CHARACTERISTICS OF ACID-SULFATE ALTERATION IN THE MARYSVALE - PIOCHE MINERAL BELT: A GUIDE TO GOLD MINERALIZATION

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ABSTRACT

The zones of extensive acid-sulfate alteration in the Marysvale-Pioche mineral belt have been of interest to explorationists for many years, most recently for their precious metal potential. Based on recent field work, existing information and advances in the understanding of alunite formation these occurrences have been characterized and assessed.

Acid-sulfate alteration is recognized in three separate environments: 1) magmatic-hydrothermal, 2) near-surface, steam-heated and 3) supergene. The environments may be distinguished by field relations, mineral assemblages, textures and geochemistry. Differentiation is critical to determining the potential location of ore. In the magmatic-hydrothermal environment gold mineralization, if present, will be intimately associated with acid-sulfate alteration, whereas in the near-surface environment gold may occur in veins adjacent to or below acid-sulfate alteration. In supergene alteration, mineralization occurs only if the protolith was mineralized prior to weathering.

Particular types of acid-sulfate alteration tend to be grouped within three general regions of the Marysvale-Pioche mineral belt: 1) the San Francisco district, 2) the southern Wah Wah Mountains, Shauntie Hills and Black Mountains and 3) the Marysvale district. A locality from each of these areas was studied in detail. The selected occurrences illustrate the presence of both the near-surface and magmatic-hydrothermal types of alteration. The alteration in the central portion of the belt has a relatively low potential for associated gold mineralization whereas the San Francisco and Marysvale districts have a moderate to high potential.

INTRODUCTION

Extensive acid-sulfate alteration occurs throughout the Marysvale-Pioche mineral belt. Many alteration zones have been explored for a variety of commodities, most recently for precious metals. These acid-sulfate occurrences were investigated and assessed for their relative gold potential. Work included mapping, geochemistry, petrography and literature review.

Characteristics of Acid-sulfate Alteration

Acid-sulfate alteration, a type of advanced argillic mineral assemblage, typically contains alunite + kaolinite + quartz ± pyrite ± sulfur. In some cases the alteration assemblage may include pyrophyllite + diaspore and/or aluminum phosphate-sulfate minerals such as svanbergite and woodhouseite. Acid-sulfate alteration is recognized in three different environments (Meyer and Hemley 1967; Meyer et al., 1980; Berger and Bethke, 1985; Hayba et al., 1985; Bonham, 1986; Heald et al., 1987; White and Hedenquist, 1990):

1. Magmatic-hydrothermal: The disproportionation of magmatic SO_2 to H_2S and H_2SO_4 may form extensive zones of acid-sulfate alteration. Gold may be deposited within these zones of alteration, often in association with quartz-alunite ± pyrite ± enargite and are most accurately termed high-sulfidation (acid-sulfate/quartz-alunite) type deposits (White and Hedenquist, 1990). Examples of deposits of this type in the U.S.A. are Goldfield and Paradise Peak, Nevada and Summitville, Colorado. Other examples are known throughout the world: e.g. Japan, Chile, Peru, Taiwan and Australia. Magmatic-hydrothermal acid-sulfate alteration also occurs above some copper and molybdenum porphyry systems. These systems may contain other base metals and/or subordinate precious metals, but do not necessarily contain economic gold mineralization. Gold is particularly rare in the acid-sulfate zones above molybdenum porphyry deposits.

2. Acid condensates in the near-surface, steam-heated environment: Advanced argillic alteration results from condensation of vapor and oxidation of H_2S at the water table above a boiling system. The deeper upwelling portions of these systems and their boiling zones may contain gold-silver mineralization of low-sulfidation (adularia-sericite) type (White and Hedenquist, 1990). This near-surface alteration often contains alunite ± quartz ± kaolinite ± sulfur. Examples of this type are ubiquitous above geothermal systems and may be present where the near-surface environment is preserved in epithermal systems, e.g. Buckskin Mtn., National district, Nevada and the Waihi deposit, New Zealand.

3. Oxidation of sulfides during supergene processes: Supergene oxidation forming an advanced argillic assemblage occurs in the tropical lateritic weathering environment. The process may act on any sulfide-bearing assemblage and will only be gold-bearing if gold was present in the protolith. The resultant advanced argillic alteration assemblage typically consists of

kaolinite ± quartz ± alunite which is superficially similar to the hydrothermal alteration assemblages listed above. Supergene alunite veins are also known to form during the weathering of many deposits including several of the Nevada gold deposits.

The above environments may be distinguished by field relations, mineral assemblages and texture. Alunite compositions, including trace element and P_2O_5 contents, may provide further indication of the environment in which the alteration formed (Rye et al., 1989; Stoffregen and Alpers, 1987). The contrasting origins of the above types of acid-sulfate alteration have been confirmed by stable isotope work carried out by Rye et.al. (1989). In some cases overprinting or telescoping obscures relationships resulting in alteration zones of multiple phases and origins. Additional acidic fluids may also be generated by dissolution of sulfates.

MARYSVALE-PIOCHE MINERAL BELT

The Marysvale-Pioche mineral belt extends from just west of Pioche in Nevada to the Marysvale district in central Utah and includes the Wah Wah-Tushar belt as described by Hilpert and Roberts (1964). The mineral belt (Fig. 1) is defined by a series of intrusive and volcanic centers in conjunction with known mineral occurrences and a broad band of aeromagnetic highs. The aeromagnetic data appears to represent buried intrusions (Shawe and Stewart, 1976). Overlapping the mineral belt is the east-west trending Blue Ribbon lineament of Rowley et al. (1978) which is marked by an alignment of eruptive centers, hydrothermal alteration, recent hot springs and range terminations (Fig. 1). The structural zone is approximately 15 mi across and lies within the larger (30-40 mi wide) Marysvale-Pioche mineral belt.

Geology

The igneous and volcanic activity which defines the mineral belt began in the Oligocene and continued throughout a period of minor extension into the early Miocene. Large-scale ash-flow tuffs were erupted on to an erosional surface that developed in the early Tertiary on a thick sequence of deformed Precambrian, Paleozoic and Mesozoic sediments. Volcanism was initiated at 34 Ma along the east-northeast trending belt producing a series of calc-alkaline volcanoes with compositions ranging from mafic andesite to low-silica rhyolite. In the early Miocene compositions shifted to a bimodal assemblage of mafic rocks and high-silica rhyolite. Similar volcanics continued to erupt periodically until the early Pleistocene. The current basin and range topography formed in the late Miocene-Pliocene as a result of block faulting (Steven and Morris, 1987; Best et.al., 1987, 1989a).

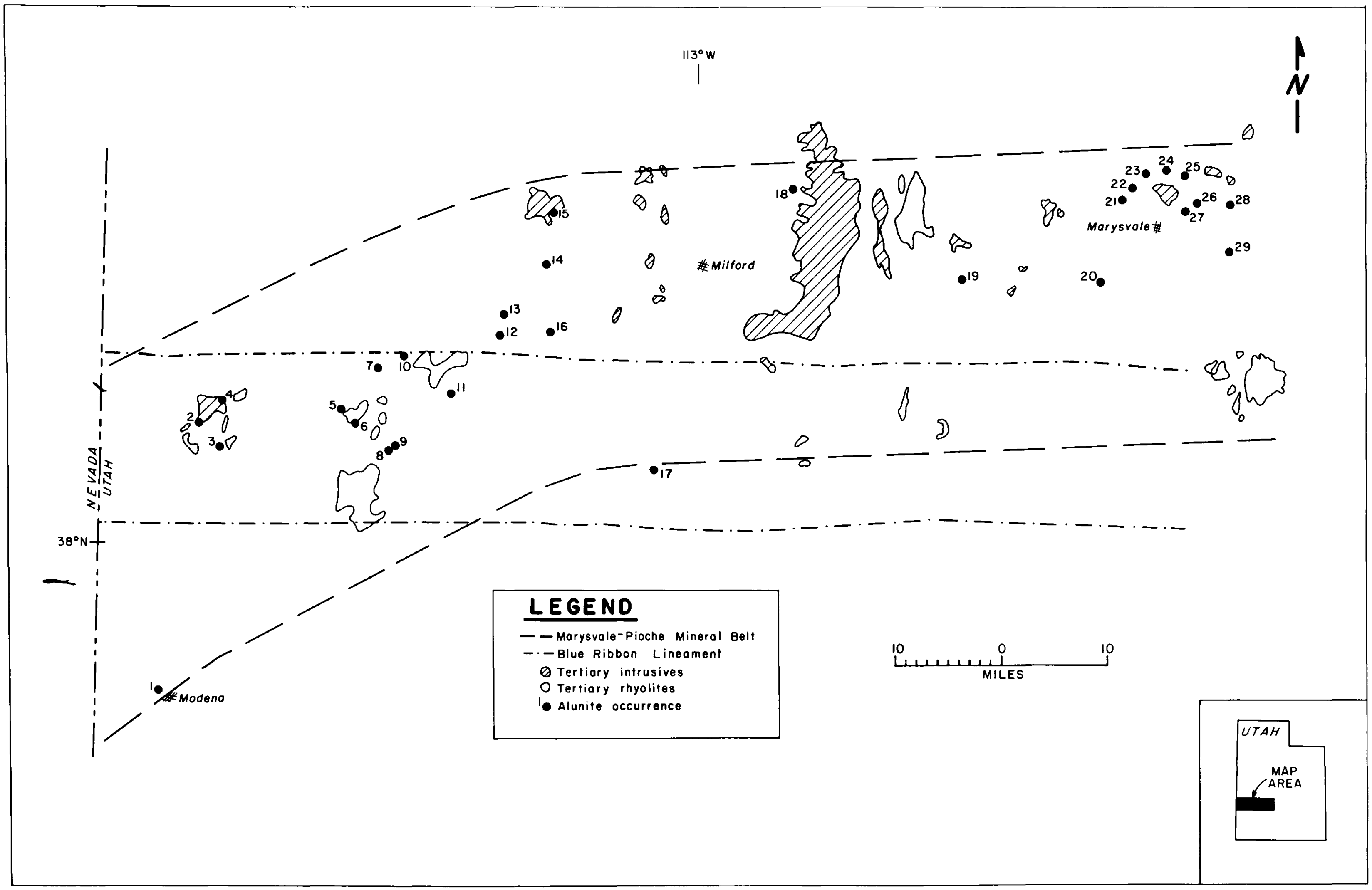

Figure 1. Location of alunite occurrences and Tertiary igneous activity in relation to the Marysvale-Pioche mineral belt and the Blue Ribbon lineament (numbered localities described in Table 1).

Mineralization

Mineralization is largely related to Tertiary volcanic and intrusive activity but is hosted both by the older sedimentary rocks and the volcanic lithologies. Base and precious metal deposits (Cu, Pb, Zn, Au and Ag) occur around intrusions along the belt of calc-alkaline centers. Alkali rhyolite fields tend to be superimposed on the same zones and have associated lithophile element enrichment (Mo, W, U, Be, Sn and F) in addition to minor base and precious metals. Alunite and kaolinite are associated with many of the mineralized systems (Steven and Morris, 1987).

ACID-SULFATE OCCURRENCES

Acid-sulfate alteration is found throughout the Marysvale-Pioche mineral belt (Fig. 1, Table 1) and includes some of the largest alunite deposits in the U.S.A. (Hall, 1978). The alteration was formed in a variety of environments and ranges in age from 28 Ma to 0.5 Ma (Lemmon et al., 1973; Mehnert et al., 1978). The local distribution of alunite within the alteration is indicated by a simple classification into vein, disseminated and massive types in Table 1. Particular types of alteration tend to be grouped within three general regions: 1) the San Francisco district, 2) the southern Wah Wah Mountains, Shauntie Hills and Black Mountains and 3) the Marysvale district. Three localities which illustrate the varieties of acid-sulfate alteration present in the belt were selected for detailed examination.

San Francisco District

Acid-sulfate alteration occurs in the San Francisco mining district in an area of approximately 1 square mi, centered 1 mi northeast of the Horn Silver mine (no. 15, Fig. 1). Numerous small breccia pipes and alteration zones were mapped by Stringham (1967). The zones of alteration and brecciation between the Frisco Contact mine and Indian Grave Peak were examined in this study (Fig. 2).

The alteration is hosted by the Horn Silver andesite (Stringham, 1967) which consists of medium to thick bedded lava flows with autoclastic margins. The flows vary in composition from andesite to dacite and quartz-latite. A K-Ar age on plagioclase in andesite yielded approximately 31 Ma (Lemmon et al., 1973). The Horn Silver andesite is intruded by the 28 Ma granodiorite Cactus stock on the west and north sides of the area (Lemmon et al., 1973). A porphyritic late phase of the stock occurs along the contact and cuts the main granitic phase (Best et al., 1989b). The porphyritic granodiorite contains propylitic and argillic alteration associated with the acid-sulfate zones. Mineralization is hosted by a granodiorite breccia at the Cactus mine, 2 mi to the northwest, which produced significant Cu with by-product Au-Ag (Butler, 1913). A grab sample of ore returned 150 ppb Au, 2.5 ppm Ag and 1.8 % Cu

TABLE 1. ALUNITE OCCURRENCES IN THE MARYSVALE-PIOCHE MINERAL BELT

NO.	OCCURRENCE NAME	TYPE[1]	COORDINATES[2]	REF[3]
1	Modena	diss	4189100N 240090E	5
2	unknown	n.d.	4230300N 247200E	4
3	W.Big Pinto Sp	diss	4226440N 250230E	5
4	Cougar Spar	diss	4232780N 251200E	4
5	unknown	n.d.	4230640N 269250E	11
6	Terminal Prospect	n.d.	4228500N 271170E	11
7	Blawn Mountain	mass	4237100N 274200E	7
8	Cina	n.d.	4224900N 276150E	11
9	Hg Prospect	n.d.	4225600N 277500E	11
10	NG Deposit	mass	4239000N 279000E	6
11	Blue Mountain	n.d.	4232900N 285800E	11
12	W.White Mountain	mass	4241800N 294000E	9
13	Grover W.	n.d.	4245000N 294450E	9
14	S.Squaw Peak	mass	4252400N 300800E	9
15	Frisco Contact	diss	4260400N 301550E	10
16	E.White Mountain	mass	4242000N 301200E	9
17	Black Mountains	mass	4221650N 316900E	3
18	Roosevelt	diss	4263000N 338150E	8
19	Sheep Rock	mass	4249150N 363200E	1
20	Alunite Ridge	vn	4248190N 385000E	2
21	Winkelman	mass	4261100N 387500E	2
22	Big Rock Candy Mtn.	mass	4263300N 389400E	2
23	Big Star	mass	4265000N 391200E	2
24	Yellow Jacket	mass	4265500N 394200E	2
25	Al Kee Mee	mass	4264800N 397100E	2
26	White Hills	mass	4260000N 398700E	2
27	White Horse	mass	4258500N 396000E	2
28	Marysvale Peak	mass	4260100N 404400E	2
29	Manning Creek	mass	4253000N 404000E	2

[1]Type: mass - massive alunite, generally > 50% in main zones only, may be disseminated elsewhere: vn - alunite occurs in either monominerallic veins or with quartz: diss - disseminated, alunite is found throughout the rock, generally mixed with silica and/or kaolinite: n.d. - not determined

[2]Coordinates: UTM (Universal Transverse Mercator grid, zone 12 and 13) coordinates, measured from 1000 m grid tick intervals on 7.5 minute series topographic maps. Positions are approximate for large replacement zones in the Marysvale district.

[3]References: 1) Callaghan, 1973: 2) Cunningham et al., 1984b; 3) Erickson and Dasch, 1963; 4) Grant, pers. com. 1989; 5) Hall, 1978; 6) Hofstra, 1984; 7) Lindsey and Osmonson, 1978; 8) Parry et al., 1980; 9) Stringham, 1963; 10) Stringham, 1967; 11) Utah Mineral Occurrence System, UGMS unpub.

(sample 9001, Table 2). The Horn Silver mine was one of the largest producers of Pb-Ag in Utah (Butler, 1913).

The Frisco Contact mine shaft was sunk in 1909, apparently in pursuit of extensions to the Horn Silver mineralization. A depth of 700 ft was reached and a cross-cut to the granodiorite was driven at a depth of 600 ft. No ore is reported from the workings, however the dump contains alunite-quartz-pyrite altered andesite and granodiorite. Analyses of this material returned slightly elevated Au and base metal values (15 ppb Au; sample 8939, Table 2). Several reconnaissance samples were taken in the area and all showed similar geochemical results (Table 2). Fissures in the granodiorite northwest of the Frisco Contact were reported to contain Pb-Ag mineralization (Butler, 1913).

The alteration is characterized by small zones of quartz-alunite ± kaolinite ± Fe-oxides with variable zones of brecciation. Alteration immediately south of the Frisco Contact mine and at Indian Grave Peak appears to be localized by nearly north-south structures (Fig. 2) and contains limited brecciation. The pods found between these two zones show no linear control and are irregular in shape. These pods host significant breccias which vary from an angular clast, clast-supported breccia at the margin to a matrix-supported breccia, with large rounded clasts up to 6 in. across, in the center (Fig. 3). This relationship suggests that these pods may represent small breccia pipes of magmatic- or meteoric-hydrothermal origin.

Petrographic and x-ray diffraction studies on altered rocks from these pods and from the Frisco Contact mine dump show that the dominant alteration is quartz-alunite-pyrite (Table 3). The alunite occurs in needles and mosaics replacing feldspar phenocrysts and disseminated within the microcrystalline silica. Pyrite has been weathered to produce Fe-oxides in the surface exposures. Preliminary geochemistry (neutron activation analysis) suggests that the alunite has a relatively high sodium content, with 8800 ppm in a sample of quartz-alunite-pyrite (26% alunite, see Table 4). A possible grain of svanbergite was identified during reconnaissance microprobe work and neutron activation analysis of the same sample yielded 0.12 % Sr (no. 8939, Table 4) which could also be in alunite as a solid solution.

These acid-sulfate occurrences may be classified as magmatic-hydrothermal for the following reasons:

1. The pods of alteration show a direct spatial association with the granodiorite, particularly with the late stage porphyritic phase.
2. Alunite occurs as well formed crystals intimately associated with microcrystalline quartz.
3. No surficial silica deposits or acid-leach alteration occurs in the area.

TABLE 2. ICP GEOCHEMISTRY - ANALYSIS BY CMS LABORATORY, SALT LAKE CITY, UTAH

No.	Au ppm	Ag ppm	Cu ppm	Pb ppm	Zn ppm	Mo ppm	Co ppm	Ni ppm	Cr ppm	Mn ppm	As ppm	Sb ppm	Hg ppb	Bi ppm	Ba ppm	Be ppm
West White Mountain Area																
8907	3	<.3	<3	3	3	<2	<3	<3	14	20	20	<5	40	<2	550	<1
8911	<2	<.3	6	<3	8	12	3	3	90	190	<5	<5	100	2	650	1
8912	<2	<.3	3	3	4	<2	<3	<3	<3	8	<5	<5	20	<2	530	<1
8915	3	<.3	3	13	<3	<2	<3	<3	<3	5	30	<5	<20	<2	110	<1
8917	2	<.3	3	85	3	<2	<3	3	150	15	25	<5	100	<2	600	<1
8920	8	2.0	10	5	20	<2	10	13	130	200	7	<5	13400	<2	30	<1
8943	2	0.3	3	3	5	<2	<3	<3	30	10	7	<5	260	<2	390	<1
8945	2	<.3	<3	3	4	<2	<3	<3	5	5	17	<5	<20	<2	280	2
8946	<2	<.3	3	4	3	<2	<3	3	140	30	5	<5	20	<2	60	<1
Frisco Contact Mine Area																
8936	<2	<.3	20	30	4	<2	<3	45	20	20	5	<5	40	<2	1350	<1
8937	<2	<.3	14	9	3	<2	<3	3	120	30	30	<5	90	<2	920	<1
8938	4	<.3	15	50	5	5	<3	5	130	40	5	<5	40	3	1230	<1
8939	15	<.3	25	30	8	3	5	7	40	15	20	<5	100	<2	1270	<1
8983	2	<.3	20	15	5	3	<3	<3	35	40	10	<5	510	<2	1010	<1
8984	2	0.4	120	20	3	3	<3	<3	90	30	25	<5	80	<2	1060	<1
9003	5	0.2	110	18	90	6	3	7	n.a.	n.a.	50	<1	<20	1	n.a.	n.a.
9004	5	0.2	20	620	8	7	<2	5	n.a.	n.a.	6	1	200	<1	n.a.	n.a.
9001	150	2.5	17900	85	45	100	25	3	n.a.	n.a.	35	2	20	1	n.a.	n.a.
Yellow Jacket																
8929	<2	<.3	11	20	5	5	3	5	100	70	7	<5	<20	2	2050	<1
8930	2	<.3	5	18	3	3	3	3	125	35	10	<5	500	<2	1140	<1
8932	2	<.3	3	30	6	<2	<3	<3	45	5	30	<5	160	<2	620	<1
8963	2	<.3	49800	3	40	<2	<3	<3	40	5	16	<5	<20	<2	450	<1

8964	2	0.4	10	<3	4	4	3	5	180	65	<5	<5	<20	<2	1300	<1
Alunite Ridge (Min. Products & Clyde Mine)																
8953	9	<.3	8	4	3	<2	<3	<3	11	5	10	<5	<20	<2	1280	<1
8974	240	203	21900	450	50	5	5	35	100	25	3600	1850	<20	750	1530	<1
NG Deposit																
8903	2	<.3	3	5	5	<2	3	<3	50	5	15	<5	100	<2	430	<1

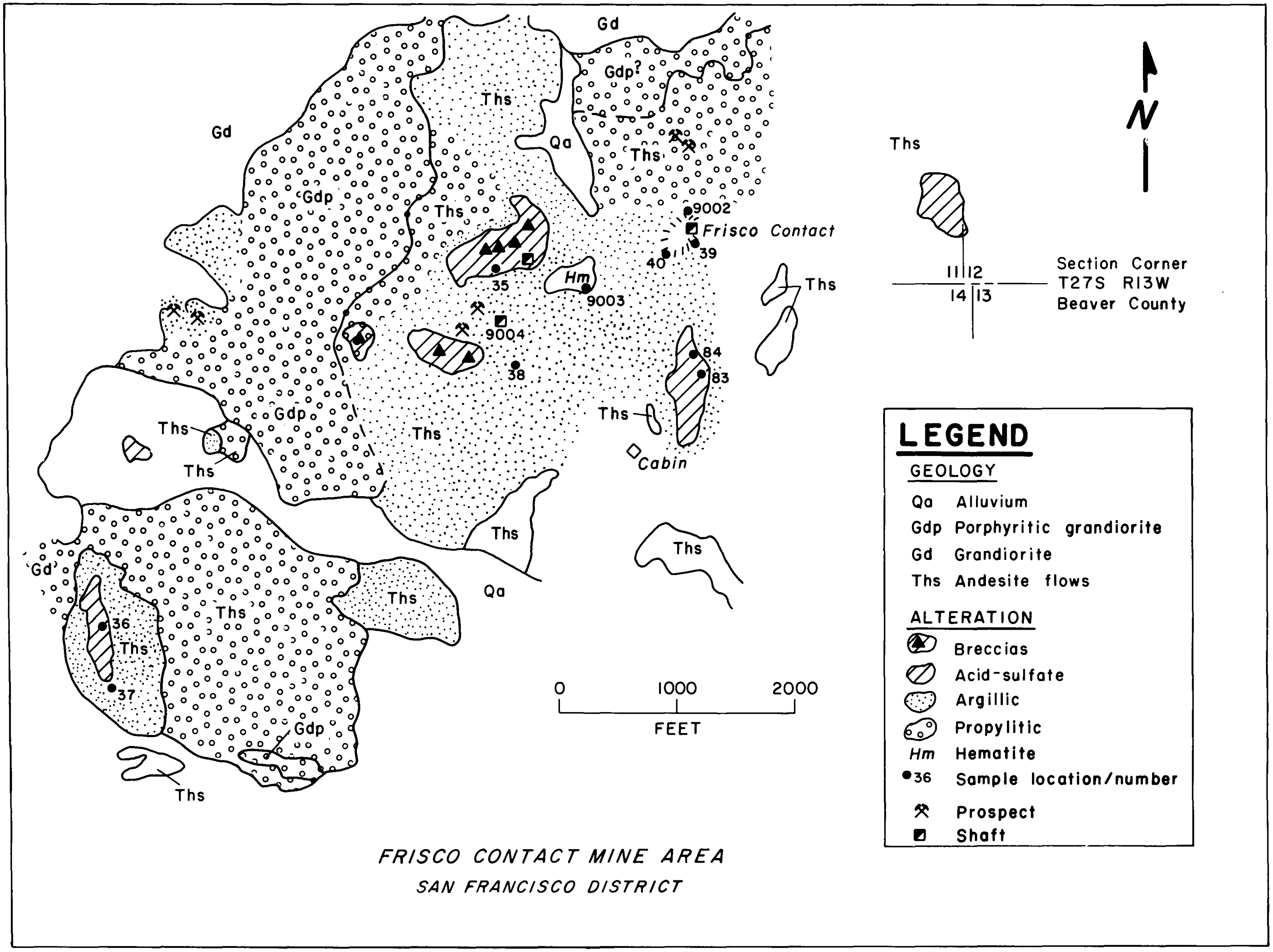

Figure 2. Geology and alteration map of the Frisco Contact-Indian Grave Peak area, San Francisco district. Modified from Stringham (1967). Samples from the 89 series shown without the 89 prefix.

Figure 3. Clast-supported breccia with angular clasts from the peripheral zone of pipe just west of the Frisco Contact mine.

TABLE 3. X-RAY DIFFRACTION RESULTS

No.	Qz	Cs	Al	Ka	Di	Sm	Kf	Cc	Py	Ja	Hm	Go	Uk
NG Alunite Area													
8903	9	-	87	-	4	-	-	tr	-	-	-	-	-
8904	X	-	-	-	-	-	-	-	-	-	-	-	-
White Mountain Area													
8907	34	-	-	-	65	-	-	1	-	-	-	-	-
8913	1	45	32	21	-	-	-	-	1	-	-	-	-
8917	8	20	70	-	-	2	-	-	-	-	-	-	-
8945	1	71	5	20	-	-	3	-	-	-	-	-	-
Yellow Jacket													
8927	52	1	30	17	-	-	-	-	tr	-	-	-	-
8932	19	-	75	-	tr	-	-	-	-	-	5	-	1
8933	52	-	14	-	18	-	-	-	-	5	-	5	6
8963	X	-	X	-	-	-	-	-	-	-	-	-	-
Frisco Contact Area													
8937	X	-	X	-	-	-	-	-	-	-	-	-	-
8939	52	-	26	-	-	-	-	-	11	tr	-	-	11
8984	X	-	X	-	-	-	-	-	-	-	-	-	-

Table 3. X-Ray diffraction results, percentages are approximate (S. Juch-Lutz, UURI); X indicates mineral is present, relative abundance not determined. Mineral abbreviations as follows: Qz-quartz, Cs-cristobalite, Al-alunite, Ka-kaolinite, Di-dickite ± kaolinite, Sm-smectite, Kf-potassium feldspar, Cc-calcite, Py - Pyrite, Ja-jarosite, Hm-hematite, Go-Goethite, Uk-unknown.

TABLE 4. GEOCHEMISTRY OF ALUNITE SAMPLES

No.	Au ppb	As ppm	Ba ppm	Co ppm	Cr ppm	Fe %	Mo ppm	Na ppm	Ni ppm	Sb ppm	Sr %	W ppm	U ppm
8903	<5	6	430	<5	230	0.23	<5	<500	<50	<0.2	0.05	<4	1.4
8917	<5	23	520	<5	210	1.18	16	1680	<50	0.3	<.05	<4	2.9
8932	<5	10	520	<5	91	0.60	10	3000	<50	11	0.08	6	3.7
8939	16	22	1000	6	92	1.93	<5	8800	63	2.1	0.12	<4	2.7
8953	14	17	900	<5	43	3.44	<5	5410	<50	8.6	0.13	13	4.2

No.	Br ppm	Hf ppm	Sc ppm	Th ppm	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm
8903	2	<1	1.3	3.4	21	18	5	0.5	0.4	<.5	0.17	<.05
8917	<1	5	1.8	13	35	39	8	0.5	0.5	<.5	0.3	<.05
8932	5	6	9.5	13	51	86	34	2.3	0.5	0.5	0.45	0.07
8939	<1	6	12	15	89	130	45	6.3	1.6	0.8	1.39	0.26
8953	<1	<1	6	49	200	150	28	2.9	0.4	<.5	<.05	<.05

Table 4. Geochemistry of alunite samples: results from neutron activation analysis (Geochemical Services, Inc., CA.). Other elements analyzed but not detected are: Ag (<5ppm), Ca (<1%), Cs (<2ppm), Hg (<1ppm), Ir (<5ppb), Rb (<30ppm), Se (<5ppm), Sn <0.01%), Ta (<1ppm), Zn (<50ppm). All samples contain >70% alunite, except for 8939 which contains 26%. See Table 4 for complete mineralogy and sample locations except for sample 8953 from Alunite Ridge which is >95% alunite based on petrography.

4. Geochemical results suggest the presence of minor phosphate phases which may be indicative of the magmatic environment (Rye et al., 1989).

Mineralization in this area is dominated by Ag and base metals and any hidden mineralization, associated with the acid-sulfate alteration, will probably be of this type. These mineralized zones may contain subordinate gold. The potential for large gold-rich zones is considered relatively low.

Wah Wah Mountains, Shauntie Hills, Black Mountains

Numerous zones of acid-sulfate alteration are known in the central region of the Marysvale-Pioche mineral belt (Fig. 1, Table 1). These occurrences vary dramatically in size from the NG deposit to minor occurrences such as the zone just south of Squaw Peak (Stringham, 1964). Two of the significant alteration areas in the region were selected for further study: the NG deposit and the ridge west of White Mountain. Field work was concentrated in the White Mountain area due to the recent, unpublished work by Hofstra (1984) at the NG.

NG Deposit

The NG deposit is situated in the southern Wah Wah range, approximately 30 miles due southwest of Milford. Evaluation of the property by Earth Sciences, Inc. in the early 1970's delineated 620 million tons of >30% alunite as a nonbauxite aluminum resource (Hofstra, 1984).

Other known mineralization in the immediate area includes the Pine Grove porphyry molybdenum deposit 6 mi to the northwest, and the Blawn Mountain/Staats Mine areas which are adjacent to the NG deposit. The latter two are host to fluorspar and minor uranium respectively (Whelan, 1965). The Pine Grove porphyry molybdenum deposit formed during a period of calc-alkaline bimodal volcanism (Keith et al., 1986). The intrusive porphyry occurs in the eroded vent of the lower Miocene (22-23 Ma) co-magmatic ash-flow tuff. The molybdenum mineralization has many of the characteristics of a Climax-type deposit, including: high-silica rhyolites, fluorite, topaz and huebnerite in the ore zone and a lack of appreciable copper (Keith et al., 1986).

The Staats Mine, at the southern end of the NG deposit area, contains fluorine and uranium mineralization with anomalous Sn, Be and Mo in montmorillonite and illite altered rhyolite and breccia (Lindsey and Osmonson, 1978). The topaz rhyolite which crops out immediately adjacent to the mineralized area has yielded K-Ar ages of 20.2 $\pm$ 0.9 m.y from sanidine (Mehnert et al.,1978). The alteration overlaps to the north with alunite-kaolinite-iron oxide alteration in the lapilli tuff of the Blawn Wash Formation (Lindsey and Osmonson, 1978: Abbott et al., 1983).

The alteration at the NG deposit is hosted by Oligocene and early Miocene rhyolitic tuffs. Acid-sulfate alteration occurs as four largely tabular to funnel-shaped bodies which are zoned horizontally from the center outwards: silica to quartz-alunite to kaolinite-hematite to montmorillonite-chlorite-pyrite to chlorite-calcite. Vertical zonation is characterized by silica at the top grading downwards to quartz-alunite then to quartz-alunite-sericite-pyrite at a depth of 820-980 ft (Hofstra, 1984). The alteration is largely barren of metals (Hofstra, 1984) and one sample of alunite dominant alteration from this study (8903, Table 2) likewise contained negligible amounts of trace elements.

Petrographic and X-ray diffraction examination (Table 3) indicates that some of the siliceous alteration is the result of intense acid leaching, resulting in residual silica. Fluids generated prior to the main alunite alteration in the calcite, calcite-quartz and quartz veins ranged from 275 to 325^{0}C and contained <2 eq wt % NaCl (Hofstra, 1984). These fluids may have boiled generating the acidic steam environment which produced the extensive acid-sulfate alteration and leaching.

The alteration zones are proximal to three apparently unaltered Miocene porphyritic plugs (Tbr) which yielded a K-Ar age of 22.2 ± 0.8 Ma from biotite (Abbott et al., 1983). A K-Ar age of 22.5 Ma is reported by Hofstra (1984) on an alunite vein and Best et al. (1987) obtained an alunite K-Ar age of 20.6 ± 0.9 Ma. The acid-sulfate alteration is therefore clearly related to the 23 to 18 Ma period of Blawn Formation intrusive and extrusive activity. The precise phase of intrusive activity, however, remains equivocal. Alunite K-Ar ages correspond to dates obtained on the Pine Grove porphyry (22-23 Ma) and to the Staats mine topaz rhyolite (20 Ma). A single sulfur isotope value of +1.45 per mil is interpreted to represent a magmatic source of sulfur and further confirms a genetic association with an intrusion (Hofstra, 1984).

The NG acid-sulfate alteration formed in the near-surface environment. The system is probably related to the emplacement of a shallow intrusion which drove geothermal activity and may have contributed some magmatic vapor. The evidence is summarized below:

1. Tabular to flat bottoms are dominant on quartz-alunite alteration zones and indicate alteration controlled by the water table. Funnel shapes probably resulted from the system collapsing down the controlling fractures.
2. Areas of intense acid leach, with 100% remnant silica, and no vug infillings, are indicative of formation in a vapor-dominant environment.
3. Uniformly low trace metal contents exist in the acid-sulfate alteration (including Mo, Cu, Zn, Pb, Ag and Au).
4. The age of the alunite correlates with the range of rhyolite plugs and volcanics in the region.

5. A sulfur isotope value of +1.45 per mil is interpreted as representing a magmatic sulfur source.

Hofstra (1984) mapped several quartz-sericite-pyrite veins and sporadic quartz-carbonate veins immediately adjacent to, but beneath the level of acid-sulfate alteration. Such veins are possible targets for precious metal mineralization and locally contain anomalous values of Cu, Zn and Ag (Hofstra, 1984). A high Ag-base metal style of mineralization is the most likely target (e.g. San Juan-type veins; Burt et al. (1982)). Quartz-carbonate veins also crop out just southeast of The Tetons (Best et al., 1987). The Stateline district, approximately 30 mi west-southwest, produced Au-Ag from quartz-carbonate-adularia veins (Keith, 1980).

White Mountain Area, Shauntie Hills

Extensive zones of acid-sulfate alteration crop out on a low ridge which extends for 3 mi to the west of White Mountain (Fig. 4). The alteration is hosted by rhyolite flows and ash-flow tuff and is controlled by a major east-west and smaller north-south trending faults. This zone has been previously referred to as the Brimstone lineament (Haymond, 1981). No significant mining has occurred in the area, although prospects are numerous and a small quarry was worked in an alunite-kaolinite zone. Small amounts of uranium mineralization are known on the east side of White Mountain in close proximity to similar acid-sulfate alteration.

Rhyolite outcrops on the ridge are predominantly flow banded and autobrecciated and are assigned to the Rhyolite member of the Blawn Formation (Best et al., 1989b). Smaller amounts of the Tuff member which is compositionally similar to the flows, also crop out along the zone. Ash-flow tuff and a sandstone unit within the Tuff member are both recognized on the ridge and are locally displaced by faulting.

The distribution of alteration zones, host lithologies and structures is shown in Figure 5. Stringham (1963) produced a detailed alteration map of the area. Solfataras and opaline silica sinter are found at the western end of the ridge, at the edge of the Wah Wah Valley. Native sulfur is common and cinnabar occurs locally in one pod of chalcedonic silica (sample 8920, Table 2). Typical alteration from this zone, based on x-ray diffraction, contains variable amounts of cristobalite $\pm$ quartz, alunite, kaolinite and smectite. Cristobalite and alunite are the dominant minerals (Table 3). In thin section the alunite and kaolinite are often indistinguishable within brown, mottled masses. Occasionally alunite crystals occur as needles and plates in clots.

Alteration towards the eastern portion of the area is virtually identical, consisting mainly of cristobalite-alunite-kaolinite and

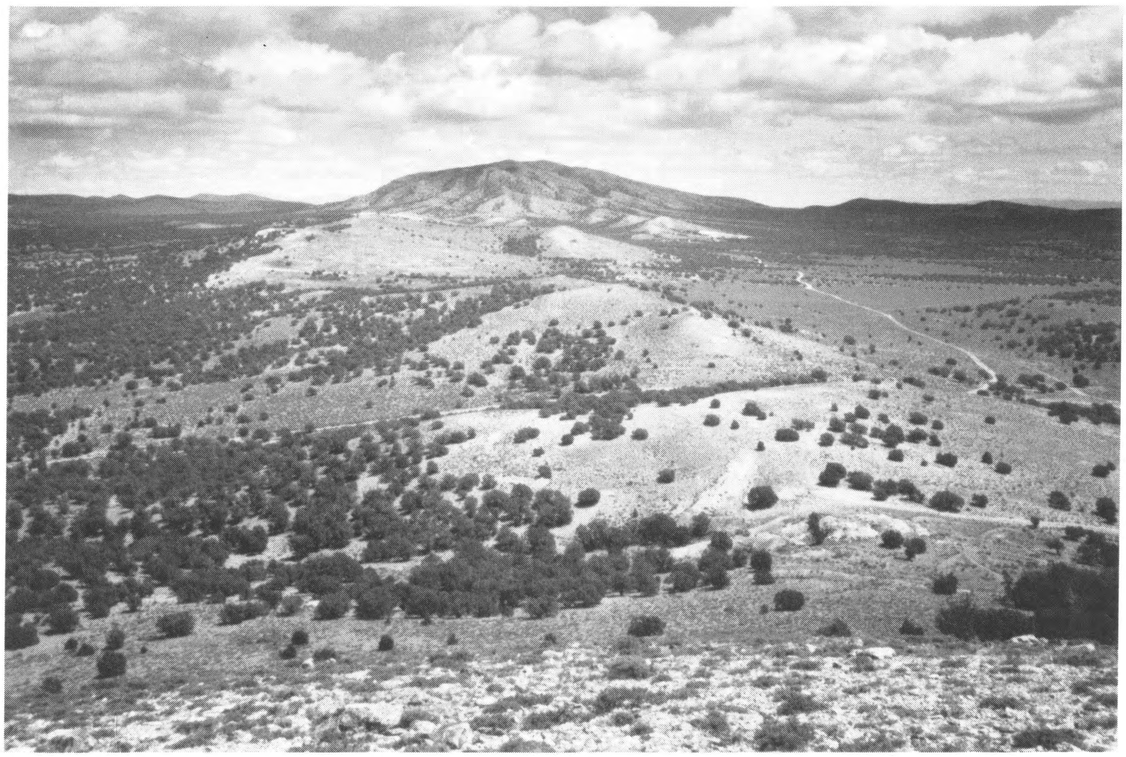

Figure 4. East-west ridge with extensive acid-sulfate alteration extending from White Mountain (center towards the Wah Wah Valley.

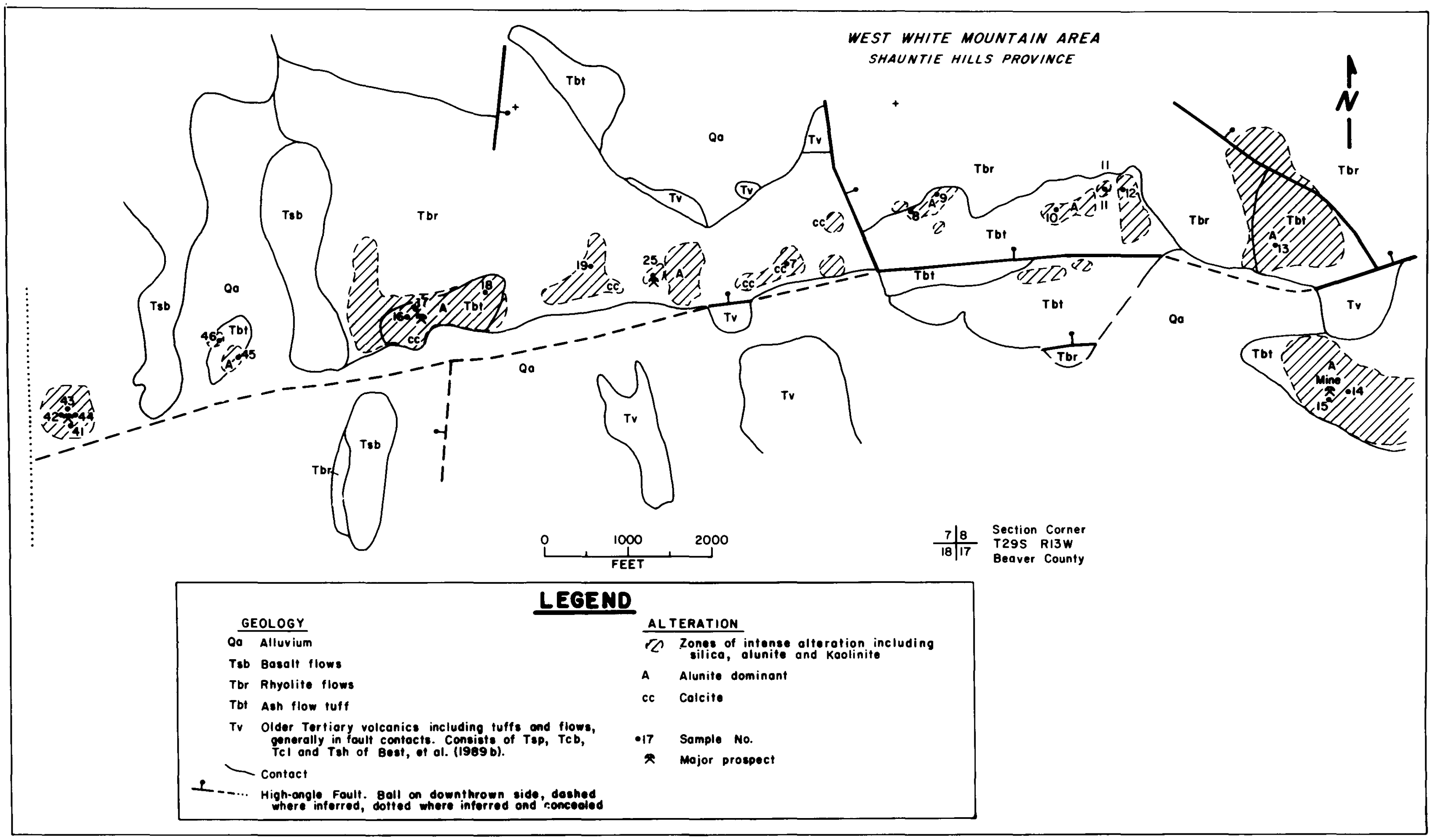

Figure 5. Geology and alteration map of the area west of White Mountain, Shauntie Hills province. Geology adapted from Best et al., (1989b). All sample numbers correspond to the 89 series in Tables 2, 3 and 4.

includes minor zones of acid-leached material and chalcedonic silica. A significant zone of calcite alteration was observed in the central portion of the mapped area (Fig. 5). X-ray diffraction of this material yielded quartz-calcite-dickite/kaolinite (Table 3, Fig. 5). Hematite is found throughout the area, varying from a finely disseminated black crystalline form to an earthy, bright red stain.

The alteration is clearly related to hot spring activity and was formed by steam-heated water in the near surface. The following characteristics identify this environment:

1. Solfataras and porous opaline silica sinter crop out at the western end of the zone.
2. Alunite is generally fine grained; hand samples of massive alunite have an earthy appearance; some occurs in powdery acid-leached material containing remnant silica.
3. Small zones of chalcedonic silica contain cinnabar.

Alteration also continues on the east side of White Mountain (Stringham, 1963), where an K-Ar age of 22.5 $\pm$ 5.7 Ma was obtained from alunite (Best et al., 1987). This date is consistent with the age of the Blawn formation rhyolites (Best et al., 1989b) as was observed in the NG/Blawn Mountain area. In contrast, the rhyolites at the Roosevelt geothermal area have been dated at approximately 0.5 Ma (Mehnert et al., 1978) and are considered to be directly related to hot spring activity and associated acid-sulfate alteration. These relationships suggest a variety of ages for acid-sulfate alteration related to alkali rhyolite volcanism within the region.

Marysvale District

Numerous alunite deposits (Table 1) and small zones of argillic alteration are known in the Marysvale district (Cunningham, et al. 1984b). These deposits occur as massive replacements and large crystalline veins (Callaghan, 1973: Cunningham et al., 1984a). The replacement alunite deposits represent the bulk of the acid-sulfate alteration within the district.

Alteration is hosted by the Bullion Canyon volcanics which were erupted episodically from 35 to 22 Ma (Steven et al., 1979). These rhyodacitic lava flows, volcanic breccias and mudflows were then intruded by the monzonite to quartz monzonite Central intrusion in the waning stages of volcanism (23 Ma). Between 23 and 21 Ma, magma compositions switched to a bimodal assemblage of alkali rhyolites (Mount Belknap volcanics) and mafic andesite-basalt. The rhyolites ceased eruption at approximately 14 Ma, whereas the mafic rocks continued to erupt to the present. Acid-sulfate alteration occurred both at 23 Ma and in the 17-14 Ma period (Cunningham et al., 1984a).

Sheep Rock

Alunite occurs in direct proximity to the Sheep Rock gold mine on the west side of the Tushar Mountains (no. 19, Table 1). This area lies just west of the Marysvale district and was included in the district for the purpose of this study. The area was first reported on and mapped by Loughlin (1916). The gold mineralization is contained in quartz veins which are locally amethystine and contain platy calcite textures. Fluorite is reported at a depth of 300 ft (Butler et al., 1920). The wallrock latite is sericitized adjacent to the veins.

The alunite deposit lies immediately to the south and west within rhyolite. It forms a circular out crop area (900 ft in diameter) which has weathered to rounded boulders. The alunite is intimately associated with quartz and varies from massive, to banded and brecciated. A concretionary texture is apparent in some areas, with alunite occurring as fan shaped crystals up to 0.5mm long which enclose microcrystalline quartz (Callaghan, 1973: Loughlin, 1916). The proximity of the two deposits suggest they represent a near-surface hot spring environment with acid-sulfate alteration occurring adjacent to the mineralized quartz veins. However, the two zones are in fault contact and no unequivocal evidence for a direct relationship between the two deposits was observed.

Alunite Ridge

Coarsely crystalline veins of alunite, up to 60 ft wide, are located 7 mi southwest of Marysvale on and adjacent to Alunite Ridge. Several mines were developed on the veins including the Mineral Products, Bradburn and Christmas mines. These occurrences are grouped in Figure 1 (no. 20) and have been described by Loughlin (1916), Callaghan (1973) and Cunningham et al. (1984a). Other mineralization in the area consists of small precious metal bearing veins and the Deer Trail gold-silver-lead-zinc manto deposit (Cunningham et al., 1984a).

The veins typically contain coarsely crystalline alunite growing in bands of plumose aggregates. Areas of fine grained alunite also occur, with infilling pods of coarser alunite. Veins are massive but irregular and occasional stockworking occurs. The Bullion Canyon volcanics, adjacent to the veins, have been extensively silicified and contain disseminated pyrite (1-3%) and variable minor alunite. Veinlets of dickite are also reported (Hild, 1946). A sample of nearly pure alunite from the Mineral Products Mine area was virtually barren of metals (sample 8953, Table 2), however sporadic gold values have been reported from within alunite-altered areas. Ore from the Clyde Mine at the base of Alunite Ridge (no acid-sulfate alteration) contained high levels of Ag, As, Sb and Bi (sample 8963, Table 2). Based on stable isotopes, fluid inclusions and field relations, Cunningham et al. (1984a) concluded that the veins formed from magmatic vapor. Field observations during this study, however, indicate extensive associated hydrothermal alteration, suggesting that the magmatic vapor may be part of a larger magmatic-hydrothermal system. A strong magmatic association is also suggested by the high Bi (750 ppm) in the Clyde mine ore.

Yellow Jacket

The Yellow Jacket quarry is a well exposed example of the replacement type alunite deposits. The quarry is situated approximately 6 mi north-northeast of Marysvale (no. 24, Fig. 1) within the main alunite zone of a large area of acid-sulfate alteration (Fig. 6). The Bullion Canyon volcanics host the alteration and consist mainly of thin bedded tuffs and pyroxene andesite (Callaghan, 1973). Small normal faults may locally displace these units.

The alteration mineral assemblages are broadly zoned both vertically and horizontally (Cunningham et al., 1984a). Drill hole information suggests that the alunite and its alteration halo narrow at depth (Kerr et al., 1957). The upper levels consist of massive replacement silica, locally containing volcanic and hydrothermal breccias. Sinter textures have been inferred locally (Cunningham et al., 1984a) although no evidence was found to support this origin during this study. All silica, examined in detail, showed primary volcanic textures. The siliceous alteration is underlain by a hematitic and jarosite stained quartz-alunite rock which overlies the main alunite deposit. The massive alunite is also cut by silica veins and pods (Callaghan, 1973). Alunite decreases outward into kaolinite dominant alteration which in turn grades to a propylitic assemblage. X-ray diffraction results from quarry samples, indicate quartz-alunite-kaolinite in variable proportions with up to 75% alunite (Table 3). In thin section the alunite occurs as well formed needles and mosaics. Small zones of vuggy silica occur adjacent to the main alunite pod. The vugs in these samples are lined with quartz crystals.

The Yellow Jacket appears to have contained anomalously high levels of phosphorous possibly in the form of aluminum phosphate-sulfate minerals. Callaghan (1973) reported an analysis of a carload from the quarry in 1941 with 0.71 % P_2O_5. Reconnaissance geochemistry returned 0.08% strontium from a quarry sample, consistent with the the presence of svanbergite or contained in solid solution in alunite (no. 8932, Table 4). Copper mineralization crops out immediately north of the quarry area (Fig. 6: no. 8963, Table 2) and occurs within quartz-natroalunite alteration of unknown age and association. Cunningham et al. (1984a) suggest that all of the natroalunite in the region is related to a second phase of hydrothermal activity in the 17-14 Ma range. Two thousand feet to the north, the Copper Cap prospect contains uranium mineralization

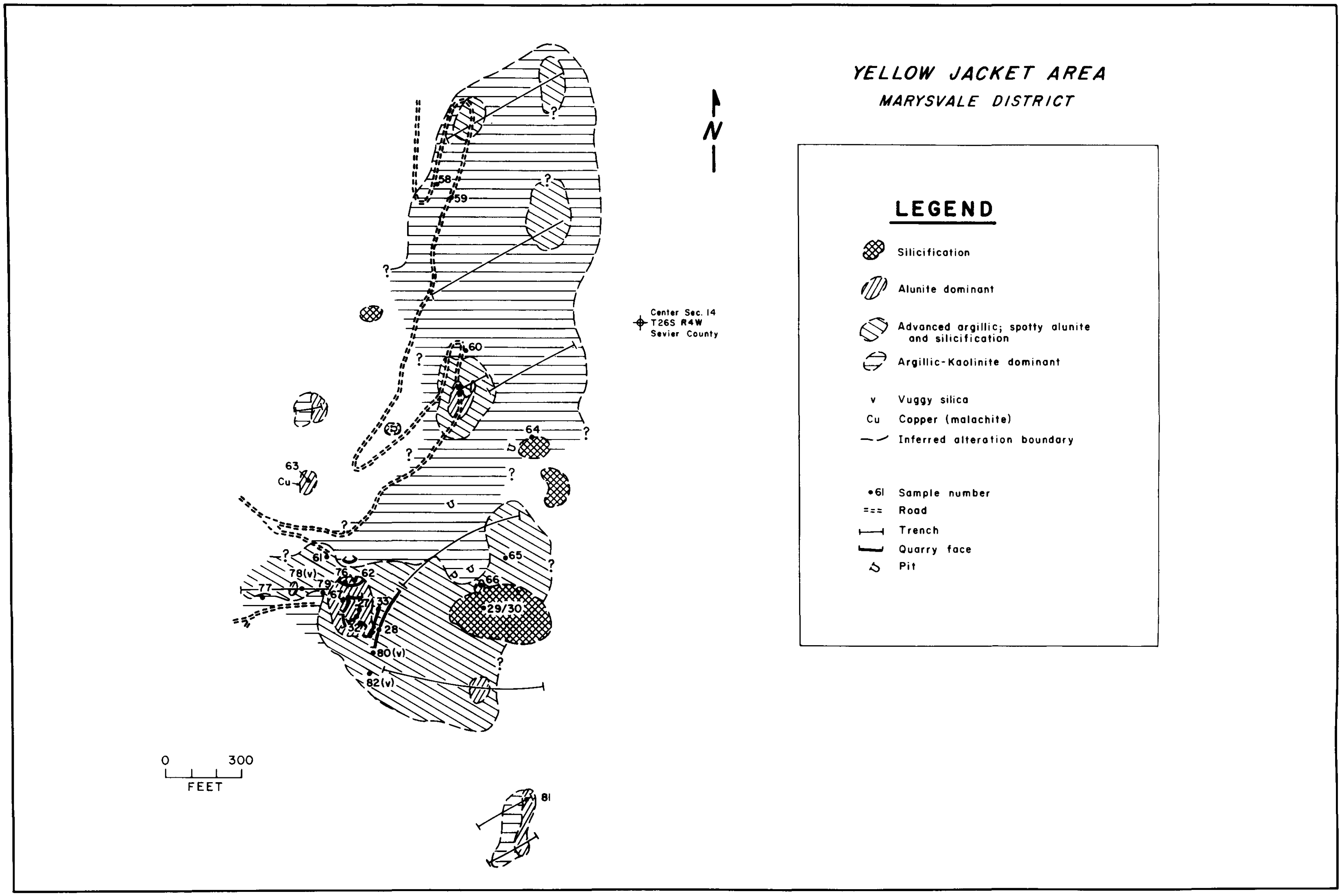

Figure 6. Alteration of the Yellow Jacket quarry area, Antelope Range, Marysvale district. Based on field inspection, x-ray diffraction results and interpretation of data from Hild (1946). All sample numbers correspond to the 89 series in Tables 2, 3 and 4.

in veins cutting alunite (Kerr et al., 1957). The uranium mineralization appears to be related to two small intrusions which may substantially postdate the replacement alunite.

A K-Ar age of 22.5 ± 1.0 Ma on alunite from the Yellow Jacket correlates well with K-Ar ages of 23 to 22 Ma from the Central intrusion (Steven et al., 1979). These dates, combined with the spatial association (Fig.1), suggest a genetic relationship. Cunningham et al. (1984a) concluded that the large zones of acid-sulfate alteration found in the region represent hydrothermal cells which ringed the intrusion. However, the relative timing of intrusion, alteration and uplift remain poorly defined. Uplift of the Central intrusion is necessary to account for its present position adjacent to the alteration zones (Cunningham et al., 1984a). Sulfur isotope data suggest that the sulfate may be derived from underlying evaporitic sequences. Alternatively, the data may be explained by partial sulfide-sulfate equilibration within the system (Rye et al., 1989). The Marysvale district was a dynamic environment in which repeated intrusive activity and associated hydrothermal systems overprinted each other episodically from 23 to 14 Ma.

Several features of the replacement alunite deposits are indicative of a magmatic-hydrothermal system. Evidence for the depth of formation of the alteration system is, however, ambiguous and added complexity may have resulted from overprinting during younger events. The important characteristics of the Yellow Jacket alteration are:

1. Silica alteration occurs as massive pods and veins, dominantly in the upper levels ('silica cap'). Silica is present as microcrystalline quartz and is intermixed with alunite. Vuggy silica contains quartz lined cavities.
2. Alunite occurs as well-formed crystals, indicative of hypogene formation.
3. The quarry material is reported to have contained high phosphate levels.
4. No sulfur, mercury mineralization, surficial acid-leach textures or opaline sinter associated with the steam-heated environment were observed in the area.

DISCUSSION

Zones of acid-sulfate alteration are generally difficult to explore due to their tendencies to cover wide areas and to be geochemically barren. They are, however, clear indicators of hydrothermal systems and are known in numerous cases to be associated with precious metal mineralization. Effective exploration must be tailored to the particular type of alteration.

Acid-sulfate alteration occurrences in the Marysvale-Pioche mineral belt were formed in both the magmatic-hydrothermal and the near-surface, hot spring environment. Replacement type alunite occurrences in the Marysvale district may exhibit overlapping characteristics of both types of systems.

Those occurrences found in the central portion of the belt (Wah Wah Mtns., Shauntie Hills, Black Mtns.) were dominantly formed in the near-surface environment. They exhibit numerous characteristics in common:

1. A genetic association with alkali rhyolites.
2. Sulfur and/or mercury mineralization is commonly present.
3. Acid-leached rock, containing remnant silica and minor alunite and/or opaline silica sinter are contained within the zones of alteration.

Geochemical sampling of these areas has produced little encouragement (Table 4) and provides few clues to the location of potential upwelling or boiling zones. Moore (1990) suggests that upwelling in active geothermal systems may be found in areas where the acid-sulfate cap is thinnest. Quartz-carbonate veins are known locally and quartz-sericite-pyrite veins crop out near acid-sulfate alteration at the NG deposit (Hofstra, 1984). Areas containing such veins are possible exploration targets.

The overall potential of these areas is low. Mineralized vein systems, however, are generally of limited dimensions making hidden veins difficult to discover. Structural analysis is critical in determining targets in such areas. Exploration may be most successful in zones adjacent to but lacking the acid-sulfate alteration.

The San Francisco district contains acid-sulfate alteration that is clearly related to a magmatic-hydrothermal system. These zones and the replacement alunite pods at Marysvale exhibit some features in common:

1. Hydrothermal breccias are contained within the quartz-alunite alteration.
2. Alunite occurs as well formed needles and mosaics; silica is present as microcrystalline quartz; no halloysite or dickite are reported.
3. No associated quartz-carbonate veins are known.

Field relations in the San Francisco area show a clear relationship between intrusion, magmatic mineralization and acid-sulfate alteration. Relationships in the bulk of the Marysvale district are less clear. Although the alteration is interpreted as magmatic-hydrothermal, the depth of formation and relationship to the Central intrusion remain uncertain.

The best guides to ore within these systems will be geochemistry within the alteration combined with mapping of alteration and brecciation patterns. Zones of quartz-alunite-pyrite which contain hydrothermal breccias are the most prospective. Large volumes of barren material may be present. Reconnaissance sampling near the Frisco Contact and the Yellow Jacket did not return significant gold values, however gold is reported from within their respective alteration zones (P. Blakemore, C. Elder, pers. comm. 1990). Both areas are prospective for precious metals; however, the size and complexity of the hydrothermal system in the Marysvale district suggest that this area has the highest potential for undiscovered gold mineralization.

CONCLUSIONS

Acid-sulfate alteration occurrences in the Marysvale-Pioche mineral belt may be categorized on the basis of mineral assemblages, textures and distribution patterns. The near-surface, hot spring and magmatic-hydrothermal systems in the belt are distinctive and are related to alkali rhyolite and granodiorite or quartz monzonite intrusions, respectively. The magmatic-hydrothermal related alteration in the mineral belt has the highest potential for precious metal mineralization. The Marysvale replacement zones are the most complex and show features of the magmatic type; therefore, the Marysvale district remains the most prospective for gold mineralization.

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