MINERAL-RESOURCE ASSESSMENT OF THE MÁTRA AND BÖRZSÖNY-VISEGRÁD MOUNTAINS, NORTH HUNGARY

LAWRENCE J. DREW, BYRON R. BERGER, WALTER J. BAWIEC, DAVID M. SUTPHIN, GYÖRGY CSIRIK, LÁSZLÓ KORPÁS, ÉVA VETŐ-ÁKOS, LÁSZLÓ ÖDOR, and JÁNOS KISS

1 US Geological Survey, 12201 Sunrise Valley Drive, Reston, VA 20142, USA
2 US Geological Survey, P. O. Box 25046, Denver, CO 80225, USA
3 Geological Institute of Hungary, H-1143 Budapest, Stefánia út 14., Hungary
4 Eötvös Loránd Geophysical Institute, H-1145 Budapest, Kolumbusz utca 17–23., Hungary

ABSTRACT

A pilot mineral-resource assessment for a study area in the Mátra and Börzsöny–Visegrád Mountains, North Hungary was used to transfer the assessment method developed during the past 25 years at the US Geological Survey to the Geological Institute of Hungary. A wide range of geological, geochemical, geophysical, drill core, and mining data were used in this assessment. These data were acquired from field observation and satellite images, as well as the large body of recent literature on the geology, tectonics, and magmatic activity associated with the formation of the Pannonian Basin. The results of the assessment confirm that the Middle Miocene volcanic complexes in the study area are permissive for the occurrence of mineral deposits that belong to the porphyry copper/polymetallic vein system. The estimated undiscovered resources for each volcanic complex, the expected number of undiscovered deposits by type, and the aggregated metal tonnages across all deposit types are reported.

1. INTRODUCTION

Mineral-resource assessment is a field of research and application of economic geology that has developed rapidly during the past 25 years (Singer 1993). The goal of this field is to produce information about the occurrence of undiscovered resources for minerals exploration and land-use planning. The region chosen for the pilot mineral-resource assessment was the Mátra and Börzsöny–Visegrád Mountains, North Hungary (Fig. 1). For the assessment, geologic information on the occurrence of metallic mineral deposits was collected, reconnaissance field trips to Slovakia (1995) and Romania (1997) were made to examine mineral deposits of the types known to occur in the study area, and estimates were made of the numbers of undiscovered mineral deposits of these types in the study area.

2. MINERAL-DEPOSIT MODELS

The Mátra and the Börzsöny Mountains have been prospected for base metal mineral deposits during the past several decades. A large polymetallic vein deposit type (Bliss and Cox 1986, Cox 1986) was discovered and mined until 1986 at Gyöngyösoroszi in the southern Mátra Mountains (Fig. 2; Varga et al. 1975, Bartók and Nagy 1992) and a similar but much smaller deposit was mined until 1954 near Nagybörzsöny at Röszá-bánya in the Börzsöny Mountains (Fig. 2; Csillagné–Teplánszky et al. 1983, Korpás and Lang 1993, Korpás et al. 1998). The Gyöngyösoroszi deposit has proven reserves of 4.8 million tonnes (t) of lead, zinc, and silver ores, whereas the Nagybörzsöny deposit has 40,000 t of reserves of similar ores. In addition to the Nagybörzsöny polymetallic vein deposit, three small low-grade porphyry copper deposits were discovered and evaluated (Csillagné–Teplánszky et al. 1983, Korpás et al. 1998). Collectively, the porphyry copper deposits contain approximately 100 million t of material with a grade of 0.1 percent copper. Magnetite-, sphalerite-, and chalopyrite-bearing xenolites of skarn deposits (Fe₂O₃+FeO: 63.4–67.7 percent; Zn: 4,000–6,000 ppm, Cu: 100–400 ppm).
ppm) were described by Csillag—Teplanszky and Korpas (1982) from the basal horizon of the Börzsöny—Visegrád Andesite at Dunabogdány. The primary skarn deposit, hosted in Middle to Late Triassic dolomites and limestones of the pre-Tertiary basement, is located at a depth between 1500 to 2500 m.

In addition to being permissive for the occurrence of porphyry copper and polymetallic vein deposits, calc-alkaline volcanic complexes, such as those in the Börzsöny—Visegrád and the Mátra Mountains, are generally permissive for the occurrence of skarn deposits (Cox 1986, Sawkins 1990). No assessment for skarn deposits was performed for the Börzsöny and the Visegrád Mountains because of the deep position of the possible skarn deposits. An assessment for these deposits was initially considered for one small area where limestone occurs in the Mátra Mountains, but too little field data for this area were available to execute a quantitative assessment for this deposit type.

The determination that certain packages of rocks are permissive for the occurrence of particular types of mineral deposits (for example, polymetallic veins and porphyry copper deposits) implies that there is at least a specific probability for the occurrence for these type of deposits. Singer (1993) defined a package of rocks as permissive if the probability of occurrence of an economic deposit is 1 to 10,000 or greater. In application, the concept of permissiveness is based on the fact that particular types of deposits usually occur in association with particular packages of rocks in various parts of the world. Further, given the permissiveness, the probability of occurrence is usually assumed to increase with the size of the permissive rock volume. The probability estimate, however, must be determined from the available data on the land tract under consideration. Further, in such highly explored regions as the study area, the probability that most (perhaps all) of the mineral resources have already been discovered must be considered.

The Mátra Andesite and the Börzsöny—Visegrád Andesite Formation are each about 600 km² in areal extent. These areas are only small parts of the much larger inner Carpathian magmatic arc (Fig. 1) in which about 50 sig-
Fig. 2: Map showing the location of the study area in the Börzsöny and Visegrád and the Mátra Mountains

The Mátra Mountains, which are localized in a Middle Miocene right-lateral strike-slip fault system, are probably within a right-stepping extensional duplex. As the extension began to dominate in the Middle to Late Miocene, the strike-slip faults became connecting transfer structures among the developing sedimentary basins, one of which is the Zagyva trough. The volcanic complex in the Börzsöny and the Visegrád Mountains is probably located in a similar pull-apart basin. Compiled from Tari et al. (1992), Korpás and Lang (1993), Marton and Fodor (1995), and Korpás et al. (1998)
significant polymetallic vein districts and several porphyry deposits have been discovered in Slovakia (Western Carpathians) and Romania (Apuseni Mountains and East Carpathians; BORCOS 1994). Therefore, solely from the ratio of the areal size of the study area to the areal size of the inner Carpathian magmatic arc, we might expect that a small number of polymetallic vein districts and porphyry deposits occur in the study area.

3. TECTONIC MODEL OF PORPHYRY COPPER/POLYMETALLIC VEIN KIN-DEPOSIT SYSTEM

A tectonic model for the porphyry copper/polymetallic vein kin-deposit system is developed from empirical descriptive models from field data (COX and SINGER 1986), model and theoretical studies of the behavior of strike-slip fault systems (SEGALL and POLLARD 1980), and studies of heat dissipation and mechanics associated with intrusive rocks (NORTON 1982, SONDER and ENGLAND 1989). The kernel of this model is derived from the observation that these kin deposits occur in close spatial and temporal associations in the strike-slip fault systems and, in particular, in duplexes.

The members of this system of kin deposits range from those formed in an initial magmatic phase to those that are derived from mixed meteoric/magmatic inputs; that is, from porphyry copper deposits to polymetallic veins. The initial phase begins when far-field stress in the crustal plate is released in the principal deformation zones (PDZ) of strike-slip fault systems. As stress is propagated, it is transferred from one master fault tip to another, and, depending on the direction of transfer, either extensional or compressional duplexes are formed (SEGALL and POLLARD 1980). Extensional duplexes form at the releasing bends, whereas compressional duplexes form at the constraining bends. Extensional duplexes are easily recognized by the sedimentary basins that form and are readily preserved. Compressional duplexes are formed less frequently and, as structural high features, are eroded easily and, therefore, are less well preserved. Within both of these duplex structures, zones of crustal extension develop that provide channelways for magma to rise to shallow levels in the crust. The zones of extension, however, are smaller in the compressional duplexes. These duplexes may also hold a shallowly intruded stock in place for the necessary length of time so that hydrothermal fluid can be focused into small rock volumes where the necessary mesothermal reactions (carapace development, hydrofracturing, and brittle intrusive fracturing) can occur to create a porphyry copper deposit.

During this process, the intruding igneous stock elevates the temperature of the encapsulating host rocks (Fig. 3; NORTON 1982) enough to nullify the effect of the far-field stress (σ1 and σ2 are made nearly equal; that is, Δσ is near zero). In this structural environment, ductile behavior can occur at a shallow level in the Earth's crust. With high temperature and low differential stress, the rocks fracture when the hydraulic pressure under the carapace exceeds the confining pressure. Additional brittle fractures are formed by the mechanical/hydraulic processes associated with emplacement of magma and hydrothermal convection. With repeated sealing through mineral precipitation and fracturing, an interconnected stockwork of veins is developed. Silica, potassium feldspar, and copper sulfide minerals precipitate in the low-pressure environment that exists after a fracturing event.

When new batches of magma are no longer emplaced into the magma chamber and heat dissipates in the stock and surrounding wallrock, the likelihood for throughgoing brittle fracturing increases as the far-field stress regains structural dominance over the rock volume (σ1 again dominates, or Δσ > 0); that is, as the thermal environment becomes retrograde, the effect of the stress in the far field is reestablished, and throughgoing straight brittle fracturing dominates.

The polymetallic veins that often crosscut and (or) are intimately associated with porphyry copper deposits are deposited in the brittle fractures that develop after strain is partitioned and accommodated within the large volume of rock that surrounds the porphyry. The polymetallic nature of these veins is attributed to the introduction of meteoric water into the igneous hydrothermal system. When the porphyry system is arrested owing to strain partitioning, the hydrothermal system is then opened to nonmagmatic sources of zinc, lead, and other components that have been leached from the rocks that surround the intrusive complex by the incoming meteoric waters. The Mátra Andesite and the Zagyva trough tectonic system is interpreted as an example of this type of tectonic evolution.

Polymetallic veins often occur in positive flower structures (Fig. 4A). These structures break upward toward a free surface and are compressive. The converse structure [the negative flower structure (Fig. 4B)], which also forms in the same fault system, breaks upward along expansion fractures. The negative flower structure is then open to the surface, and the hydrothermal system often leaks out at the surface. The configurations shown in Fig. 4 are the end members often observed in a PDZ of a strike-fault system.

Because the movement of the horses of rock in a PDZ of a major strike-slip fault system can be rather heterogeneous, and the general model has to be modified on a case-by-case basis to allow for the progressive nature of
Fig. 3: Diagram showing the model of the distribution of magmatic heat associated with a plutonic stock and isotherms for temperatures after 30,000 years of heat dissipation (Norton 1982)

Fig. 4: Diagrams showing cross sections through flower structures
A, positive; B, negative; A, tectonic movement is away from viewer; T, tectonic movement is toward viewer
simple shear. In this progression, individual horses may record different histories of internal strain (domains) as the local stress fields reorientate to accommodate rotation and locking and unlocking of horse blocks. When horse blocks unlock, previously developed faults may be reactivated, and other structures (bedding planes and foliations) may be activated. Consequently, the permeability that controls fluid flow can vary in direction over time, and the deposition of mineralization in negative and positive flower structures can occur (WILLIS and TOSDAL 1992).

The positive flower structure is, by virtue of its compressional nature, a fluid-flow-constraining reaction-containing (self-sealing) structure; that is, locally along a positive flower structure, there will be regions where $\sigma_1$ is equal or nearly equal to $\sigma_3$. These compressional structures are frequently found in the field as readily mapable antiforms. Before the flower structures were formally identified and named by R. F. GREGORY in 1970 (HARDING and LOWELL 1979), many examples were known. A summary diagram has been widely used to express the idea that such structures are compressional and that they are created in transpressive sections (constraining bends) of strike-slip fault systems (Fig. 5; LOWELL 1972).

Well-documented examples of the porphyry copper/polymetallic vein kin-deposit system that illustrate the initial phase of porphyry development followed by the development of polymetallic veins are found within the inner Carpathian magmatic arc in the Apuseni Mountains, Romania (BORCOS 1994, BERBELEAC et al. 1995a, b, MITCHELL 1996). For example, in the Zlatna region (Fig. 6), where low-grade porphyry copper deposits have been emplaced, these deposits are often cut by polymetallic veins that have grades in the range of 5 to 7 percent combined zinc and lead (I. BERBELEAC, P. S. A., oral commun., May 1997). Also in the same region, the economic polymetallic veins that occur in the Hanes deposits (Fig. 6 and Fig. 7) are in the footwall (more-compressive) section of complex positive flower structures. Interpretation of the evolution of this structure is ambiguous because of the intruding andesite. This complexity is probably associated with large vertical and horizontal displacements on the main fault with considerable left-oblique movement. The intruding andesite completely filled the hanging-wall segment (northeastern side) of this flower structure, and the footwall (southwestern side) is interleaved with horses of marl beds that were thrust upward from lower in the stratigraphic section.

At Hanes, then, the intimate relation between the strain features created by the strike-slip faults (flower structure) and the intruding andesite is obvious—the andesite body takes the form of the flower structure with a dikelike root and a dome-shaped top (Fig. 5). Subsequent to intrusion of the andesite along the fault system, throughgoing brittle fracturing occurred in the andesite, and polymetallic veins were deposited in the southwestern side of the flower structure. Northwestward along the fault system, however, compression increased across the whole structure. Consequently, the polymetallic veins are more broadly distributed across the flower structure.

Fig. 5: Diagram showing a positive flower structure as a self-sealing reaction-containing structure (LOWELL 1972)
Fig. 6: Diagram showing a cross section through the Larga porphyry copper and the Hanes polymetallic vein deposits, Zlatna district, Romania (BORCOS 1994)

Fig. 7: Diagram showing interpretation of the flower structure that hosts the polymetallic veins in the Hanes deposit, Zlatna district, Romania
Based on data from BORCOS et al. (1962)
4. GEOLOGICAL SETTING AND TECTONIC HISTORY OF THE STUDY AREA

The study area is located in the West Carpathians within the inner volcanic arc of the Carpathian-Pannonian region (Fig. 1, ROYDEN et al. 1982, SANDULESCU 1988, CSONTOS et al. 1992). The pilot mineral-resource assessment for this area was confined to volcanic complexes [the Börzsöny–Visegrád and the Mátra Mountains (Fig. 2)] permissive for selected mineral-deposit types. These volcanic complexes are Middle Miocene and localized in zones of crustal extension within a continental plate that overrode the subducting plate in a continent-to-continent collision (ROYDEN et al. 1983).

The zones of extension in which these volcanic/plutonic complexes evolved (Fig. 2) are interpreted as strain features that resulted from the release of stress that was built up during the continent-to-continent collision of the Pannonian and the European plates. WOODCOCK (1986) described the mechanism that produced these strain features as "indent-linked strike-slip fault systems" (Fig. 8). An additional condition was the development of a large escape structure to the east (ROYDEN et al. 1983). Many small basins were formed in the region as this escape structure fragmented along a series of northeast- to southwest-trending strike-slip faults. Individual basins and pop-up structures vary greatly in configuration because the various fragments escaped at differential rates during the Miocene. The Börzsöny–Visegrád and the Mátra Mountains were formed during the evolution of this structurally dynamic system. The volcanic rocks in these complexes are of calc-alkaline affinity and are principally andesitic in composition with some dacites and rhyolites (SZABÓ et al. 1992, KORPÁS et al. 1998).

PÓKA (1988) placed the main period of volcanic activity in the Börzsöny Mountains between 19 and 16.5 Ma and somewhat later in the Mátra Mountains (18 to 14.5 Ma). SZABÓ et al. (1992) reported ages of 16.5 to 15.5 Ma for the volcanics in the Börzsöny Mountains and 16.5 to 14 Ma for the Mátra Mountains. PÉCSKAY et al. (1995) have summarized the chronology of the Neogene to Quaternary volcanism of the Carpatho-Pannonian region. They estimated similar age intervals for the Börzsöny–Visegrád Mountains (16.5 to 13.5 Ma) and the Mátra Mountains (16.0 to 13.7 Ma). KARÁTSON (1995) estimated the same age (16.0 to 13.7 Ma for the Börzsöny volcanism. KORPÁS and LANG (1993) and KORPÁS et al. (1998) reported a much tighter and younger age (15.2 to 14.5 Ma) for the volcanic activity of the Börzsöny–Visegrád Mountains.

WOODCOCK (1986) discussed, in general terms, how stress is released through the development of strain features in the continental crust above the subducting plate in a continent-to-continent collision (Fig. 8). Consequently, indent-linked strike-slip faults then become the far-field strain features caused by such collisions [thus, the maximum principal stress (\(\sigma_1\)) is in the plane of the Earth's surface]. Within the PDZ of these fault systems, extensional and compressional strain features develop that can localize magmas at shallow crustal levels. The flow of hydrothermal fluids is similarly controlled by the same stress field and localized in the resulting strain features (SIBSON 1986). Simultaneously with this focusing of magma and fluids in the crust, sedimentary basins (strain features) are created as surface expressions of dissipated stress in the same PDZ (SYLVESTER 1988).
In the vicinity of the study area, the direction of \( \sigma_1 \) during the Early and Middle Miocene has been established as having been north-south through detailed analysis of kinematic indicator data (PERESSON and DECKER 1997), whereas the Late Miocene was characterized by a transient east-west compression. PERESSON and DECKER (1997) argued that the inversion of motion on Early and Middle Miocene structures indicates that east-west tension switched to east-west compression during the Late Miocene. They suggest that the Late Miocene soft collision in the East Carpathians transmitted east-west compression from the East Carpathian plate boundary westward through the previously extended upper plate and into the eastern Alps; that is, the effect of this collision was transmitted for more than 1,000 kilometers behind the subduction zone. FODOR (1995) presented a similar analysis for the Vienna Basin and the East Alpine-Western Carpathian junction where the Oligocene through Miocene period is characterized within the same context of having evolved from transpression to transtension and identified four different stress fields.

The strain features developed in the study area as a result of the dissipation of stress during the Middle Miocene (Fig. 2) are shown in detail in Fig. 9 (Mátra Mountains) and Fig. 10 and Fig. 11 (Börzsöny and Visegrád Mountains). The Mátra Andesite ascended to the surface in a zone of extension clearly identifiable on the geologic sketch map presented by MÁRTON and FODOR (1995). Elements of this map were used to compile the tectonic map shown in Fig. 2 where the northern boundary of the Mátra Andesite is located at the top of a right-lateral right-stepping strike-fault system. The Gyöngyösoroszi polymetallic vein mining district is hosted in a flower structure with the same northwest orientation as the master fault system (Fig. 2 and Fig. 4). The age of the mineralization is about 14 Ma (PECSKAY et al. 1995). As the right-lateral strike-slip fault system continued to evolve, sedimentary basins developed marginal to the Mátra Andesite like the Zagyva trough to the west, and other minor basins to the east and south (Fig. 2 and Fig. 9). A seismic section through the Zagyva trough (Fig. 2) has been interpreted by TÁR et al. (1992) as a half-graben structure in a transfer fault system. This interpretation is consistent with the idea that the Mátra Andesite and the volcanosedimentary complex of the Zagyva trough was created in a extensional duplex between two master faults. One of these faults is located in the Etes trough (expressed as a negative flower structure at the surface?), and the other has to lie mostly buried to the south (Fig. 2). This second master fault is clearly identified on tectonic maps by CSONTOS et al. (1991) and MÁRTON and FODOR (1995). The southern master fault is also identified in the Börzsöny–Visegrád Mountains as a regional strike-slip fault (Fig. 2) and as a collection of faults forming a PDZ in Fig. 10. The movements of the strike-slip faults controlling the porphyry copper and polymetallic vein mineralization in the area (Fig. 2, Fig. 9 and Fig. 10) are discussed below.

5. ASSESSMENT OF THE UNDISCOVERED DEPOSITS IN THE STUDY AREA

In the study area, both members of the porphyry copper/polymetallic vein kin-deposit system have been discovered. In the Mátra Mountains, however, only polymetallic vein deposits have been discovered, whereas in the Börzsöny Mountains, small porphyry copper deposits have been discovered. The three deposits discovered to date near Nagybörzsöny have a total of 100 million t of material with an average grade of 0.1 percent copper. The associated polymetallic vein deposits discovered in the same area (Fig. 2, Fig. 10 and Fig. 11) are also small (40,000 t) and have low grades (combined lead and zinc grade of 2.4 percent, 0.85 ppm gold, and 45 ppm silver; BARTÓK and NAGY 1992).

The polymetallic veins discovered at Gyöngyösoroszi in the Mátra Mountains are large (4.8 million t) and of higher grade (4.8 percent combined lead and zinc; BARTÓK and NAGY 1992). No associated porphyry copper deposits, however, have been found. The porphyry copper deposit located nearby at Recsk, on the northern edge of the Mátra Mountains, has an Eocene age (approximately 35 Ma; BÁKSA 1984) and is in an exotic tectonic block. This deposit may have been emplaced during the formation of the western Alps and carried eastward along strike-slip faults associated with the development of the Carpathian/Pannonian escape structure (KÁZMÉR and KOVÁCS 1985).

5.1. Previous exploration data

In April 1995, the assessment team examined several kilometers of drill core from the Nagybörzsöny porphyry copper deposits (Börzsöny Mountains) and one core from the area in the vicinity of the Gyöngyösoroszi deposit (Mátra Mountains). The cores from the Nagybörzsöny area contained sparse vertical fractures filled with quartz and occasional chalcopyrite, pyrite, magnetite, pyrrhotite, sphalerite, and galena. Little connective fracturing was evident, although sections of the cores were silicified. The assessment team also examined maps of the
Fig. 9: Map showing locations of strike-slip faults, mineralized faults, and sedimentary basins in the Mátra Mountains
See Fig. 2 for the location of the study area and the description of symbols
Börzsöny and the Mátra Mountains that showed a dense pattern of drilling, as well as many cross sections that had been constructed by using the data in these drill holes. Many chemical analyses of vein material and wallrock were studied (Varga et al. 1975, Csillagné–Teplánszky et al. 1983, Korpás et al. 1998). From these data, as well as supporting geochemical and geophysical investigations and associated literature (Csillagné–Teplánszky and Korpás 1982, Vétő 1988, Ődor et al. 1997, Korpás et al. 1998), the team concluded that the volcanic complexes in the Börzsöny–Visegrád and the Mátra Mountains had been extensively explored for porphyry copper and polymetallic vein deposits. This conclusion was the basis for the prediction that only a small number of deposits remain to be discovered in the study area.
5.2. Assessment of the Mátra Mountains

The Mátra Andesite was supplied by at least six volcanic centers (Kiss et al. 1996, ZeLENKA oral commun., 1998). The assessment area is shown by a dotted line in Fig. 9. Within the approximately 100 km² area, a collection of strike-slip faults that host the polymetallic veins occurs. The collection of northwest-to southeast-trending faults that cut across these mountains were located by combining data from a detailed map (Varga et al. 1975).
and photolinear analysis of a satellite image of the area. Although fieldwork would be required to measure the kinematic indicators essential to establish fault movement, it can be argued from the surface expression of these faults, that the central group (faults near the Gyöngyösoroszi deposit) are a complex flower structure with compressional segments (right-lateral and left-stepping), as well as extensional segments (right-lateral and right stepping), that is, a cross section from southwest to northeast would show a mixture of positive and negative flower structure features (Fig. 4). Such mixed flower structures host the gold-bearing quartz vein in the Mesquite mining district of southeastern California (Willis and Tósdal 1992). Again, this structural interpretation of these faults must be to be considered preliminary because field work is required to ensure proper structural analysis.

During the assessment of the Mátra Mountains, the following data were considered to be most relevant for predicting the occurrence of undiscovered polymetallic vein deposits – the basic geology is permissive (six or more volcanic centers), hydrothermal alteration is widely distributed, one major producing polymetallic vein district (Gyöngyösoroszi) has been discovered, and the inner Carpathian arc hosts many polymetallic veins nearby in Slovakia and Romania. The consensus estimate for the inventory of undiscovered polymetallic veins in the Mátra Mountains is a 90 percent probability of 4 deposits, a 50 percent probability of 5 deposits, a 10 percent probability of 6 deposits, and a 1 percent probability of 10 deposits. On the basis of this distribution, the expected number of undiscovered deposits is 5.08 deposits, which was estimated by using the method in which the solution is determined by weighing the individual probabilities associated with the regions of the probability among each number of deposits (Root et al. 1992).

This estimate of 5.08 deposits is for the occurrence of deposits distributed in size as shown in Fig. 12. Inspection of this figure reveals that the Gyöngyösoroszi deposit is an exceptionally large polymetallic vein deposit with proven reserves of 4.8 million t of ore (Bartók and Nagy 1992). This tonnage is at the upper end of the observed range of sizes for this type of deposit. The mean size of these deposits is 111,000 t, which is 43 times smaller than that of the Gyöngyösoroszi deposit. The assessment of an expected 5.08 deposits remaining to be discovered is associated with this mean, the distribution of which is shown in Fig. 12. Therefore, the assessment team's conclusion for ore grade material “at the mean” is equal to 5.08 x 111,000 = 560,000 t. This expectation is also a small fraction of the amount of ore produced from the Gyöngyösoroszi deposit.

In addition to an assessment for polymetallic vein deposits, the assessment team concluded that the probability of porphyry copper deposits remaining to be discovered in the Mátra Andesite is nontrivial. The general basis for
this determination was that although no porphyry copper deposits have been discovered, three silicified areas have been mapped, and polymetallic vein deposits have been discovered. The observed silicification could be a manifestation of a porphyry copper system and (or) the occurrence of polymetallic vein deposits. After considering the field data and exploration history, the assessment team reached a consensus that no porphyry copper deposits occur in the Mátra Mountains at the 90 and 50 percent probability levels, that one would occur at the 10 percent level, and that two would occur at the 1 percent level. The expected number of undiscovered porphyry copper deposits was computed to be 0.38 deposit (ROOT et al. 1992).

Finally, because no limestone or dolomite beds are known in the basement of the Mátra Andesite, the assessment team assigned a zero probability for the occurrence of undiscovered lead-zinc skarn deposits.

5.3. Assessment of the Börzsöny and the Visegrád Mountains

The assessment for undiscovered deposits in the porphyry copper/polymetallic vein kin-deposit system and associated lead-zinc skarn deposits in the Börzsöny and the Visegrád Mountains was less favorable than that for the Mátra Mountains. The assessment team concluded that there is no chance for the occurrence of a porphyry copper deposit of the size and grade described in the grade and tonnage model (SINGER et al. 1986). The porphyry copper deposits that have been discovered and drilled (Fig. 10 and Fig. 11) proved to be very small and of low grade, little more than occurrences. After discussion of the field data, the team concluded that insufficient data exist to continue with this assessment; thus, no assessment for undiscovered porphyry copper deposits was reported. A primary determinant in this decision was that the necessary rock-alteration patterns associated with this deposit type are not present. No assessment is reported for lead-zinc skarn deposits because of the deep level of the only occurrence described to date.

As postulated by the assessment team, the lack of porphyry copper deposits is probably related to the structural history of the Börzsöny and the Visegrád Mountains. The pattern of faulting in the vicinity of the volcanoes is predominately extensional (Fig. 10), which is shown clearly in the north-northeast-to-south-southwest cross section constructed by KORPÁS and LANG (1993, Fig. 8). In the middle of this area of extension, a domal feature (north-south-trending antiform) with a crestal fault is shown on Fig. 10; this fault is also shown on a map in CsilLAGNÉ-TEPLÁNSZKY et al. (1983, Fig. 14). The porphyry copper and polymetallic vein mineralization is directly adjacent to and almost entirely to the west of this fault (Fig. 11). The porphyry copper mineralization is confined on the east by this crestal fault and is mapped as a steeply dipping jumble of five small and adjacent fault blocks, each with lengths and widths that range from about 100 to 200 meters (CSILLAGNÉ-TEPLÁNSZKY et al. 1983).

As a consequence of extensional fault mechanics in the Middle and Late Miocene, the Börzsöny and the Visegrád Mountains are not favorable for the occurrence of high-grade and high-tonnage mineralization because the fault system was open (that is, the difference between $\sigma_1$ and $\sigma_3$ was large) and fluid flow was not sufficiently focused to result in large tonnages of high grade ore. Within this zone of general extension, however, it is not uncommon to find local compression features, such as the central anticline. In such a region of compression, fluid flow is contained (focused), thus allowing for the conditions that result in ore formation. As shown in Fig. 11, the location of the strike-slip faults relative to the volcano, shallow intrusions, and mineralization are consistent with the notion that in an even smaller area (less than 1 km²) the stress field was equant ($\sigma_1$ equal to $\sigma_3$).

Although the assessment team concluded that no undiscovered porphyry copper and lead-zinc skarn deposits remain to be discovered in the Börzsöny and the Visegrád Mountains, it did reach a consensus that the region was permissive for polymetallic veins whose tonnages are described by the cumulative frequency distribution in Fig. 12. The range of opinion within the team was vast—one member was almost certain that the probability that these deposits occur is nearly zero, and another member was sure that as many as 10 such deposits occur in the volcanic complexes of these mountains.

The consensus was that there is a 90 percent probability of one polymetallic vein deposit occurring, a 50 percent probability of two occurring, a 10 percent probability of three occurring, and a 1 percent probability of four occurring. The mean of a distribution with these probabilities is two deposits (ROOT et al. 1992). Thus, the assessment team concluded that in the approximately 600 km² Börzsöny–Visegrád Mountains assessment area, the statistical expectation is that two polymetallic vein deposits remain to be discovered.

6. AGGREGATE RESOURCE ESTIMATES

The Mark3 simulation software (ROOT et al. 1992) was used to estimate the inventory of undiscovered mineral resources contained in porphyry copper and polymetallic veins deposits in the study area (Table 1). The num-
ber of these deposits expected to occur in the study area is shown in Table 2. The estimates of aggregate metal and ore tonnages were computed as probability distributions (Fig. 13 and Table 3). The three quantiles and the mean of each of these aggregate metal distributions are shown in Table 3. These distributions are bimodal for copper and ore tonnage because the probability masses for contained metal and ore tonnages in porphyry copper deposits are much larger than those for polymetallic vein deposits (Fig. 13). This bimodality is clearly shown by the leftward breaks in the cumulative distributions for copper and ore tonnage at about the 35 percent probability level, which is the estimated marginal probability for the occurrence of this type of deposit. This result is based on the assessment team's consensus estimate that there is only a 35 percent probability that a porphyry deposit remains to be discovered anywhere in the study area.

Mineral-deposit models considered in the assessment of the undiscovered mineral resources in the study area

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Median tonnage</strong></td>
</tr>
<tr>
<td>Copper (pet)</td>
</tr>
<tr>
<td>Polymeric veins</td>
</tr>
<tr>
<td>Porphyry copper</td>
</tr>
<tr>
<td>Zinc-lead skarns</td>
</tr>
</tbody>
</table>

Summary of the expected number of undiscovered mineral deposits determined by the USGS/GIH assessment team in the study area

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area</strong></td>
</tr>
<tr>
<td>Mátra Mountains</td>
</tr>
<tr>
<td>Börzsöny and Visegrád Mountains</td>
</tr>
</tbody>
</table>

Fig. 13: Graph showing the cumulative distributions of the aggregate metal and ore tonnages contained in the undiscovered porphyry copper and polymetallic vein deposits in the study area.
Summary statistics for the tonnage of contained metal and ore in the undiscovered deposits in the study area

<table>
<thead>
<tr>
<th>Metal or ore</th>
<th>90 percent</th>
<th>50 percent</th>
<th>10 percent</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>7.4</td>
<td>310</td>
<td>1.0x10^6</td>
<td>350,000</td>
</tr>
<tr>
<td>Silver</td>
<td>41</td>
<td>300</td>
<td>1,600</td>
<td>800</td>
</tr>
<tr>
<td>Zinc</td>
<td>1,300</td>
<td>13,000</td>
<td>110,000</td>
<td>39,000</td>
</tr>
<tr>
<td>Lead</td>
<td>4,400</td>
<td>30,000</td>
<td>130,000</td>
<td>58,000</td>
</tr>
<tr>
<td>Gold</td>
<td>0.024</td>
<td>1.1</td>
<td>83</td>
<td>28</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.0</td>
<td>0.0</td>
<td>3,700</td>
<td>2,300</td>
</tr>
<tr>
<td>Ore material</td>
<td>85,000</td>
<td>890,000</td>
<td>2.1x10^8</td>
<td>68x10^6</td>
</tr>
</tbody>
</table>

Once such marginal probabilities for each type of deposit were considered, the Mark3 simulator produced the following summations for the mean undiscovered tonnages listed in the fifth column of Table 3. The mean tonnage of ore material from both deposit types is estimated to be 68 million t. The individual mean-aggregate metal tonnages are estimated to be 350,000 t of copper, 800 t of silver, 39,000 t of zinc, 58,000 t of lead, 28 t of gold, and 2,300 t of molybdenum. The table also lists the companion tonnages for each metal at three probability levels in the aggregate metal distributions shown in Fig. 13.

7. CONCLUSIONS

The methods developed at the USGS during the past 25 years for mineral-resource assessment were successfully transferred by performing an assessment on a study area in Mátra and the Börzsöny–Visegrád Mountains, North Hungary, from 1994 to 1997. A wide variety of field evidence, which included descriptions of the known deposits, geologic maps, geophysical information, inspections of drill core, and data from the literature, were used in the assessment of the undiscovered resources of the study area. The tectonic history of the Mátra and the Börzsöny–Visegrád Mountains was a principal determinate in constructing a geologic framework for the assessment. The volcanic mountains are situated in extensional duplexes associated with northwest- to southeast-trending master strike-slip faults. The assessment team determined that these areas are permissive for the occurrence of deposits that belong to the porphyry copper/polymetallic vein kin-deposit system. The broadly extensional tectonics that prevailed during the Middle Miocene, however, did not create many sites where conditions were favorable for the formation of economic mineral deposits. Therefore, the resulting assessment of the undiscovered metallic resources in the study area, although not insignificant, was low.

8. REFERENCES


