apex ore body is primarily hosted by the Pennsylvanian Callville Limestone (plate 2). The Callville is a medium-gray, medium- to thick-bedded, commonly cherty and fossiliferous limestone, having light-gray dolomite increasingly in the upper third of the formation. The Callville is also cyclically interbedded with orange-weathering, calcareous siltstone or sandstone, which produces ledge-slope topography. Hintze (1986) reports that the Callville Limestone ranges in thickness from 1500 to possibly as much as 2000 ft, and Hammond (1991) indicates a thickness of 1520 ft. Kinkel (1951) notes that limestone predominates in the Apex mine above the 1100 ft level and shale only makes up a minor amount of the host rock; however, below the 1350 ft level "mottled green and red shales make up as much as 30% of the rock." Further, Kinkel (1951) notes that on the west side of the Apex ridge, the shale section is only a few hundred feet thick and is underlain by more massive limestone, presumably the Redwall.

The original Apex mine discovery pit is located approximately 250 to 550 ft above the base of the Permian Pakoon Dolomite (plate 2). The Pakoon primarily consists of light-gray, fine-grained dolomite that is commonly cherty and rarely fossiliferous, having massive gypsum or anhydrite present in the uppermost 60 ft. The Pakoon Dolomite produces ledge-slope topography similar to that of the underlying Callville Limestone, and the two are not readily distinguishable from each other. Hintze (1986) reports that the Pakoon Dolomite ranges in thickness from 700 to 900 ft.

Overlying the Pakoon Dolomite is the Queantoweap Sandstone, which is composed of fairly uniform, very-pale-orange to grayish-orange-pink, thin- to thick-bedded, fine- to medium-grained, variably cemented sandstone. The Queantoweap Sandstone ranges in thickness from 1500 to 2000 ft (Hintze, 1986). The Toroweap Formation overlies the Queantoweap Sandstone and consists of three members. The lower Seligman Member ranges in thickness from 50 to 200 ft, and is composed of a lower thin-bedded sandstone, a middle dolomitic sandstone and dolomicrite, and an upper sandy siltstone or gypsiferous sandstone. The middle Brady Canyon Member ranges in thickness from 200 to 300 ft, and is composed of biomicrite to biosparite that contains bedded nodular pinkish chert. The upper Woods Ranch Member ranges in thickness from 150 to 350 ft, and is composed of interbedded white laminated gypsum, gypsiferous siltstone, and thin-bedded dolomite. The Kaibab Formation overlies the Toroweap Formation and is composed of two members. The lower ledge-forming Fossil Mountain Member ranges in thickness from 250 to 300 ft, and consists of yellowish-brown to medium-gray biomicrite to biosparite that contains abundant chert. The upper Harrisburg Member ranges in thickness from 80 to 350 ft, and consists mainly of bedded gypsum, and lesser amounts of cherty dolomite, gypsiferous siltstone, and fossiliferous limestone. A significant unconformity is present between the Harrisburg Member of the Kaibab Formation and the overlying Moenkopi Formation (Hintze, 1986).

Few Mesozoic rocks are present in the vicinity of the SITLA project area, but significant exposures of Triassic rocks do occur several miles to the northeast. Cenozoic rocks in the project area consist of Quaternary alluvial and colluvial deposits (plate 2). No post-Proterozoic igneous rocks are exposed in the vicinity of the SITLA project area. The nearest igneous activity is approximately 10 mi to the northeast, and consists of numerous Quaternary basaltic lava flows.

Structure

The Beaver Dam Mountains are in a transitional region between the Basin and Range Province and Colorado Plateau. Structural features of the Beaver Dam Mountains are enigmatic, and the folds and faults have been interpreted differently as to their age and origin. Hintze (1986) concluded that the Beaver Dam Mountains anticline, Shivwits syncline, and Reef Reservoir fault zone and associated strata attenuation are late Mesozoic Sevier orogeny compressional features. Biek and others (2009) reported that the Beaver Dam Mountains anticline or culmination, Shivwits syncline, and the Gunlock-Reef Reservoir-Grand Wash fault zone are the result of late Tertiary and Quaternary displacement on left-lateral oblique-slip faults. These folds and faults are consistent with a regional pattern of significant left-lateral strike- and oblique-slip faulting at the eastern margin of the Basin and Range Province. Footwall uplift associated with the Piedmont-Red Hollow range-front fault zone along the western Beaver Dam Mountains also influenced the creation of the main Beaver Dam Mountains culmination.

The Beaver Dam Mountains are a structural culmination cored by Proterozoic crystalline rocks and overlain by mostly Paleozoic sedimentary rocks. The range trends north-northwest and is on the eastern edge of the Basin and Range physiographic province. Biek and others (2009) describe the range structure as an internally faulted and folded, northeast- and east-dipping homocline bounded on the east by the Gunlock-Reef Reservoir-Grand Wash fault zone and Shivwits syncline, and bounded on the west by the Piedmont-Red Hollow fault zone and Castle Cliff fault. The range is interpreted as a synextensional structure of late Tertiary age (Biek and others 2009). The Castle Cliff fault and gravity-slide blocks on the west side of the Beaver Dam Mountains document the rapid and major uplift of the range that occurred during the late Miocene along the range-front Piedmont fault. The Shivwits syncline is a major structure present approximately 3 mi to the northeast of the Apex mine. The northward-plunging axial trace extends for 9 mi west of and parallel to the Reef Reservoir fault and southern part of the Gunlock fault. Biek and others (2009) have interpreted the Shivwits syncline as a synextensional feature produced by left-lateral oblique-slip on the Gunlock-Reef Reservoir fault zone and structural crowding against the Beaver Dam Mountains culmination.

The Reef Reservoir and Grand Wash faults are the most significant faults in the Apex mine area and have greatly affected the region's structure. The northerly trending Reef Reservoir fault extends from just south of the Santa Clara River into Mine Valley, and is approximately 1.5 mi east of the Apex mine. The fault is a steeply dipping reverse fault that bounds the southeast-plunging nose of the Shivwits syncline. The Grand Wash fault is present about 2 mi east of the Apex mine in Mine Valley. The fault has normal displacement with the west side down and increasing displacement southward, forming an abrupt boundary between the Colorado Plateau and the Basin and Range at the Grand Canyon. The fault dies out 5 mi north of the Utah-Arizona state line near the Reef Reservoir fault (Biek and others, 2009).

Apex Ore Body

Ore Deposit Geology

The Apex ore body is classified as a carbonate hosted Cu ±Pb ±Zn deposit; these deposits are also referred to as Kipushi type (Model 32c) or Tsumeb type deposits (table 2; Cox and Bernstein, 1986; Trueman, 1998). Kipushi type deposits are characterized by high-grade, base-metal sulfide and As-sulfosalt replacements in dolomitic breccias. The deposits are typically Cu-rich with high Cu:Fe and Cu:S ratios and may have important Pb, Zn, Ag, As, Ge, Ga, and geochemical Co, Bi, Cd, Mo, U, V, and Ba. The primary copper minerals are commonly chalcopyrite (35% Cu) and the Cu-rich sulfides bornite (63% Cu), chalcocite (80% Cu), and the As-sulfosalts tennantite (48% Cu) and enargite (48% Cu). Other common minerals include galena, sphalerite, pyrite, barite, dolomite, calcite, and silica. Kipushi type deposits occur in zones of high fluid flow in karst terranes (i.e., breccia pipes and fault zones). High ore permeability can result in the deposits being oxidized to a considerable depth, often resulting in a bewildering array of oxide and carbonate minerals. Dolomitization is the most prominent alteration associated with these ore bodies. Kipushi type deposits are generally generated by basinal fluids and not with magmatic activity (Cox and Bernstein, 1986; Trueman, 1998). These deposits are sometimes crudely vertically zoned with more Cu near the surface and higher Fe at depth (Trueman, 1998).

The Apex ore body is located in dolomitized and silicified breccia, gouge, and fissures in steeply dipping fault zones, within a thick Paleozoic carbonate sequence on the east slope of the southern Beaver Dam Mountains. The ore deposit is located in the Pennsylvanian Callville Limestone and lowermost part of the Permian Pakoon Dolomite. In the vicinity of the mine, beds in the Callville Limestone generally dip gently east, but have variable dips of up to 10°, although farther east from the mine, the beds dip more steeply to the east.

The Apex ore zone (figure 4) is centralized in a steeply (75° to 80°) west-plunging, irregularly shaped breccia pipe, having minor fracture and stratigraphic controlled extensions into the surrounding country rock. The steep westerly plunge makes the pipe nearly normal to the host strata. This offers a slight suggestion that the pipe may have formed when the beds were still flat-lying (i.e., prior to folding). Rocks surrounding the breccia pipe are strongly fractured, forming a concentric pattern around the breccia pipe.

The Apex fault (plate 2) strikes about N. 30° W. and dips 70° SW., and has a spatial and perhaps genetic relationship with the ore body. The fault has approximately 250 ft reverse displacement (Kinkel, 1951), typically having a distinctive sharp fault plane, but sometimes represented by limonitic gouge and breccia several feet thick. This structure has a surface trace of 2000 ft or more. The ore zone is in contact with the Apex fault only at the surface, and diverges from the fault at depth (figure 4) where it is associated with numerous smaller, subparallel faults. Almost all of the ore body mineralization is located in the footwall of the Apex fault, while the hanging wall consists mostly of barren dolomitized limestone. Erosion has removed any mineralization that may have occurred in the upthrown block. Petersen and others (1988) report that the fault post-dates formation of the breccia pipe, which diverges from the fault with increasing depth, and that the timing of the mineralizing event versus the fault cannot be determined. However, ore deposition is confined to brecciated, fissured, and sheared zones associated with the Apex fault and breccia pipe.

The breccia pipe ore at the Apex mine has been developed to about the 1400 ft level (figure 4), and at this depth it consists almost entirely of oxide and sulfate minerals. Formation of the breccia pipe was critical to preparing the ground for mineralization. The pipe crops out at the surface in the lower Pakoon Dolomite and has been mined down through the middle Callville Limestone, but its downward termination is unknown. The breccia pipe is approximately elliptical in plan, elongated up to 350 ft northwesterly and 100 ft trending northeasterly (Petersen and others, 1988). Alteration of the country rock surrounding the breccia pipe is extensive and has produced concentric zoning around the ore body. At the periphery are unaltered limestones and dolostones, which become more siliceous and eventually give way to a siliceous dolostone interval approximately 10 to 65 ft in width (Petersen and others, 1988). Closer to the pipe, siliceous dolostone gradually becomes more siliceous until only completely silicified rock remains. This completely silicified rock zone ranges in width from 0 to 30 ft, and its width increases with depth (Petersen and others, 1988). The breccias within the pipe are composed of polylithologic fragments randomly oriented

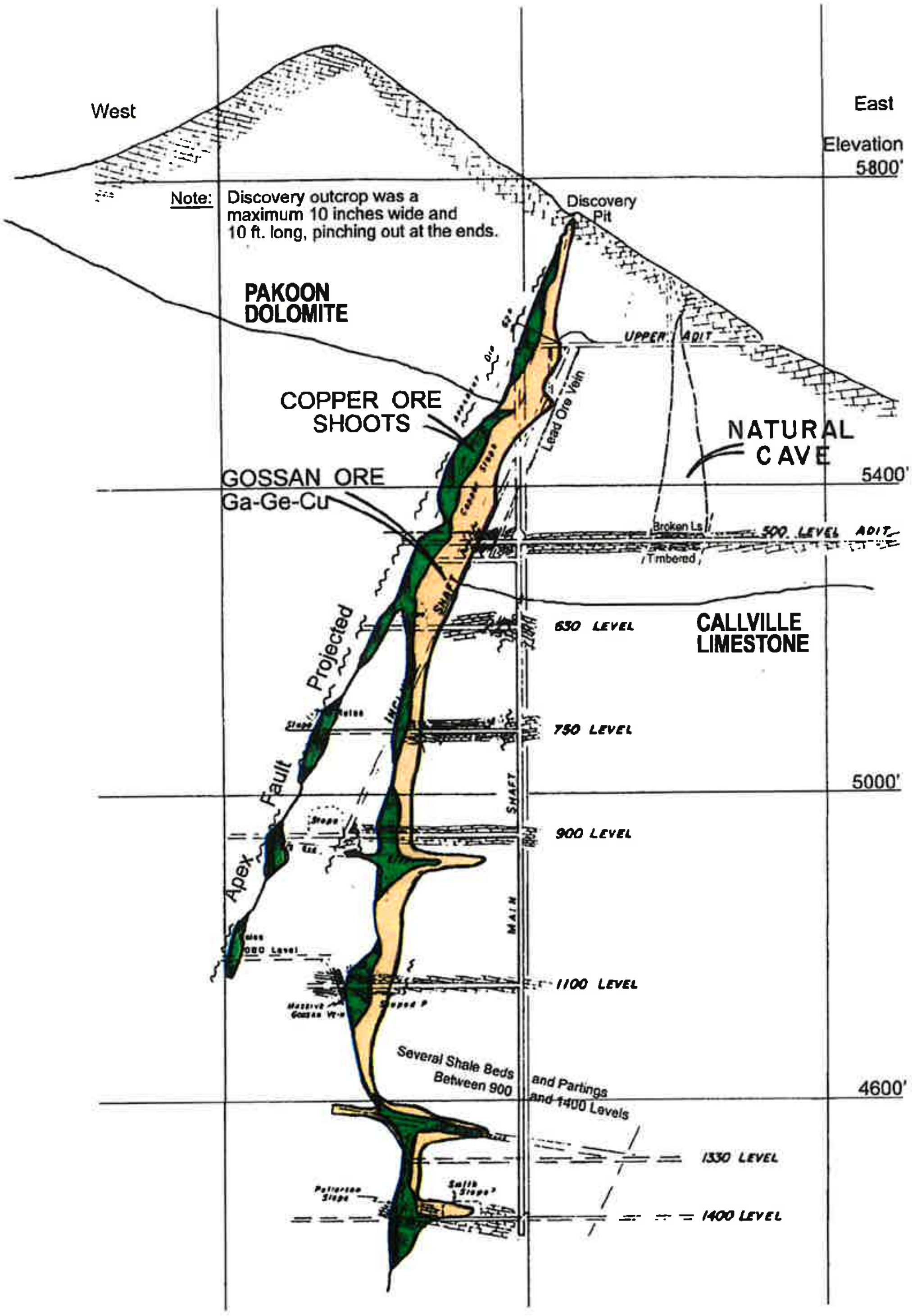


Figure 4. Diagrammatic east-west cross section through the Main Shaft (winze) of the Apex mine; after Kinkel (1951) and modified from Hansen and others (1999). The Callville Limestone-Pakoon Dolomite contact is approximated based on mapping by Hammond (1991) and a stratigraphic correlation by Kinkel (1951).

and varying in size from submillimeter sand to blocks over 50 ft in diameter. Clasts have been completely replaced in many areas in the ore zone, and silicified clasts in a limonitic matrix commonly occur on the periphery of the ore zone. Completely replaced breccia clasts consist of either yellow limonite in a matrix of darker yellow to red goethite and hematite or white to pink silica powder (Petersen and others, 1988).

The breccia pipe hosting the Apex ore body is a solution-collapse structure formed from low-temperature (<194° F) solutions moving through fractures and faults to dissolve soluble limestone beds in the Callville Limestone and Pakoon Dolomite (Petersen and others, 1988). Limestone ^{18}O depletion and the low temperature of dolomitization strongly indicate that the formation of the breccia is not related to the main mineralization event. Fluid inclusion work (Petersen and others, 1988) indicates a maximum temperature in excess of 392° F for main-stage ore mineralization. Other evidence for a solution-collapse origin is found in the concentric fractures surrounding the pipe, which implies inward collapse of the beds. In northwestern Arizona, solution-collapse breccias in late Paleozoic rocks also exhibit these concentric fractures (Wenrich, 1985). Unmineralized breccias, breccias having equally silicified clast and matrix material, and textural evidence from the complete replacement of clasts also indicate that breccia pipe formation occurred prior to ore mineralization (Peterson and others, 1988). Solution-collapse timing is problematic, but cross-cutting structure and stratigraphic relationships and a widespread erosional interval taking place in the Late Permian through the mid-early Triassic, suggest this period, or later, for karst development (Petersen and others, 1988).

In addition to the breccia ore, several short zones of bedding replacement ores (mantos) occur adjacent to the pipe in favorable carbonate horizons. These shallow-dipping replacement bodies can extend as much as 50 ft from the subvertical breccia ore (Hansen and others, 1999).

Since ores on the 1400 ft level were nearly completely oxidized, Bernstein (1986) estimates that the present-day water table may lie about 230 ft below the bottom of the workings, possibly in the Redwall Limestone. However, due to the reactive carbonate host rocks the Apex ores are oxidized, but not leached of metals, so it is doubtful that significant supergene enrichment would occur even if sulfides were encountered. However, Wenrich and others (1987) argue that U may have been present in the pipe, and was completely leached near the surface and could occur at the oxide/sulfide interface at depth.

The deposits in Tsumeb, Namibia and Kipushi, Zaire are large, important deposits (table 2) similar to the Apex deposit (Bernstein, 1986). These three deposits have carbonate host rocks near the margins of sedimentary basins, and also lack igneous rocks in the mineralized areas. In such deposits, solution-collapse in a karst environment initially prepared the ground for mineralization. Mineralization occurs in pipes, chimneys, and/or mantos where solutions encountered horizons favorable for replacement (Hansen and others, 1999). The deposits have distinctive elemental assemblages containing Cu, Zn, Pb, As, Co, Ag, Ge, Ga, Mo, W, Sn, Bi, U, and V that have great vertical continuity and deep oxidation (Cox and Bernstein, 1986).

The Apex ore deposit has a Kipushi type geochemical signature. UGS sampling shows the Apex Cu-Ga-Ge ore is strongly anomalous in Ag, As, Bi, Cd, Mo, Pb, Sb, Te, and moderately anomalous in Re, S, and Zn. Curiously, the ore seems to be depleted in Mn. Grades at the Apex mine do not decrease with depth (Hansen and others, 1999).

Mineralogy and Paragenesis

The following sections were taken from Petersen and others (1988). The ore zone exposed in the Apex mine consists primarily of earthy, yellow-brown, friable limonite; dark-brown, compact to glassy goethite; greenish-yellow to amber, coarsely crystalline, delicately zoned jarosite-family minerals; microcrystalline jarosite-family minerals; fine-grained quartz; alunite-family minerals; and minor muscovite and hematite. Supergene oxidation minerals in locally high concentrations are found rimming dolomite clasts and lining vugs in goethite and include azurite, malachite, and other Cu-Pb-Zn-As minerals. Only small concentrations of primary pyrite, marcasite, galena, chalcopyrite, chalcocite, bornite, and covellite are found dispersed in the limonitic ore matrix. Bernstein (1986) also reports the presence of sphalerite, barite, and possible tennantite, renierite, germanite, and gallite [$CuGaS_2$].

The ore deposit has a difficult to discern paragenetic sequence because the overprint of supergene oxidation is not easily distinguishable from oxidized hypogene minerals, and some minerals from an earlier stage are oxidized in later stages. However, three stages of mineralization are recognized. Stage 1 mineralization consists of intense silicification of the host rock, having jasperoid replacing limestone or dolostone in the breccia pipe. Pale green pseudo-cubic crystals of alunite-family goyazite [$SrAl_3(PO_4)_2(OH)_5(H_2O)$] minerals and dolomite, and small amounts of hydrothermal sericite, are associated with the jasperoid. Locally abundant marcasite rimmed by pyrite, and minor chalcopyrite also appears in Stage 1 mineral assemblages. Colloform quartz banding attributed to the transition from Stage 1 to Stage 2 mineralization may be recognized as a result of crystallization from a silica gel at temperatures below 392° F (Petersen and others, 1988).

Stage 2 mineralization consists of high-temperature quartz, sulfates, Ga-bearing sulfides, Ga-bearing jarosite-family minerals, Fe-oxides, possibly Ge-bearing goethite, and very fine grained powdery limonite. Chalcopyrite, bornite, galena, and primary or secondary chalcocite also appear in Stage 2 mineral assemblages. Stage 2 consists of relatively clean interlocking grains of quartz that contain sparse to abundant fluid inclusions, and the lack of colloform quartz and chalcedony indicate the quartz is primary. High-temperature (<356° F) fluid inclusions in the quartz suggest the presence of hypogene jarosite in Stage 2. Also, the presence of sulfate in Stage 1 and anhydrite and svanbergite [$SrAl_3(PO_4)(SO_4)(OH)_6$] in Stage 2 indicate oxidizing conditions conducive to jarosite formation existed during part of the main mineralizing event. In supergene environments jarosite is observed forming directly from pyrite; however, at the Apex deposit pyrite weathers directly to hematite and lesser limonite, and jarosite has not been observed to replace galena or any other sulfide (Petersen and others, 1988).

Minerals of possibly late hypogene and supergene origin occur in Stage 3 mineralization. In the core of the breccia pipe, Ga-bearing beudantite [$PbFe_3(AsO_4)(SO_4)(OH)_6$] group minerals (probably gallobeudantite [$PbGa_{1.5}Fe^{3+}_{0.8}Al_{0.6}Zn_{0.1}(AsO_4)_{1.1}(SO_4)_{0.9}(OH)_{5.9}$]; Jambor and others, 1996) are found, and Cu carbonates and arsenates are associated with dolostone on the periphery of the pipe. In Stage 3, massive hematite after pyrite and marcasite is common. Medium- to dark-brown goethite that is quite hard due to admixed microscopic quartz grains occurs, as well as lighter brown, non-vitreous, massive to vuggy varieties of goethite. In the interior of the pipe, yellow friable limonite is the most common Fe-oxide. In Stage 3 mineralization, malachite occurs after azurite in vugs, radiating fibers of adamite [$Zn_2(AsO_4)(OH)$] - olivenite [$Cu_2(AsO_4)(OH)$] can be found lining vugs in hard goethite, and minor covellite is found replacing chalcopyrite and galena (Petersen and others, 1988).

Gallium and Germanium

Gallium is concentrated primarily in beudantite-group minerals associated with jarosite and to a lesser extent in limonite in the Apex ore body. Gallium in the Apex ores may have originally been contained in the Cu sulfides, but other Ga-bearing minerals (sphalerite, gallite, germanite, renierite, and briartite [$Cu_2Zn_{0.75}Fe_{0.25}GeS_4$]) could have added to the overall grade. Gallium is found in Fe, Zn, and Cu sulfides and substitutes for Fe in beudantite-group and jarosite-family minerals in the deposit. Chalcopyrite can carry up to 1300 ppm Ga, and lesser amounts of Ga (ranging up to 600 ppm) can occur in pyrite, chalcocite, and bornite (Petersen and others, 1988). Coarsely crystalline jarosite carries up to a few hundred ppm Ga, and massive Fe-oxide can rarely contain up to 1400 ppm Ga in an unknown state. Beudantite-group minerals contain most of the Ga in the Apex deposit and individual crystals contain over 18.1 wt % Ga_2O_3 (Petersen and others, 1988). Gallium ore grades may have been influenced by the presence of gallite (Petersen and others, 1988).

Germanium is concentrated primarily in goethite and to a lesser extent in hematite in the Apex ore body. In Fe and Cu sulfides, Ge occurs in small amounts ranging from 0 to 700 ppm; however, unless significant enrichment has taken place these sulfides cannot account for the overall Ge grade in Apex ores (Peterson and others, 1988). Primary Ge minerals have not been recognized in the Apex ores, but were likely present originally. Germanium is found in the ore in hematite ranging up to 7000 ppm, and in goethite ranging up to 11,000 ppm, but is irregularly distributed (Petersen and others, 1988).

Source(s) of Gallium and Germanium

Carbonate rocks in the Apex mine area are depleted in Ga and Ge in respect to average crustal abundance, so it is unlikely that the elements could have been leached from the extensive carbonate section surrounding the deposit (Petersen and others, 1988). Metamorphic rocks, felsic igneous rocks, and some shales, however, may be naturally enriched in these elements. Proterozoic gneiss, schist, and pegmatite exposed a few miles to the northwest of the Apex mine, and the Cambrian Bright Angel Shale are possible source rocks. Petersen and others (1988) report strontium isotope evidence for a deep source for all the metals present in the Apex ore body. Their work demonstrates that Stage 1 minerals have much higher strontium content than the carbonate wall rocks, but a lower content than the Proterozoic rocks and Bright Angel Shale, suggesting that some of the strontium in the deposit may have been derived from these older rocks. The highly fractured nature of the entire stratigraphic section would permit fluid movement from the basement rocks up to the deposit, a vertical distance of over 8800 ft. Fluid inclusion work by Petersen and others (1988) indicates that the fluids transporting the ore minerals were formed in a boiling environment, and the trapped fluids in the inclusions represent heated meteoric water or connate water from a basin in which halide evaporites are absent.

The Apex ore body and other mineral deposits in the district have no spatial connection to igneous activity and the timing of the mineralization remains enigmatic. However, K-Ar dating of muscovite from underground workings at the Apex mine gave a Triassic-Jurassic age of 200 ±7 Ma (Petersen and others, 1988). The muscovite was collected from a fracture near the margin of the breccia pipe and is presumably of hydrothermal origin related to mineralization. Coarsely crystalline jarosite samples taken from approximately the same underground workings level as the muscovite give K-Ar ages of 12.0 ±0.7 Ma and 6.8 ±0.4 Ma (Petersen and others, 1988). The 200 Ma age may relate to the original period of ore mineralization; however, the 12 Ma age is more likely tied to the period of Basin and Range extension, uplift, rotation, and supergene oxidation of the Apex ore.

Apex Ore Deposit Summary

The following genetic model proposed by Petersen and others (1988) summarizes the Apex mine Ga-Ge deposit.

1. The subvertical Apex solution-collapse breccia pipe formed sometime after the Late Permian and prior to the Jurassic.

2. Hydrothermal waters (<392° F) that leach Ga, Ge, base metals, and possibly S from deep in the section entered the breccia pipe about 200 million years ago, forming early (Stage 1) jasperoid, dolomite, muscovite, goyazite, marcasite, pyrite, and chalcopyrite.

3. Hot (>392° F), low-salinity, hydrothermal fluids (Stage 2) boiled, causing “acid sulfate” alteration and precipitating high-temperature quartz, anhydrite, Ga- and Ge-bearing sulfides, goyazite, crystalline jarosite, and oxidized some of the early sulfides to goethite and limonite (hypogene oxidation).

4. Supergene oxidation by near-neutral-pH meteoric water formed goethite and Cu-carbonates at the margins of the pipe and limonite and beudantite-group minerals in the core of the breccia.

SITLA PROJECT AREA GALLIUM AND GERMANIUM RESOURCES

Data Sources

Published Reports

Modest amounts of published work exists on the Apex mine and the mineral resources associated with it, but very little published information could be found on mineralization in the two SITLA sections that are the focus of this investigation. No published information was found on mineralization in SITLA section 36, T. 42 S., R. 18 W., SLBM. A very small amount of published information exists on the Jessie mine located in the southeast corner of SITLA section 2, T. 43 S., R. 18 W., SLBM.

Perry and McCarthy (1977) report that all of the workings on the Jessie mine are shallow, and are aligned along a fault or fissure striking N. 45° E. and dipping 40° to 50° northwest. Ore minerals recognized at the deposit include azurite, malachite, and cerussite in a gangue of limonite and manganese oxides that replace Mississippian Redwall Limestone. Copper carbonate mineralization occurs as rims on limonite, cerussite, and manganese oxide centers. Perry and McCarthy (1977) report that the mineralized zone ranges in width from 2 inches to 3 ft, was followed to a depth of 50 ft, and there are no reserves remaining in the mine. Hammond (1991) mapped the geology of the Jarvis Peak quadrangle and collected a grab sample from the Jessie mine adits and dumps, but it was not assayed for Ga or Ge.

Unpublished Reports

A significant amount of unpublished work exists on the Apex mine and the mineral resources associated with it, and some unpublished information was found on mineralization in SITLA sections 2 and 36 that are the focus of this investigation. In April, 1985, geologist Robert U. Suda prepared a report for Cominco American Inc. titled "Evaluation of the Apex Property Washington County, Utah." He collected 46 samples for geochemical analysis from mines and prospects on the adjoining Hansen and Musto Explorations Ltd. Apex properties. The Hansen Apex Property was a huge 9000-acre claim and lease block controlled by Gaylon Hansen, which surrounded Musto's Apex claim block. This property extended north-northwest along the crest of the Beaver Dam Mountains and included SITLA section 32, T. 41 S., R. 18 W.; section 16, T. 42 S., R. 18 W.; section 36, T. 42 S., R. 18 W.; section 32, T. 42 S., R. 17 W.; section 2, T. 43 S., R. 18 W.; and section 16, T. 43 S., R. 17 W., SLBM. Analytical results of these samples are given in table 3. Within the Hansen property several small mines, prospects, and occurrences demonstrate similar characteristics to the mineralization at the Apex deposit. Most of these locations contain base-metal-bearing gossan occurrences in the Redwall Limestone. A large part of the SITLA project area coincides with the Hansen Apex Property; however, some of the samples collected were from outside of the SITLA project area.

Suda (1985) mostly collected high-grade samples from gossanous material from mine walls or dumps, and four samples (455-458) were collected from Musto's Apex mill stockpiles. Samples were analyzed for Ag, As, Au, Cu, Fe, Ga, Ge, Hg, Pb, and Zn (table 3). Eight of the samples, not including Apex mill site dumps, contained elevated Ge values ranging from 30 to 4000 ppm; seven samples, not including Apex mill site dumps, contained elevated Ga values ranging from 35 to 156 ppm. The high Ga-Ge values all occur in or stratigraphically above the Redwall Limestone and generally correlate with anomalous Ag, Cu, Pb, and Zn values. When compared to the Apex mill stockpile samples, the gossan-bearing mine and prospect samples show lower overall values for Ga, Ge, Ag, and base metals, but a similar correlation of Ga and Ge with base metals, As, and Hg. High Ge values, above or equal to Apex mill stockpiles, were detected at the Westside/Eldorado, Hot Box, and Jessie mines (plate 1). A comparison of the geochemistry between the Apex ores and other gossan-base metal occurrences indicates that the processes that formed the Apex deposit also occurred at other deposits in the area. Weaker base metal and Ag values for the other occurrences indicate a lower intensity of mineralization or that the level of exposed mineralization differs from that of the Apex deposit.

Only four samples (129-132) were collected by the Suda (1985) investigation on SITLA land within the project area (plate 1). The samples were collected from the Jessie mine in SE¼ section 2, T. 43 S., R. 18 W., SLBM, and show elevated values for Ga, Ge, As, Cu, Fe, Pb, and Zn. Gallium values range from <20 to 77 ppm, and Ge values range from <20 to 1350 ppm (table 3). Highly anomalous Ge, measuring 4000 ppm (highest of the 46 samples), was found by the Suda (1985) investigation at the Westside/Eldorado mine that is less than a quarter mile east of SITLA section 2. Gallium in the sample is slightly elevated at 44 ppm.

In April 1987, consulting geologist Bernard Dewonck prepared a summary report for GaGe Minerals Corporation on its Apex properties that surrounded Musto's Apex mine and claims. GaGe Minerals

Table 3. Assays from Suda (1985) sampling on the Hansen Apex and Musto Explorations properties in the Beaver Dam Mountains, Washington County. Units in parts per million (ppm), parts per billion (ppb), and percent (%).

SAMPLE No.	LOCATION	UTM-E (m)	UTM-N (m)	UTMZ	DATUM	MINE OR PROSPECT	Ag (ppm)	As (ppm)	Au (ppb)	Cu (ppm)	Fe (%)	Ga (ppm)	Ge (ppm)	Hg (ppb)	Pb (ppm)	Zn (ppm)
113	NW SW NW sec. 1, T.43S., R.18W.	249068	4107104	12	NAD 83	Westside	0.4	73.0	10.0	80.0	0.39	<20	<20	<10	11.0	32.0
114	NW SW NW sec. 1, T.43S., R.18W.	249068	4107104	12	NAD 83	Westside	29.0	E 8000	5.0	19800.0	28.00	44.0	4000.0	750.0	781.0	698.0
115	NE SW NW sec. 1, T.43S., R.18W.	249157	4107121	12	NAD 83	Westside	0.7	39.0	<5	76.0	0.90	<20	<20	10.0	19.0	72.0
116	SW SW NW sec. 1, T.43S., R.18W.	249093	4106953	12	NAD 83	Westside	0.7	38.0	<5	61.0	2.10	<20	<20	40.0	21.0	562.0
117	NW SW NW sec. 1, T.43S., R.18W.	249108	4107071	12	NAD 83	Westside	4.4	44.0	<5	74.0	20.20	<20	<20	50.0	3820.0	204000.0
118	NE NW SW sec. 1, T.43S., R.18W.	249235	4106676	12	NAD 83	Surprise	0.4	57.0	<5	70.0	0.76	<20	<20	44.0	37.0	1370.0
119	NE NW SW sec. 1, T.43S., R.18W.	249235	4106676	12	NAD 83	Surprise	0.5	125.0	110.0	1690.0	0.78	<20	<20	40.0	8.0	261.0
120	NW SE SW sec. 1, T.43S., R.18W.	249471	4106357	12	NAD 83	Hot Box	4.4	E 8000	<5	41100.0	28.00	156.0	580.0	420.0	286.0	3780.0
121	NW SE SW sec. 1, T.43S., R.18W.	249471	4106357	12	NAD 83	Hot Box	81.0	E 3180	<5	4860.0	9.90	109.0	234.0	366.0	1820.0	938.0
122	NW SE SW sec. 1, T.43S., R.18W.	249471	4106357	12	NAD 83	Hot Box	1.0	348.0	<5	615.0	1.40	<20	<20	50.0	45.0	267.0
123	SW NE SW sec. 1, T.43S., R.18W.	249428	4106542	12	NAD 83	adit north of Hot Box mine	4.6	370.0	<5	568.0	20.10	<20	<20	70.0	7500.0	76500.0
124	SW SE NW sec. 1, T.43S., R.18W.	249369	4106941	12	NAD 83	road to Eldorado	0.6	48.0	<5	25.0	0.62	<20	<20	<10	80.0	367.0
125	NE SW NW sec. 1, T.43S., R.18W.	249257	4107178	12	NAD 83	Eldorado	1.1	429.0	<5	49.0	15.80	<20	<20	80.0	800.0	1640.0
126	NE SW NW sec. 1, T.43S., R.18W.	249257	4107178	12	NAD 83	Eldorado	0.7	E 1120	<5	90.0	20.10	<20	<20	154.0	262.0	5560.0
127	NE SW NW sec. 1, T.43S., R.18W.	249257	4107178	12	NAD 83	Eldorado	1.1	E 1550	<5	48.0	18.90	<20	30.0	156.0	703.0	3730.0
128	SE NW NW sec. 1, T.43S., R.18W.	249227	4107300	12	NAD 83	Eldorado	0.8	E 1400	<5	33.0	17.80	<20	<20	60.0	557.0	3160.0
129*	SW SE SE sec. 2, T.43S., R.18W.	248606	4106152	12	NAD 83	Jessie	0.7	E 1410	10.0	7550.0	38.00	22.0	1350.0	120.0	55.0	186.0
130*	SW SE SE sec. 2, T.43S., R.18W.	248606	4106152	12	NAD 83	Jessie	0.7	50.0	<5	5480.0	2.20	<20	<20	40.0	13.0	103.0
131*	SW SE SE sec. 2, T.43S., R.18W.	248606	4106152	12	NAD 83	Jessie	0.2	151.0	<5	293.0	0.81	<20	<20	240.0	18.0	80.0
132*	SW SE SE sec. 2, T.43S., R.18W.	248606	4106152	12	NAD 83	Jessie	4.7	E 11600	<5	17050.0	55.00	77.0	<20	188.0	985.0	913.0
133	NE NE SE sec. 21, T.43S., R.18W.	245381	4101873	12	NAD 83	Jose Cuervo	0.4	1800.0	<5	79.0	1.74	<20	<20	40.0	<4	111.0
134	NE NE SE sec. 21, T.43S., R.18W.	245381	4101873	12	NAD 83	Jose Cuervo	0.7	15200.0	<5	240.0	22.00	<20	<20	42.0	10.0	1060.0
135	NE NE SE sec. 21, T.43S., R.18W.	245381	4101873	12	NAD 83	Jose Cuervo	1.2	33600.0	<5	301.0	38.00	26.0	<20	80.0	53.0	1790.0
136	NE NE SE sec. 21, T.43S., R.18W.	245381	4101873	12	NAD 83	Jose Cuervo	0.4	2340.0	<5	54.0	4.40	<20	<20	20.0	<4	639.0
137	SW SW SW sec. 22, T.42S., R.18W.	245945	4110936	12	NAD 83	North Castle Cliff Wash	0.2	173.0	<5	52.0	28.00	<20	<20	<10	455.0	118.0
138	NE NW NW sec. 27, T.42S., R.18W.	246028	4110847	12	NAD 83	North Castle Cliff Wash	0.5	72.0	<5	63.0	30.00	<20	<20	30.0	933.0	769.0
139	NE NW NW sec. 27, T.42S., R.18W.	246136	4110840	12	NAD 83	North Castle Cliff Wash	0.3	58.0	<5	105.0	50.00	20.0	<20	<10	273.0	1260.0
140	SW SW SW sec. 22, T.42S., R.18W.	245866	4110952	12	NAD 83	North Castle Cliff Wash	0.2	102.0	<5	27.0	28.00	<20	<20	<10	247.0	249.0
141	SW SE SW sec. 27, T.42S., R.18W.	246294	4109443	12	NAD 83	outcrop	0.3	12.0	<5	8.0	0.66	<20	<20	<10	12.0	38.0
143	SW NW NE sec. 27, T.42S., R.18W.	246795	4110614	12	NAD 83	Jubilee	0.2	59.0	<5	24.0	26.00	<20	<20	<10	289.0	398.0
144	SW NW NE sec. 27, T.42S., R.18W.	246795	4110614	12	NAD 83	Jubilee	0.2	61.0		22.0	31.00	<20	<20	<10	337.0	409.0
145	NW NE SE sec. 1, T.43S., R.18W.	250211	4106576	12	NAD 83	shaft northwest of the Apex mine	2.0	492.0	20.0	17.0	16.30	35.0	37.0	1420.0	3390.0	2330.0
146	NW NE SE sec. 1, T.43S., R.18W.	250211	4106576	12	NAD 83	shaft northwest of the Apex mine	7.3	1200.0	25.0	37.0	15.20	49.0	32.0	1274.0	1600.0	1180.0
147	NW NE SE sec. 1, T.43S., R.18W.	250211	4106576	12	NAD 83	shaft northwest of the Apex mine	100.0	780.0	30.0	15.0	14.00	48.0	36.0	2500.0	4700.0	1410.0
148	NW NE SE sec. 1, T.43S., R.18W.	250244	4106564	12	NAD 83	shaft northwest of the Apex mine	0.7	26.0	<5	12.0	0.66	<20	<20	100.0	72.0	65.0
149	SE SE NE sec. 22, T.42S., R.19W.	237758	4112084	12	NAD 83	Reber Wash	1.2	4.0	<5	4140.0	4.70	<20	<20	50.0	23.0	36.0
150	SW SW NW sec. 23, T.42S., R.19W.	237889	4112009	12	NAD 83	Reber Wash	0.2	7.0	<5	709.0	1.79	<20	<20	36.0	8.0	15.0
451	SW SW NW sec. 23, T.42S., R.19W.	237911	4111991	12	NAD 83	Reber Wash	0.6	18.0	<5	3060.0	4.30	<20	<20	100.0	6.0	39.0
452	SW SW NE sec. 23, T.42S., R.19W.	238653	4112109	12	NAD 83	outcrop	0.9	9.0	15.0	641.0	4.20	<20	<20	80.0	40.0	111.0
453	SW NW SE sec. 30, T.42S., R.18W.	241890	4109983	12	NAD 83	Welcome Spring	0.9	7.0	385.0	4230.0	0.74	<20	<20	54.0	<4	8.0
454	NW NW SE sec. 30, T.42S., R.18W.	241740	4110074	12	NAD 83	Welcome Spring	1.3	10.0	1860.0	16100.0	2.60	<20	<20	210.0	13.0	26.0
455	NW SW SW sec. 6, T.43S., R.17W.	250715	4106245	12	NAD 83	Apex mill site dump	42.2	3780.0	5.0	19200.0	10.70	372.0	608.0	1060.0	10600.0	20200.0
456	NW SW SW sec. 6, T.43S., R.17W.	250715	4106245	12	NAD 83	Apex mill site dump	53.0	4780.0	<5	19300.0	10.80	412.0	646.0	1320.0	13400.0	20200.0
457	NW SW SW sec. 6, T.43S., R.17W.	250715	4106245	12	NAD 83	Apex mill site dump	48.0	4340.0	<5	13100.0	22.20	316.0	1014.0	1806.0	13300.0	10280.0
458	NW SW SW sec. 6, T.43S., R.17W.	250715	4106245	12	NAD 83	Apex mill site dump	27.0	3560.0	5.0	20300.0	9.20	323.0	532.0	920.0	6730.0	16200.0

* indicates samples collected on SITLA owned land.

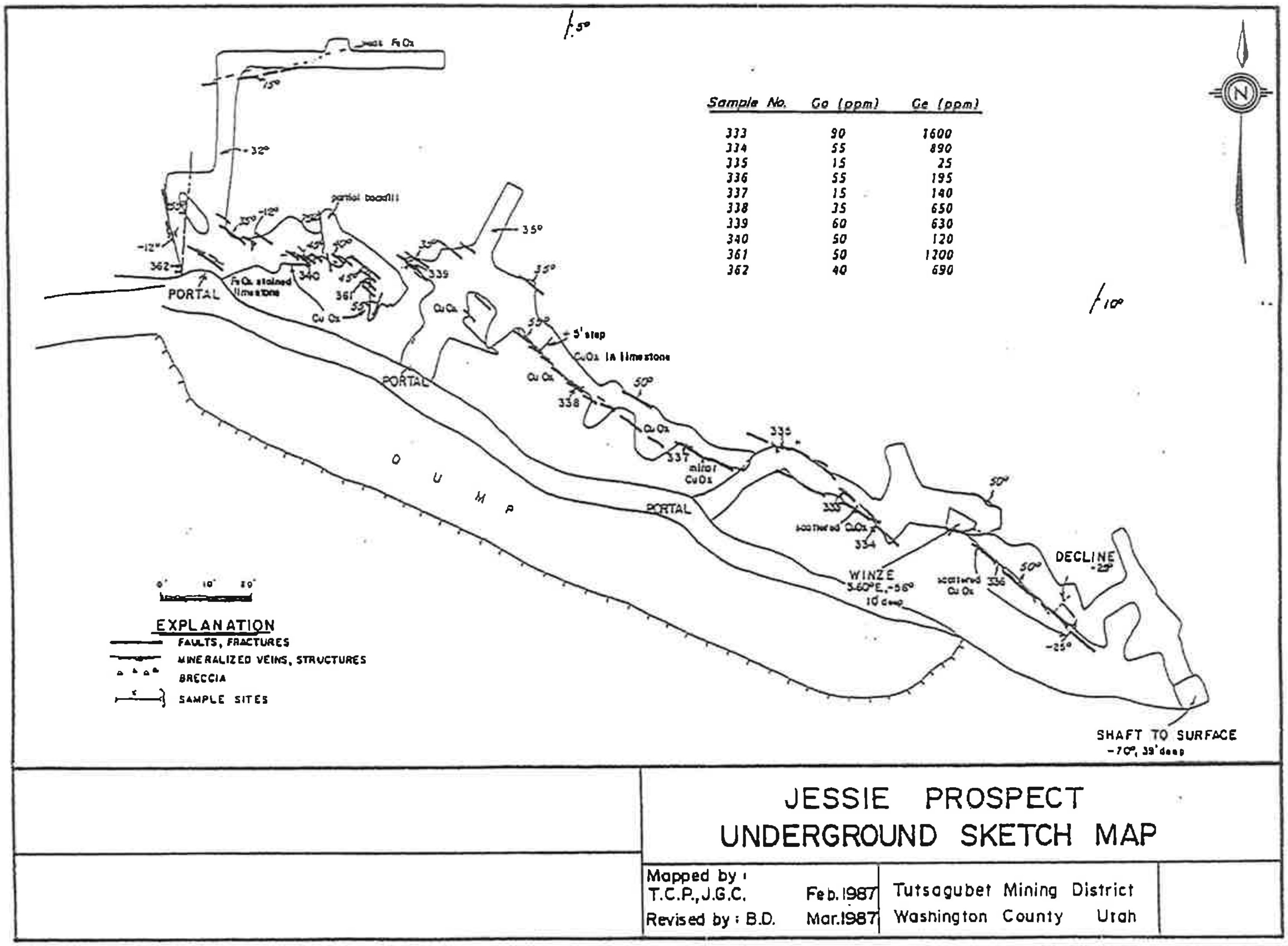
Corporation, controlled by Gaylon Hansen, was formerly the Hansen Apex property also held by Hansen. GaGe Minerals increased its land holdings to 23,000 acres mostly northwest of the old Hansen Apex property block. Dewonck (1987) identified several small mines and prospects that have mineralogy, geochemistry, and structure similar to that at the Apex mine. Dewonck (1987) reports that the mines and prospects of greatest interest are the Westside (West Eldorado), East Eldorado, Jessie, South Jessie, and Higgins. None of these mines had significant production, but the numerous short adits and shafts indicate that there was a serious effort made to find more ore similar to the Apex mine. The Jessie mine is the only one of these locations that occurs on SITLA land, and is about three-quarters of a mile southwest of the Westside-Eldorado mine area, which is the most significant area of mineralization other than the Apex mine.

Dewonck (1987) reports that the Jessie mine consists of a gossanous fracture or shear system striking northwest and dipping 35° to 55° northeast. Three portals and a series of short adits accessible from a shaft expose the structure for about 200 ft. The mine is located adjacent to, but not part of, a small solution-collapse breccia. An underground sketch map of the Jessie mine, from Dewonck (1987), showing structures, workings, sampling sites, and geochemical sampling results is shown in figure 5. Underground sampling of the workings indicates the deposit is strongly anomalous in Ge, ranging from 25 to 1600 ppm, and Ga, ranging from 15 to 90 ppm. A trace element survey also indicated that Co, Cu, Sb and Fe are strongly anomalous, V and Zn are moderately anomalous, and Cr, Ni, As, Pb, Se, Mo, Eu, Yb, and Hg are weakly anomalous at the Jessie mine (Dewonck, 1987).

In January 1987, GaGe Minerals Corporation exploration manager Thomas C. Patton prepared a summary report on their Apex properties. Patten reports gossans "strongly anomalous" in Pb, Zn, As, Ga, and Ge up to 7 mi north of the Apex mine at the Kari (section 34, T. 41 S., R. 18 W.) and Higgins prospects (section 3, T. 42 S., R. 18 W.), Ga up to 105 ppm and Ge to 900 ppm, along the Pakoon Flat fault. These northern prospects are also hosted in the Redwall and Callville Limestones. The Apex mine area lies on the southerly projection of the Pakoon Flat fault.

Patton (1987) also reports that a 2500-line-mi aeromagnetic survey of the Apex and surrounding region was conducted in 1985; flight lines were flown on 0.25 mi line spacing in an east-west direction, and covered an area of over 600 mi^2. The objective of the survey was to determine if structural features in the Paleozoic rocks overlie zones of structural weakness in the Precambrian basement. Since it is likely that most faults and veins overlie structurally weak basement zones, the aeromagnetic survey could potentially identify areas with potential for Ga-Ge-Cu mineralization similar to the Apex deposit.

The survey showed a few broad magnetic highs west of the West Mountain Peak fault, associated with areas of exposed Proterozoic metamorphic rocks in the western Beaver Dam Mountains. There are no notable magnetic anomalies directly associated with the Apex mine or the Apex fault. However, several interpreted basement magnetic discontinuities were found to coincide with areas of favorable host rocks (Callville or Redwall Limestones) and faulting (Patton, 1987). Structures mapped by Hintze (1985a, b) correlate well with major magnetic discontinuities. The most significant magnetic discontinuity extends northwesterly from the Apex mine, and lies between the West Mountain Peak and Jackson-Pakoon Flat faults. These two faults may be surface expressions of the basement magnetic



Sample No.	Ga (ppm)	Ge (ppm)
333	90	1600
334	55	890
335	15	25
336	55	195
337	15	140
338	35	650
339	60	630
340	50	120
361	50	1200
362	40	690

Figure 5. Underground sketch map and gallium and germanium concentrations for the Jessie mine in SITLA section 2, T. 43 S., R. 18 W., SLBM (from Dewonck, 1987).

discontinuity, which may have acted as a conduit for ore-bearing fluids to gain access to the overlying Paleozoic carbonates at the Apex mine and surrounding small mines and prospects.

UGS Sampling

During October and November of 2010, Taylor Boden examined SITLA lands for Ga-Ge potential in the southern Beaver Dam Mountains. The Jessie mine in the SW¼SE¼SE¼ section 2, T. 43 S., R. 18 W., and a prospect in the SW¼SW¼SW¼ section 36, T. 42 S., R. 18 W., were the only significant mineralized locations found on SITLA lands in the project area. The Jessie mine workings in section 2, and shown in figure 6, consist of three open adits or inclines and one open shaft. The Jessie mine tailings contain abundant limonite (goethite), jarosite, and hematite, as well as prominent Cu carbonate mineralization. Tailing piles are small and work seems to have been focused on mining high-grade Cu carbonate pockets. The workings are located in a gravity-slide block or landslide block composed of Redwall Limestone (plate 2). The landslide block is relatively small in size and mineralization occurred prior to displacement. This indicates that mineralization does not extend downward into underlying rocks. A small limestone quarry is also present at the site. The prospect workings in section 36, and shown in figure 7, consist of an open adit and small dump located in a steep and rugged drainage. The adit appears to be short from the small amount of dump material. Mineralization in the dump material is sparse and collecting even a small sample was difficult, but a few Fe-oxide and greenish material (stained sandstone?) samples were obtained. The prospect occurs at the contact between the Redwall Limestone and Callville Limestone (plate 2). The adit appears to have been driven into a sandstone or siltstone in the basal part of the Callville Limestone.

A geochemical survey was conducted by the UGS to compare the various mines and prospects in the SITLA project area to the discovery showing at the Apex mine. Fifteen samples consisting primarily of limonite, jarosite, hematite, and Cu minerals were collected, mostly grab dump rocks, specifically for Ga-Ge analysis. All assay results are given in ppm and are shown in table 4. Assays were preformed by Skyline

Figure 6. Jessie mine workings in SITLA SW¼SE¼SE¼ section 2, T. 43 S., R. 18 W., SLBM.

Figure 7. Prospect workings in SITLA SW¼SW¼SW¼ section 36, T. 42 S., R. 18 W., SLBM.

Table 4. Assays of selected elements in 17 samples collected by the UGS in the SITLA Washington County gallium and germanium project area. Units in parts per million (ppm).

SAMPLE No.	LOCATION	UTM-E (m)	UTM-N (m)	UTMZ	DATUM	MINE OR PROSPECT	Ag	As	Ba	Bi	Cd	Ce	Cu	Fe	Ga	Ge	In	La
TB001A	NE SE SE sec. 1, T.43S., R.18W.	250,429	4,106,260	12	NAD 83	Apex shaft	97	>10,000	6,864	89.9	36	18	25,300	223,000	699	618	0.63	13
TB001B	NE SE SE sec. 1, T.43S., R.18W.	250,429	4,106,260	12	NAD 83	Apex shaft	35	4,505	841	3.8	34	8	323,000	116,800	605	618	0.46	10
TB002	NE SE SE sec. 1, T.43S., R.18W.	250,457	4,106,202	12	NAD 83	Apex prospect	122	>10,000	101	24.5	84	41	47,000	270,500	572	546	2.54	27
TB003	SW SW SW sec. 6, T.43S., R.17W.	250,553	4,106,008	12	NAD 83	Paymaster mine	77	3,526	164	243.5	83	13	36,400	312,800	560	17	0.97	8
TB004	NW SW NW sec. 1, T.43S., R.18W.	249,053	4,107,090	12	NAD 83	Westside mine	2	93	12	0.3	280	2	174	208,700	3	1	0.01	2
TB005	NW SW NW sec. 1, T.43S., R.18W.	249,029	4,107,009	12	NAD 83	Westside prospect	11	>10,000	24	0.1	4	1	20,500	362,600	32	>1,000	0.93	1
TB006	SW SW NW sec. 1, T.43S., R.18W.	249,050	4,106,897	12	NAD 83	prospect pit	1	450	17	<0.1	13	2	553	>500,000	11	3	0.06	2
TB007	NE NW SW sec. 1, T.43S., R.18W.	249,223	4,106,685	12	NAD 83	Surprise mine	102	6,252	42	<0.1	162	2	78,900	423,000	>1,000	>1,000	8.94	3
TB008	NW NW NW sec. 12, T.43S., R.18W.	249,071	4,105,805	12	NAD 83	Black Warrior mine	5	394	10	<0.1	36	2	705	499,900	14	7	0.18	2
TB009*	SW SW SW sec. 36, T.42S., R.18W.	249,120	4,107,793	12	NAD 83	prospect dump	0	64	215	0.2	0	19	134	66,900	6	0	0.02	10
TB010A*	SW SE SE sec. 2, T.43S., R.18W.	248,569	4,106,177	12	NAD 83	Jessie mine	6	5,257	27	0.1	1	2	38,500	449,400	14	75	0.28	3
TB010B*	SW SE SE sec. 2, T.43S., R.18W.	248,569	4,106,177	12	NAD 83	Jessie mine	5	71	6	<0.1	0	1	77,800	6,000	2	0	<0.01	1
TB011	SE NW NE sec. 11, T.43S., R.18W.	248,433	4,105,790	12	NAD 83	South Jessie mine	15	322	7	<0.1	87	4	588	>500,000	49	4	1.43	5
TB012	NW NE SW sec. 1, T.43S., R.18W.	249,435	4,106,597	12	NAD 83	shaft north of Hot Box mine	3	1,632	27	<0.1	263	8	4,555	484,400	9	8	0.35	7
TB013	SW NE SW sec. 1, T.43S., R.18W.	249,436	4,106,532	12	NAD 83	adit north of Hot Box mine	80	603	16	0.1	107	5	297	>500,000	34	17	0.44	5
TB014	SW NE SW sec. 1, T.43S., R.18W.	249,501	4,106,416	12	NAD 83	Hot Box mine	3	6,844	43	<0.1	8	9	38,600	450,300	180	10	3.25	10
TB015	SE NW NE sec. 27, T.42S., R.18W.	246,814	4,110,631	12	NAD 83	Jubilee prospect	0	138	88	0.1	5	17	204	>500,000	3	1	0.02	8

SAMPLE No.	MINE OR PROSPECT	Li	Mg	Mn	Mo	Ni	P	Pb	Re	S	Sb	Sn	Sr	Te	Th	Tl	U	W	Zn
TB001A	Apex shaft	8.8	3,100	30	395	163	620	45,700	0.059	9,400	191	2.7	1,558	9.0	2.1	2.3	10	6.3	3,652
TB001B	Apex shaft	3.0	4,500	137	277	452	280	1,685	0.007	1,500	103	1.0	499	1.3	0.8	3.7	20	8.3	8,230
TB002	Apex prospect	9.5	1,700	23	486	229	1,520	23,500	0.007	6,700	380	9.3	2,639	27.6	3.1	6.4	15	9.8	12,200
TB003	Paymaster mine	4.9	2,800	37	203	327	750	31,800	0.006	3,700	118	8.4	652	8.5	1.2	6.7	13	21.9	5,590
TB004	Westside mine	0.4	4,600	282	37	61	210	4,623	0.007	800	2	0.1	34	<0.1	0.1	0.6	11	0.3	202,000
TB005	Westside prospect	0.8	13,200	152	40	51	200	349	0.006	1,800	38	2.1	46	5.0	0.1	0.8	23	2.3	1,498
TB006	prospect pit	0.5	800	64	130	76	90	401	0.007	1,500	8	0.2	10	<0.1	0.2	0.2	9	0.8	3,492
TB007	Surprise mine	0.1	900	18	95	43	240	8,000	0.364	2,900	152	1.1	113	1.2	0.2	1.0	14	13.5	10,700
TB008	Black Warrior mine	<0.1	2,500	31	115	21	380	12,800	0.013	2,200	20	0.8	18	0.8	0.1	0.2	3	0.9	8,700
TB009*	prospect dump	10.3	2,700	62	23	166	150	93	0.009	2,300	2	0.8	136	<0.1	4.1	0.3	5	0.8	124
TB010A*	Jessie mine	0.3	7,500	70	469	198	240	469	0.005	1,600	69	0.3	35	1.1	0.2	1.0	4	3.4	294
TB010B*	Jessie mine	6.0	9,000	50	4	19	90	18	0.005	<500	1	0.1	16	<0.1	0.1	<0.1	2	0.4	43
TB011	South Jessie mine	<0.1	2,100	86	44	29	480	4,890	0.005	1,700	14	1.4	94	0.1	0.2	0.1	4	3.9	17,700
TB012	shaft north of Hot Box mine	1.1	500	52	2,122	383	250	7,067	0.013	2,100	11	0.3	40	<0.1	0.7	0.4	28	1.3	15,100
TB013	adit north of Hot Box mine	0.3	300	45	332	33	400	20,500	0.008	1,700	17	1.9	54	0.2	0.3	0.2	14	0.6	60,000
TB014	Hot Box mine	1.1	700	75	247	191	330	649	0.008	2,700	102	0.4	118	2.1	0.9	0.8	24	5.0	2,619
TB015	Jubilee prospect	1.6	3,800	147	53	58	80	472	0.005	1,200	2	0.4	18	<0.1	1.2	1.5	9	2.4	506

* indicates samples collected on SITLA owned land.

Assayers & Laboratories of Tucson, Arizona, and consisted of ultratrace analysis for 47 elements utilizing a four acid digestion process. Skyline Assayers state that Ga dissolution may not be complete, even by the four acid process. Fourteen of these samples came from mine and prospect workings in the SITLA project area (plate 1, 2). One sample (TB015) was collected from about a half mile northwest of the SITLA project area at the Jubille prospect. The Jubille prospect occurs in the Cambrian Bonanza King Formation, but no anomalous Ga or Ge was detected. From the 14 samples in the SITLA project area, two Cu-rich sub-samples, one from the Apex shaft (TB001B) and one from Jessie mine (TB010B), were split out to be assayed separately.

The Jessie mine is the only site of significant mineralization observed at the surface in sections 2 and 36. Sample TB010A (table 4) collected at the Jessie mine shows slightly elevated Ge at 74.6 ppm and low Ga at 14 ppm. When compared to the Apex shaft samples (TB001A and B), the samples collected from the Jessie mine show significantly lower values for Ga, Ge, Cu, Pb, Zn, and Ag. Sample TB009 (table 4) collected from the prospect in section 36 shows no elevated Ga or Ge, and low Ag and base metal values. Sample TB007 (table 4) collected from the Surprise mine, located less than a quarter mile east of SITLA section 2, contains the highest Ga and Ge assay vales (>1000 ppm) from the UGS geochemical survey. Sample TB007 also shows significantly elevated Cu, Pb, Zn, and Ag. Sample TB005 (table 4) collected near the Westside mine, and a few hundred feet east of SITLA section 2, contains greater than 1000 ppm Ge and elevated Cu. Summary statistics for assays of selected elements in the 17 samples collected in the SITLA project area are given in table 5. The average Ga content of the samples is 223 ppm and the average Ge content is 231 ppm. Average Cu content of the samples is 40,777 ppm; Pb, 9589 ppm; Zn, 20,732 ppm; and Ag, 33 ppm. A correlation chart for selected elements in 17 samples collected in the SITLA project area is shown in table 6. Gallium and Ge show a strong correlation with Ag, As, Cu, In, Re, and Sb.

Exploration Model or Target Concept

The Apex mine suggests the potential for the discovery of other Kipushi type Cu-Ga-Ge mineralization in the broader mine area including the nearby SITLA tracts. Numerous mines and prospects in the project area have mineralogical, geochemical, and structural similarities to the Apex deposit. Various consulting exploration firms working for GaGe Minerals Corporation (Hansen properties) have identified similarities between several mines and prospects in and around the project area and the surface expression of the Apex mine. The ore bodies, if present, will likely have a very small surface footprint, but could present high-grade, valuable exploration targets (table 2). The mines and prospects of greatest interest for Apex-type Ga-Ge mineralization are the Westside (West Eldorado), Eldorado, Jessie, South Jessie, Higgins, Jubilee, and Kari. Patton (1987) reports that by analogy with Kipushi type deposits, similar ore bodies are expected to:

1. have short strike lengths,
2. have significant vertical dimensions,
3. occur along steeply dipping structures such as fault zones and/or solution-collapse breccias,
4. occur in chemically reactive beds within thick limestone and dolomite sequences, and
5. have pod-shaped or discontinuous gossan zones which may not always be anomalous in Ga-Ge.

In the Beaver Dam Mountains these targets will probably occur in or

Table 5. Summary statistics for assays of selected elements in 17 samples collected by the UGS in the SITLA Washington County gallium and germanium project area. Units in parts per million (ppm).

	Ag (ppm)	As (ppm)	Ba (ppm)	Bi (ppm)	Cd (ppm)	Ce (ppm)	Cu (ppm)
Earth Crust	0.07	1.80	425.00	0.17	0.20	60.00	55.00
Median	5.50	1632.40	27.00	0.10	35.50	5.00	20500.00
Mean	33.12	3538.31	500.24	21.35	70.68	9.06	40777.01
Maximum	121.70	10000.10	6864.00	243.50	279.90	41.00	323000.00
Standard Deviation	43.27	3848.56	1651.99	61.36	88.67	10.31	77430.87
Threshold	119.67	11235.43	3804.22	144.07	248.01	29.68	195638.75

	Fe (ppm)	Ga (ppm)	Ge (ppm)	In (ppm)	La (ppm)	Li (ppm)	Mg (ppm)
Earth Crust	50000.00	15.00	1.50	0.10	30.00	20.00	20900.00
Median	423000.00	32.00	9.90	0.44	5.00	1.10	2700.00
Mean	345782.35	223.12	230.89	1.21	6.88	2.87	3570.59
Maximum	501000.00	1000.10	1000.10	8.94	27.00	10.30	13200.00
Standard Deviation	168360.81	324.70	367.61	2.19	6.38	3.61	3456.65
Threshold	682503.98	872.53	966.12	5.60	19.65	10.10	10483.90

	Mn (ppm)	Mo (ppm)	Ni (ppm)	P (ppm)	Pb (ppm)	Re (ppm)	S (ppm)
Earth Crust	950.00	1.50	75.00	1200.00	12.50	0.00	350.00
Median	62.00	129.60	75.90	250.00	4622.90	0.01	1800.00
Mean	80.06	298.24	146.88	371.18	9589.18	0.03	2591.18
Maximum	282.00	2121.70	451.50	1520.00	45700.00	0.36	9400.00
Standard Deviation	66.72	496.12	135.06	348.58	13313.75	0.09	2253.62
Threshold	213.49	1290.48	417.01	1068.35	36216.67	0.20	7098.43

	Sb (ppm)	Sn (ppm)	Sr (ppm)	Te (ppm)	Th (ppm)	Tl (ppm)	U (ppm)
Earth Crust	0.20	2.00	375.00	0.00	10.00	0.45	2.70
Median	19.80	0.80	54.00	0.80	0.30	0.80	11.00
Mean	72.22	1.84	357.65	3.36	0.92	1.54	12.29
Maximum	379.80	9.30	2639.00	27.60	4.10	6.70	28.00
Standard Deviation	99.10	2.75	705.13	6.88	1.16	2.10	7.76
Threshold	270.41	7.34	1767.91	17.12	3.24	5.74	27.81

	W (ppm)	Zn (ppm)
Earth Crust	1.50	70.00
Median	2.40	5590.00
Mean	4.82	20732.24
Maximum	21.90	202000.00
Standard Deviation	5.80	48805.26
Threshold	16.43	118342.76

stratigraphically above the Redwall Limestone. Gossanous mineralization occurring in steeply dipping fault zones, mantos, and as a matrix in breccia zones is an important indicator, as are malachite or azurite. Zones of brecciation, dolomitization, hematite staining, and calcite veining can be useful guides to mineralization, often extending beyond the areas of gossan development. Patton (1987) suggests that the Westside-Eldorado area has the strongest surface showing of mineralization in the district. Patton (1987) reports that the Eldorado structure (about N 75° E, vertical)

Table 6. Correlation chart from assays for selected elements in 17 samples collected by the UGS in the SITLA Washington County gallium and germanium project area.

	Ag	As	Ba	Bi	Cd	Cu	Fe	Ga	Ge	In	Mn	Mo	P	Pb	Re	S	Sb	Sn	Sr	Te	Tl	W	Zn
Ag	1.00																						
As	0.56	1.00																					
Ba	0.39	0.44	1.00																				
Bi	0.44	0.20	0.30	1.00																			
Cd	0.15	-0.17	-0.12	0.00	1.00																		
Cu	0.16	0.22	0.06	-0.02	-0.14	1.00																	
Fe	-0.07	-0.07	-0.24	-0.13	0.12	-0.45	1.00																
Ga	**0.81**	**0.60**	0.42	0.42	0.10	0.48	-0.20	1.00															
Ge	0.53	**0.77**	0.30	-0.02	-0.03	0.40	-0.15	**0.67**	1.00														
In	0.51	0.41	-0.08	-0.04	0.20	0.13	0.18	**0.68**	0.56	1.00													
Mn	-0.47	-0.19	-0.17	-0.25	0.28	0.08	-0.15	-0.34	-0.05	-0.31	1.00												
Mo	0.00	0.06	0.05	-0.02	0.50	-0.05	0.23	-0.04	-0.10	-0.09	-0.22	1.00											
P	0.73	0.51	0.19	0.42	0.08	0.00	-0.05	0.46	0.20	0.16	-0.36	0.11	1.00										
Pb	0.76	0.40	0.69	0.69	0.12	-0.12	-0.05	0.54	0.18	0.04	-0.42	0.12	0.65	1.00									
Re	0.46	0.24	0.07	-0.05	0.26	0.11	0.10	**0.67**	0.57	0.90	-0.27	-0.08	-0.07	0.07	1.00								
S	0.72	0.68	0.77	0.44	-0.05	-0.06	-0.11	**0.62**	0.39	0.19	-0.44	0.14	0.70	0.84	0.15	1.00							
Sb	0.80	0.77	0.33	0.30	-0.01	0.24	-0.15	**0.74**	0.52	0.44	-0.38	0.07	0.86	0.56	0.25	0.78	1.00						
Sn	0.71	0.46	0.09	0.69	0.01	0.01	-0.11	0.49	0.22	0.13	-0.33	0.01	0.89	0.65	-0.06	0.59	0.75	1.00					
Sr	0.73	0.63	0.46	0.34	-0.03	0.13	-0.27	0.56	0.36	0.11	-0.31	0.09	0.90	0.66	-0.03	0.84	0.92	0.78	1.00				
Te	0.68	0.66	0.21	0.35	-0.04	0.03	-0.17	0.47	0.36	0.16	-0.28	0.07	0.93	0.55	-0.05	0.71	0.91	0.87	0.94	1.00			
Tl	0.63	0.47	0.14	0.70	-0.02	0.35	-0.24	**0.61**	0.26	0.10	-0.18	0.03	0.77	0.55	-0.06	0.53	0.75	0.89	0.75	0.77	1.00		
W	0.65	0.42	0.10	0.78	0.06	0.31	-0.07	**0.79**	0.35	0.50	-0.32	-0.06	0.51	0.49	0.39	0.42	0.59	0.71	0.42	0.46	0.80	1.00	
Zn	-0.07	-0.28	-0.11	-0.11	0.69	-0.16	-0.11	-0.18	-0.19	-0.13	0.70	-0.08	-0.06	-0.02	-0.07	-0.21	-0.19	-0.13	-0.12	-0.13	-0.14	-0.22	1.00

should intersect the projection of the Apex fault a few thousand feet northeast of the surface working, which would appear to be near the south-central part of SITLA section 36, T. 42 S., R. 18 W., SLBM (plate 2).

Solution-collapse breccia pipes in the SITLA project area may lack surface expression, like in the northern Arizona Strip uranium district where many "blind" pipes occur. Because solution-collapse breccia pipes develop from the bottom upward, they can terminate without reaching the surface. Discovered in 1979 by Western Nuclear, the Hack 2 U pipe did not reach the surface and is the largest uranium deposit ever found in the Arizona Strip district, producing 7 million pounds of U_3O_8. Exploring for concealed or "blind" breccia pipes in the Arizona Strip district involves airborne geophysical surveying, utilizing helicopter-supported, vertical-time-domain electromagnetic (VTEM) technology (Spiering, 2010). The first extensive airborne VTEM survey of the Arizona Strip district covered 422 mi^2 and used a 492 ft line spacing and 98 ft ground clearance. The survey detected most of the known breccia pipes in the area, and also detected more than 200 high-to-moderate priority anomalies with similar signatures to the known breccia pipes. The A-1 anomaly was the first anomaly to be tested by drilling due to the significant geophysical signature. The A-1 anomaly had no collapse cone, fracture pattern or evidence of any other structures or expressions at the surface, but drilling defined a "blind" pipe 500 ft to the north of the geophysical signature center. The A-1 pipe had no structure within 500 ft of the surface; however, drilling encountered U_3O_8 concentrations between 0.58% and 0.45% between depths of 1046 and 1119 ft (Spiering, 2010). The A-1 "blind" breccia pipe was discovered on the first VTEM anomaly drilled and was the first new mineralized breccia pipe identified in the Arizona Strip district in 18 years. Other VTEM anomalies proximal to known breccia pipes have been drilled, and subsequent additional "blind" mineralized pipes discovered.

SITLA Land

The solution-collapse breccia pipe for the Apex mine is hosted in the Callville Limestone and Pakoon Dolomite, and is believed to bottom in the paleokarst of the Redwall Limestone. In addition, no Ga-Ge anomalies are recorded in rocks older than the Mississippian Redwall Limestone. Thus, the first targeting criterion is to focus on areas underlain by Redwall and younger Paleozoic strata. Only the northeasternmost corner of SITLA section 2, T. 43 S., R. 18 W., SLBM, is underlain by in-place Redwall Limestone, the remainder being older strata or post-mineral slide blocks; however, all of SITLA section 36, T. 42 S., R. 18 W., SLBM, is underlain by Redwall Limestone or younger Paleozoic strata.

Secondly, mineralization at the Apex, Paymaster, and the shaft northwest of the Apex are associated with north-northwesterly trending structures. The Jubilee prospect is located about 3.5 mi northwest of the Apex, has weak Ga-Ge in the gossan, and shows clear evidence of a solution-collapse origin (Dewonck, 1987). Furthermore, Patton (1987) notes that two other Ga-Ge (Higgins and Kari) occurrences about 7 mi north-northwest of the Apex mine are located along the Pakoon Flat Fault. These occurrences help define a potentially important trend. SITLA section 36, T. 42 S., R. 18 W., SLBM lies directly on this trend north-northwest of the Apex.

Wenrich and others (1987) note the tendency for the solution-collapse Cu-U breccia pipes of the Arizona Strip to occur in clusters, as in the Apex mine area. In addition, solution-collapse pipes can be "blind" (i.e., not continue to the current surface). This suggests that there could be additional Cu-Ga-Ge mineralized pipes in the area of the Apex mine cluster that do not crop out and have not been discovered. As noted above, VTEM technology has been successfully used to identify blind mineralized breccia pipes in the Arizona Strip and holds the potential to delineate similar targets in the Beaver Dam Mountains. The UGS suggests a detailed VTEM survey area should cover a northwesterly oriented block of Redwall Limestone and younger Paleozoic strata, extending north-northwest from the Apex mine area for a few miles to as many as 10 mi, including SITLA Section 36, T. 42 S., R. 18 W., SLBM.

Finally, the Apex mine still hosts a 1 million ton Cu-Ga-Ge resource estimated to contain an in-place value of over $1 billion, with a surface expression smaller than a football field. Other Kipushi type Cu-rich deposits world-wide have produced or still contain mineral resources worth many billions of dollars, indicating the high value of these deposits within very small surface areas.

SUMMARY

The Apex mine lies near the crest of the southern Beaver Dam Mountains in southwestern Washington County. The Apex mine exploited a Kipushi type Cu-Ga-Ge deposit in a steeply plunging, solution-collapse breccia pipe, hosted in the Pennsylvanian Callville Limestone and overlying Permian Pakoon Dolomite. The ore body has been developed to a depth of over 1400 ft, but the ore deposit probably continues down into the heavily karstic Mississippian Redwall Limestone beneath the lowest workings. The Apex mine hosts an estimated 1 million ton Cu-Ga-Ge resource with an in-place value of in excess of $1 billion at today's metal prices; approximately two-thirds of this value is in Ge. This resource could supply the entire world market for Ga for approximately 2.8 years and Ge for 6.6 years.

A cluster of smaller, but similar, occurrences lie in an area of slightly more than 1 mi^2 adjacent to the Apex mine, but others are also reported along a north-northwesterly trend up to 7 mi to the north-northwest of the Apex mine. Worldwide, other Kipushi type deposits include the Kipushi Cu-Zn ±Ga ±Ge deposit, Zaire; Tsumeb Cu-Pb-Zn ±Ga ±Ge deposit, Namibia; and the Ruby Creek and Kennicott Cu-Ag deposits in Alaska. All of these deposits are large, high-grade, important deposits, each with several billions of dollars of copper alone at today's prices.

The Apex mine is located within one mile of SITLA lands, was the first deposit in the world to be mined primarily for Ga-Ge, and is used as a model in assessing the potential of Cu-Ga-Ge potential of the SITLA lands. Despite the presence of Cu-Ga-Ge prospects (e.g., Jesse mine, on SITLA section 2, T. 43 S., R. 18 W., SLBM), no exploration potential is recognized on this tract because the mineralization is located in a Redwall Limestone gravity-slide or landslide block (post-mineralization). Unfortunately, this indicates that mineralization is confined to the slide block itself and does not extend downward into underlying rocks. Economic amounts of Ga-Ge are unlikely to occur at the Jessie mine due to the limited size of the slide block and subsequent small tonnages of ore that could be present there. However, solution-collapse pipes can be "blind," i.e. have no surface expressions even in premineral rocks. In recent exploration for "blind" Cu-U solution-collapse breccia pipes in the Arizona Strip, just south of the Utah-Arizona border, airborne VTEM surveys have been successfully used to define targets for drilling. Since SITLA Section 36, T. 42 S., R. 18 W., SLBM lies on the mineralized north-northwest Apex mine trend and is underlain by favorable host strata, this tract contains the best exploration potential.

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Plate 1
UGS Contract Deliverable for SITLA
SITLA Washington County Gallium and Germanium Project Area

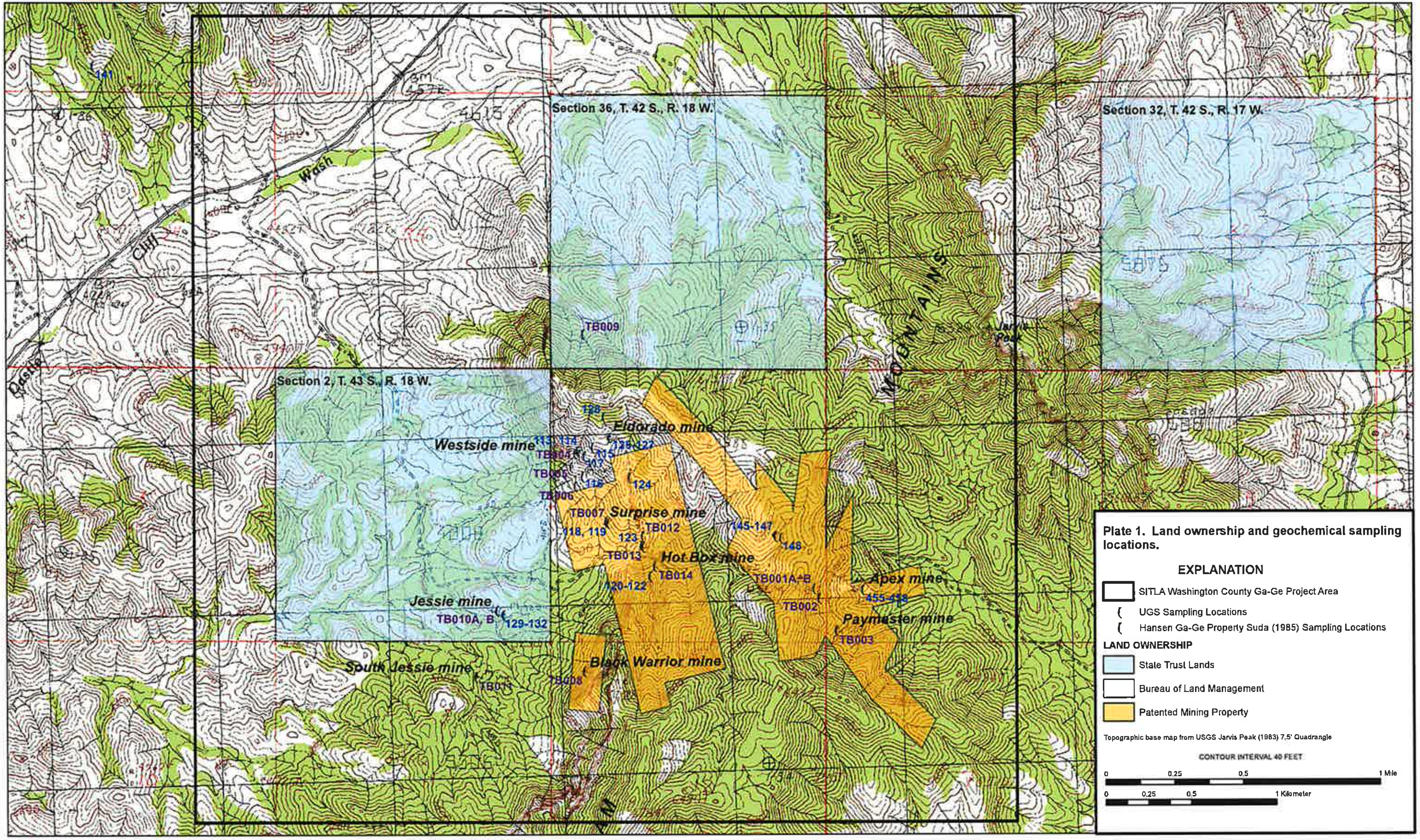

Plate 1. Land ownership and geochemical sampling locations.

State of Utah
School & Institutional
Trust Lands Administration

UTAH GEOLOGICAL SURVEY
a division of
Department of Natural Resources

Plate 2
UGS Contract Deliverable for SITLA
SITLA Washington County Gallium and Germanium Project Area

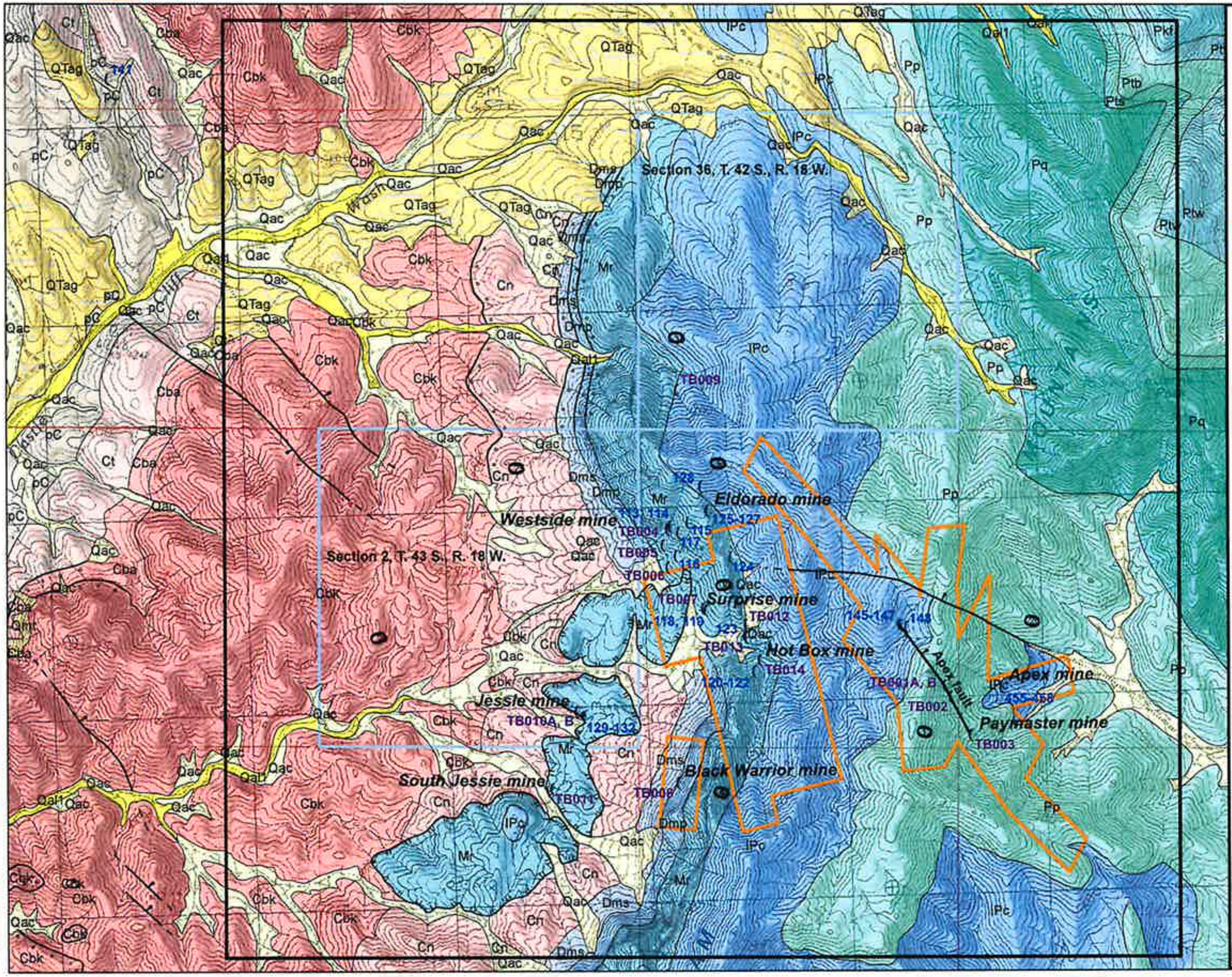

Plate 2. Geologic map and geochemical sampling locations.

EXPLANATION

▭ SITLA Washington County Ga-Ge Project Area
(UGS Sampling Locations
(Hansen Ga-Ge Property Suda (1985) Sampling Locations

LAND OWNERSHIP

▭ State Trust Lands
▭ Bureau of Land Management
▭ Patented Mining Property

GEOLOGIC UNITS

Qac	MIXED ALLUVIUM AND COLLUVIUM (HOLOCENE)
Qal1	STREAM ALLUVIUM (HOLOCENE)
QTag	HIGH-LEVEL ALLUVIUM (PLIOCENE AND PLEISTOCENE)
Pkf	FOSSIL MOUNTAIN MEMBER OF KAIBAB FORMATION (PERMIAN)
Ptw	WOODS RANCH MEMBER OF TOROWEAP FORMATION (PERMIAN)
Ptb	BRADY CANYON MEMBER OF TOROWEAP FORMATION (PERMIAN)
Pts	SELIGMAN MEMBER OF TOROWEAP FORMATION (PERMIAN)
Pq	QUEANTOWEAP SANDSTONE (PERMIAN)
Pp	PAKOON DOLOMITE (PERMIAN)
IPc	CALLVILLE LIMESTONE (PENNSYLVANIAN)
Mr	REDWALL LIMESTONE (MISSISSIPPIAN)
Dmp	PINNACLE MEMBER OF MUDDY PEAK DOLOMITE (DEVONIAN)
Dms	SLOPE MEMBER OF MUDDY PEAK DOLOMITE (DEVONIAN)
Cn	NOPAH DOLOMITE (CAMBRIAN)
Cbk	BONANZA KING FORMATION (CAMBRIAN)
Cba	BRIGHT ANGEL SHALE (CAMBRIAN)
Ct	TAPEATS QUARTZITE (CAMBRIAN)

GEOLOGIC SYMBOLS

Contact
High-angle fault - bar and ball on downthrown side; dashed where approximately located; dotted where concealed
Attenuation fault - barbs on upper plate
Gravity-slide block - barbs on upper plate

Topographic base map from USGS Jarvis Peak (1983) 7.5' Quadrangle
Geology from Hammond (1991), and Biek and others (2009)

CONTOUR INTERVAL 40 FEET

0 0.25 0.5 1 Mile
0 0.25 0.5 1 Kilometer