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# LARGE-SCALE HYDROTHERMAL ZONING REFLECTED IN THE TETRAHEDRITE–FREIBERGITE SOLID SOLUTION, KENO HILL Ag–Pb–Zn DISTRICT, YUKON

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## ABSTRACT

The zoned Keno Hill vein system of central Yukon extends laterally from a Cretaceous plutonic-metamorphic center and surrounding quartz–feldspar veins, to carbonate–Ag–Pb–Zn deposits, and further to peripheral veins having epithermal characteristics. Seven distinct mineralogical zones are recognized, and the entire sequence is continuous from east to west in a 40-km belt. The fault- and fracture-controlled veins are stratabound to the brittle moderately dipping Keno Hill Quartzite unit, of Mississippian age. The unit is graphitic and appears to have acted as a large-scale hydrothermal aquifer, restricting fluid flow during mineralization and development of zoning predominantly to the lateral direction. Tetrahedrite is distributed along a 25-km-long portion of the system, and is the principal ore mineral of Ag. Both Ag/Cu and Fe/Zn values in tetrahedrite are highest at the outer extremity of the system, where freibergite dominates over tetrahedrite; silver-rich samples are also distinguished by an overall increase in the number of cations per formula unit; the Sb/As value is high throughout.

*Keywords:* hydrothermal zoning, aquifer, tetrahedrite, solid solution, plutonic, epithermal, alteration, Keno Hill district, Yukon.

## SOMMAIRE

Le système de veines de la région de Keno Hill, dans la partie centrale du Yukon, est étalé autour d'un centre de plutonisme et de métamorphisme d'âge crétacé, et des fissures à quartz + feldspath associées, et s'étend à des gisements de carbonate–Ag–Pb–Zn et, dans les régions périphériques, à un système de veines à caractère épithermal. Sept zones minéralogiques distinctes sont étalées de façon continue d'est en ouest sur une distance de 40 km. Les veines, dont la distribution est régie par un système de failles et de fissures, sont limitées à la quartzite cassante et à faible pendage de Keno Hill, d'âge mississippien. C'est un encaissant graphitique qui semble avoir agi comme nappe aquifère à grande échelle, canalisant le flux de fluide hydrothermal au cours de la minéralisation dans une direction latérale. La tétraédrite, répandue sur une distance de 25 km dans ce système, est le principal porteur d'argent. Les valeurs Ag/Cu et Fe/Zn de ce minéral sont les plus élevées dans les parties externes du système, où la freibergite est plus répandue que la tétrahédrite. Les échantillons riches en argent se distinguent aussi par une augmentation dans le nombre de cations dans leur formule chimique. Le rapport Sb/As demeure uniformément élevé.

(Traduit par la Rédaction)

*Mots-clés:* zonation hydrothermale, nappe aquifère, tétraédrite, solution solide, plutonique, épithermal, altération, district de Keno Hill, Yukon.

## INTRODUCTION

This paper concerns the large-scale nature of the Keno Hill hydrothermal system. A broad and continuous sequence of mineral zoning can be documented within veins distributed along an extensive portion of the Keno Hill Quartzite, which is the main host rock to the ore in the area. The Keno Hill mining district is located in central Yukon, 350 km north of Whitehorse (Fig. 1). Since 1913, over 4.54 $\times$ $10^6$ t ore averaging 1412 g/t Ag, 6.8% Pb, and 4.6% Zn have been mined, and in excess of 6.4 $\times$ $10^9$ g of silver have been produced (Watson 1986).

The class of deposit relevant to the Keno Hill veins is referred to by several designations: Cordilleran vein-type deposits (Guilbert & Park 1986), felsic-intrusion-associated silver–lead–zinc veins (Sangster 1984), Pb–Zn sulfide Ag-sulfosalt deposits (Andrews 1986), or polymetallic veins. Despite the considerable economic importance of such veins, relatively little relevant research has been carried out in the last decade (Andrews 1986), and consequently their general characteristics and genesis are poorly understood.

In the most extensive geological work on the veins of the Keno Hill district, Boyle (1965) gave a thorough documentation of the various mineral associations. He recognized separate mineralogically distinct groups of veins throughout the region: cassiterite, wolframite, scheelite and related minerals occur near Cretaceous plutonic bodies, whereas veins containing siderite, galena, sphalerite, and freibergite are separated from the plutons. Boyle considered the two groupings to be unrelated; the silver lodes were thought not to be associated with the plutons, either spatially or genetically (Boyle 1965). Boyle concluded that the metals were emplaced vertically from below through diffusion processes; a flowing

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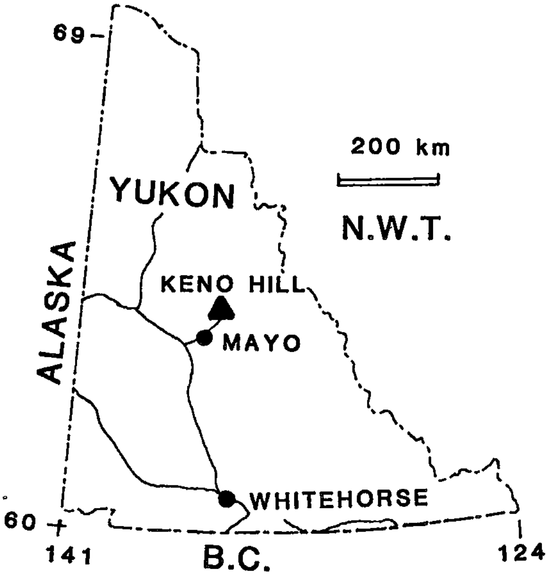


FIG. 1. Location map of Keno Hill mining district in central Yukon.

hydrothermal medium was not favored. However, hydrothermal features are clearly displayed in the vein system. Also, similar Cretaceous ages for the silver veins and for the felsic plutons of the region indicate the possibility of a genetic link (Sinclair *et al.* 1980, Godwin *et al.* 1982).

District-wide mineral zoning within the Keno Hill vein system is documented in this paper. Economic and noneconomic parts of the district are both considered in establishing the continuity of the zones. The patterns indicate a spatial association among the silver deposits, tin mineralization and the Mayo Lake pluton. Lateral movement of evolving hydrothermal fluids during mineralization along fractures in the Keno Hill Quartzite is indicated. The lateral distribution of minerals allows for the exposure of a complete cross-section of the hydrothermal column, at the present level of erosion, from plutonic to epithermal end-members. The documented zoning corresponds to Spurr's (1907, 1912) classic generalized models of zoning.

A quantitative approach to the study of geochemical zoning was pursued through an electron-microprobe investigation of the tetrahedrite-series minerals. Seventy electron-microprobe analyses were performed on tetrahedrite samples from 12 different deposits across the district. Argentian tetrahedrite, the most important silver ore-mineral in the Keno Hill district, occurs throughout a 25-km-long portion of the laterally zoned system. As reported in the literature, tetrahedrite tends to increase in Ag/Cu and Sb/As in the more evolved deposits (Hackbarth & Petersen 1984); Fe/Zn increases as well in some cases (Jambor & Laflamme 1978). Substitutions are generally insensitive to temperature, but respond to changing chemistry of the fluid (Sack & Loucks 1985). However, in the silver-rich end-member, freibergite, there may be a crystallographic restriction to the amount of arsenic present (Johnson & Burnham 1985). In the Keno Hill area, the compositional changes in tetrahedrite correspond well with the broad mineralogical zones.

Samples were gathered as a result of local surface mapping at various scales, logging of drill cores, and detailed mapping of underground exposures and open pits. X-ray diffraction was used to confirm optical identifications of the ore minerals.

## GEOLOGICAL SETTING

The Mississippian Keno Hill Quartzite, which hosts the high-grade silver deposits, outcrops in the Selwyn Basin, in a region that forms the northern extension of the Omineca Belt. The Belt is a collision-related, Cordilleran-scale, plutonic–metamorphic welt overlapping accreted terranes and the North American craton (Tempelman-Kluit 1979, Monger *et al.* 1982).

The quartzite extends for more than 220 km along strike and is bounded above and below by thrust faults (Fig. 2). The strata dip moderately toward the south, and thrusting was generally toward the north. The main unit below the quartzite is the Jurassic "Lower Schist" unit (Poulton & Tempelman-Kluit 1982). Above the quartzite are overthrust "Grit Unit" rocks of the Proterozoic Windermere Supergroup, Siluro–Ordovician Road River Formation, and "Upper Schist" unit rocks of undetermined age. This deformed sedimentary package, metamorphosed to the greenschist facies, is cut by bimodal Cretaceous felsic plutons: an alkaline suite to the west of the district, and a granitic suite in the region near the mining district (Anderson 1987). The sequence of thrusting and pluton emplacement postdates the Jurassic Lower Schist and terminates with Cretaceous plutonism.

The Keno Hill Quartzite is a dark grey, graphitic quartzite with minor muscovite, chlorite, tourmaline, zircon, and usually less than 5% carbonate. Individual layers of quartzite are typically from 1 to 3 m thick and have thin interlayers of graphitic schist. In the area of Keno Hill–Galena Hill, the structural thickness of the quartzite is approximately 1 km. Other than bedding, sedimentary structures are not common. The quartzite has been recrystallized and contains concordant segregations of metamorphic quartz. Finely crystalline grey limestone or marble units are widely distributed but are not abundant.

Concordant lenses of "greenstone" are abundant throughout the Lower Schist and in the Keno Hill

Quartzite, but are less abundant in the Upper Schist. The lenses are 1 m to 30 m in thickness, and locally persist along strike for more than 1 km. They are interpreted to be the metamorphosed equivalents of gabbro and diorite sills (Green 1971). Their most common metamorphic assemblage is zoisite–albite–actinolite–chlorite ± stilpnomelane (McTaggart 1960). The lenses are older than the undeformed granitic bodies (mid-Cretaceous), and possibly were cogenetic or younger than the Jurassic rocks.

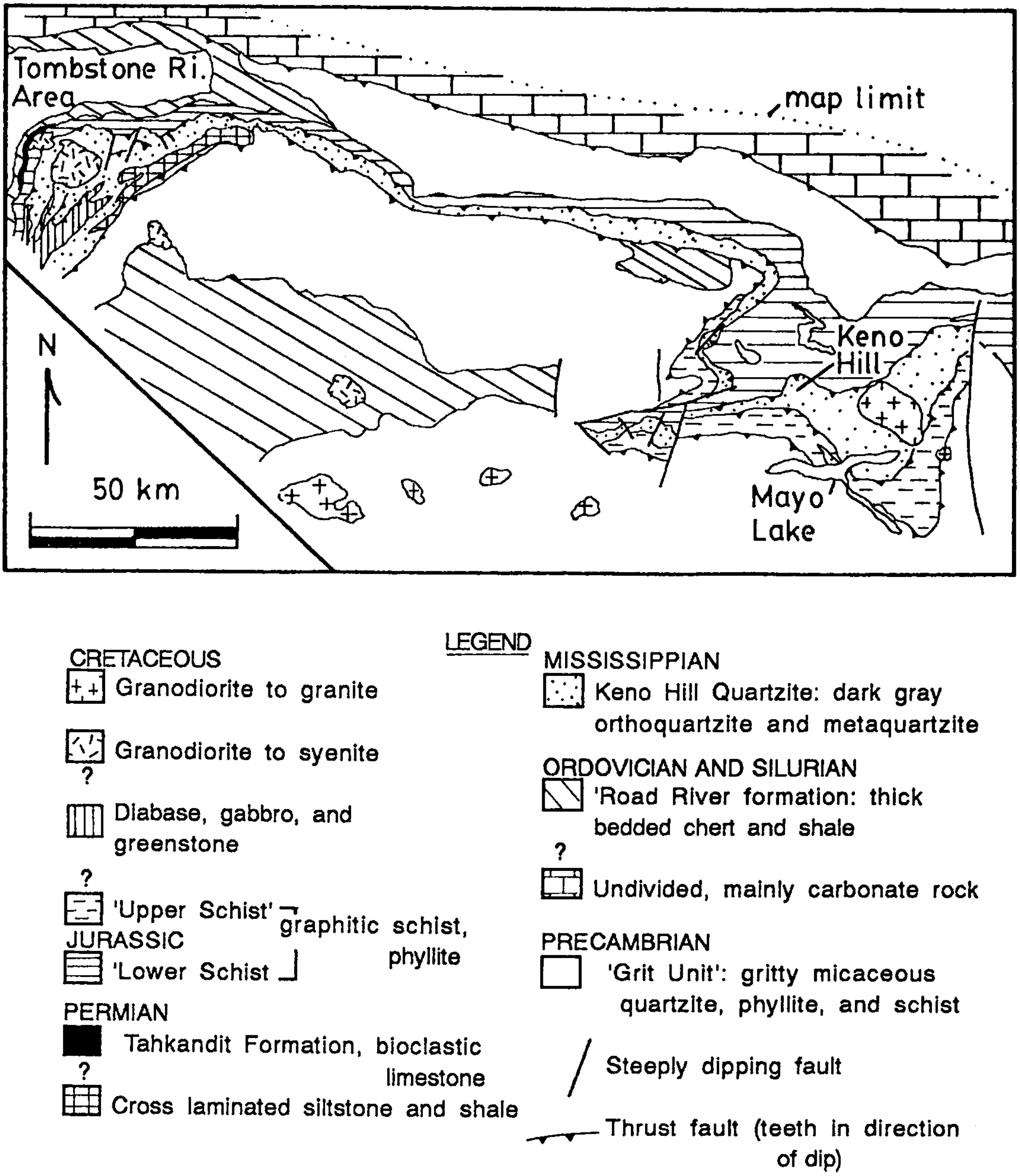


FIG. 2. Geological map of region surrounding Keno Hill, and Keno Hill Quartzite (modified from Tempelman-Kluit 1970).

The Mayo Lake pluton cuts the Keno Hill Quartzite to the east of the mining district (Fig. 3). It has been dated by the K–Ar method at 81 Ma (GSC map 1398A). The pluton varies from a core of coarse porphyritic granite containing megacrysts of alkali feldspar, black amphibole, and minor titanite, to a margin of finer equigranular granodiorite with green amphibole. Contact metamorphism extends outward for up to 4 km. Sillimanite schist at the contact grades outward into garnet–staurolite–feldspar

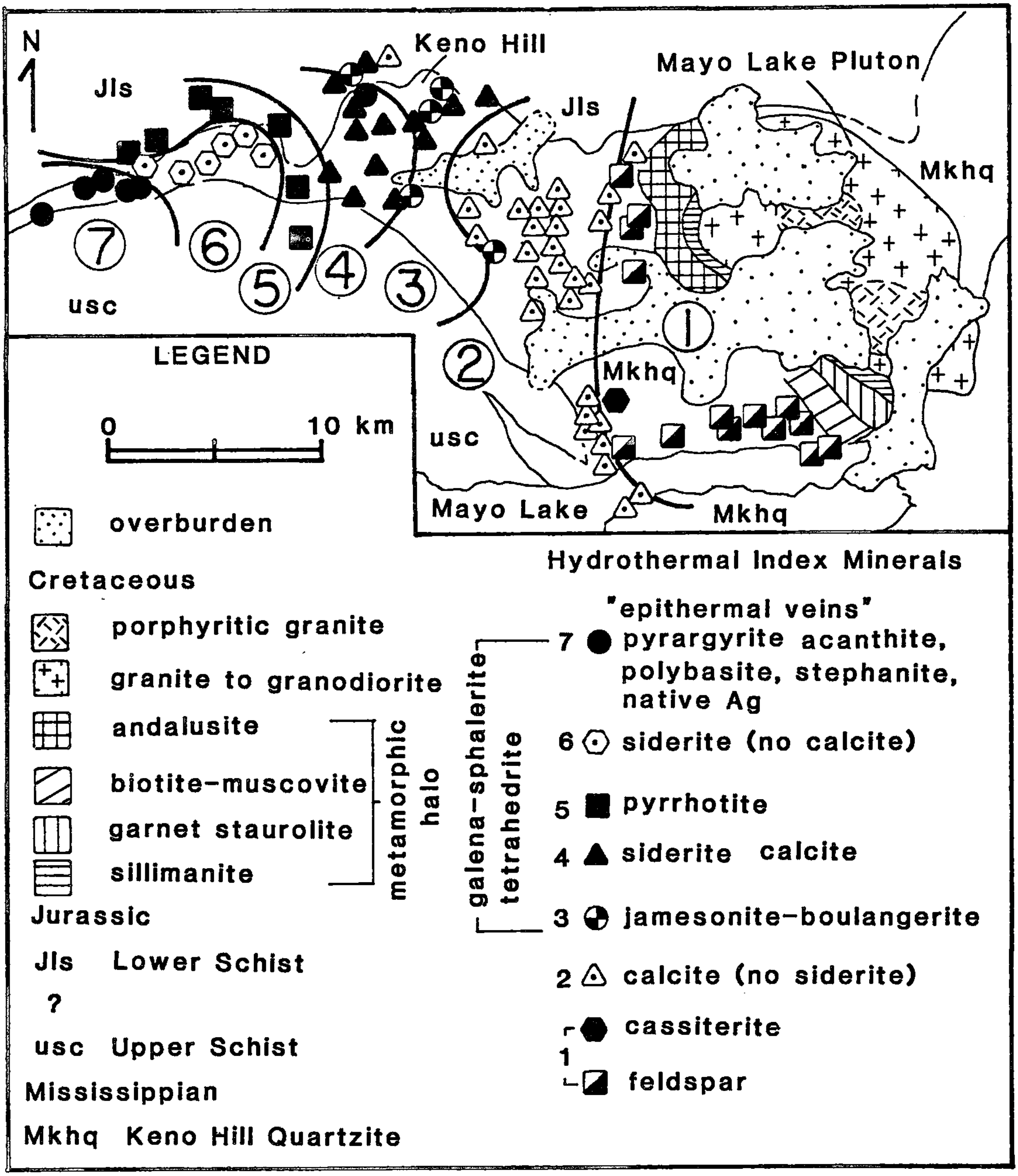


FIG. 3. Map of principal zones of hydrothermal minerals within the Keno Hill district, and relation of veins to the Mayo Lake pluton in the eastern portion of the map. The diagram emphasizes mineralogical differences, though there is considerable overlap between zones.

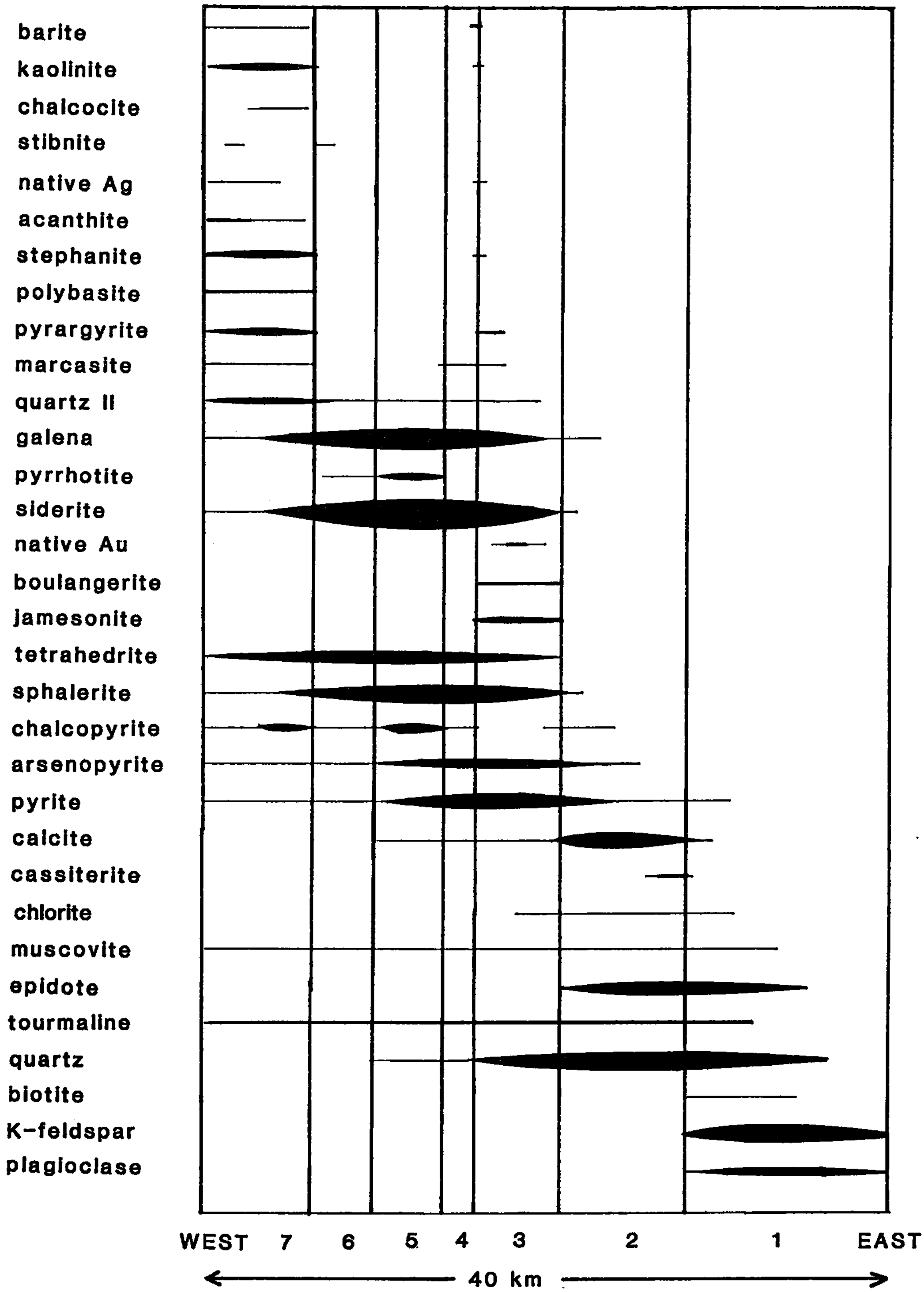


FIG. 4. Bar diagram of east-to-west mineralogical zoning, which displays mineralogical overlap between zones. The thickness of bars gives a schematic representation of relative abundance.