U.S. DEPARTMENT OF THE INTERIOR

The Role of Mineral Resource Assessments in Ecological Stewardship

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U.S. GEOLOGICAL SURVEY OPEN-FILE REPORT 96-63

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1996

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ABSTRACT

Bedrock geology and mineral resource assessments can provide important information for ecologically based stewardship of land and water. Combining information derived from mineral resource assessments and geoenvironmental mineral deposit models provides a means to rapidly screen a large region for potential for mineral concentrations, to assess the environmental risk associated with mineralized bedrock and with human disturbances of mineralized bedrock, and to establish priorities for further studies.

ROLE OF BEDROCK GEOLOGY AND MINERAL RESOURCES IN ECOSYSTEMS

Lithology affects both physical and chemical parameters of ecosystems. Physical parameters are affected because lithology provides the context for landscape development. Lithology controls the potential for the occurrence of mineral deposits, and, thereby, the potential for man-made disturbances through exploitation of these deposits. Chemical parameters of ecosystems are affected by lithology because geologic materials and processes control initial availability of nutrients, acidity and oxidation-reduction potential, and metal contents of soils and water. Extreme enrichment of minerals in the lithosphere, e.g., a mineral deposit, can create correspondingly extreme conditions by natural weathering or when exposed during mining. Undisturbed mineral deposits may cause local or regional elevated geochemical backgrounds in waters, soils, plants, or rocks. The composition of ores and host rocks control the nature and severity of impacts resulting from exploitation of mineral deposits.

The presence of mineral deposits in bedrock is especially significant because of socioeconomic issues and potential environmental risks, which can create conflicting land-use options. Development of mineral resources is a socioeconomic benefit, not only in creating high-paying jobs and tax revenues in the local area, but in providing secondary jobs and contributing to regional and national economic growth. However, social concerns are that inadequate planning or unforeseen problems during development can create hazards to human and environmental health. The interplay among social concerns, economic forces, and resource needs can create conflicts that make land-management decisions about mining and areas with potential for mineral deposits complex and controversial. The ability to predict the potential for the occurrence of mineral deposits can be used to assure that the kinds of studies that will be needed are done. A scientific information base that anticipates the potential for mining is essential to development of adequate, reasonable, and timely plans for mitigation and remediation of the impacts of mineral development.

The interaction of some minerals, such as iron sulfides, with the atmosphere or hydrosphere, can produce toxic conditions even in their naturally occurring, undisturbed condition. Under certain conditions, weathering of iron sulfides can produce acid waters and base-metal sulfides can produce a low-level bioavailability of metals. Disturbance of high-sulfide zones, whether through mining, road building, or community development, increases the amount of surface area available for reactions to take place and can increase potential for toxicity and acidity of soils and waters. An example is fish kills in the Great Smoky Mountains that resulted from water draining through iron-sulfide-rich rocks used as rip-rap in the base for highway construction.

Knowledge of the types of deposits that can occur in a region provides a basis for identifying areas that have the potential for developing naturally occurring toxicity in surface or ground waters. Identification of land areas with potential for specific types of mineral deposits and associated mineralization can be used to assess the environmental risk associated with disturbing mineral concentrations. For areas with high potential for mineral deposits of the types that might cause environmental hazards, more detailed geologic maps and geochemical baseline studies allow land managers to anticipate and prevent hazardous conditions.

In addition to potential environmental hazards, some rock types, such as limestone form a natural buffer for acidic waters. Carbonate rocks serve as a calcium source, thereby increasing initial availability of one of the nutrients that are derived from bedrock.

EXAMPLE OF SCREENING PROCESS IN THE SOUTHERN APPALACHIAN MAN AND THE BIOSPHERE REGION

The U.S. Geological Survey's mineral resource assessments predict potential for mineral deposits and geoenvironmental models predict environmental affects from mineralized bedrock. These tools can be combined to rapidly screen large areas and establish priorities for further studies. The following example shows how information from mineral resource assessments can be combined with information from geoenvironmental models to delineate areas and establish priorities for further studies in the Southern Appalachians Man in the Biosphere Ecosystem (SAMAB) region. The SAMAB region, which was designated by the United Nations Scientific, Educational, and Cultural Organization (UNESCO) in 1988, as a regional biosphere reserve, covers the Appalachian part of six states: Virginia, Tennessee, North Carolina, South Carolina, Georgia, and Alabama.

The U.S. Geological Survey's National Mineral Resource Assessment, which was compiled at a scale of 1:500,000 and 1:1,000,000, provides digital information on the types of deposits that are known and that might be present in an area for five important metals: gold, silver, copper, lead, and zinc (Ludington and Cox, 1996). For this example, only copper, lead, and zinc are included. These metals are important in our economy, have been produced widely and extensively, and can cause a range of environmental affects ranging from benign to very hazardous, depending on deposit type.

Mineral resource assessments provide information about the types of rocks and mineral deposits that are present in an area, the parts of the area that are favorable for the occurrence of additional mineral deposits, and estimates the probable amounts of undiscovered mineral resources. Mineral resource assessments answer the questions of what, where, and how much. The mineral resource assessment method is based on mineral deposit models, which describe a groups of deposits with similar characteristics and provide the link between deposit type and geologic environment (Cox and Singer, 1986). The models are based on worldwide literature and observation, and they describe the common geologic attributes of deposits and the environments in which they are found. Grade and tonnage models consist of frequency distributions of the grade and size of the individual deposits that serve as examples for that deposit type. A mineral resource assessment is carried out by an interdisciplinary team of geoscientists who review the geology of an area, select appropriate deposit models, and delineate permissive tracts for each type of deposit. The permissive tracts are defined by the geologic environments of formation described in the deposit model. Permissive tracts are defined as those for which the probability of deposits occurring outside the tract is negligible.

Within the SAMAB region the National Mineral Resource Assessment identified permissive tracts for 5 deposit types: Kuroko-type massive sulfide, Besshi-type massive sulfide, sedimentary exhalative zinc-lead, Appalachian zinc, and sandstone-hosted lead-zinc, as described in Cox and Singer (1986).

The two types of massive sulfide deposits, Kuroko and Besshi, have similar characteristics, and are combined on figure 1. Both types form as sheetlike or lens shaped concentrations of copper, lead, and zinc sulfides with high pyrite contents and are spatially associated with volcanic rocks. Five tracts were defined, each of which has a different combination of geologic characteristics that are considered favorable for the occurrence of massive sulfide deposits. Three of the permissive tracts (SA01, SA02, and SA03) are wholly within the SAMAB region, and two (SA08 and SA09) are partly within the SAMAB region. Several deposits are known in the permissive tracts including deposits in the Ducktown (Copper Hill) district. For tract SA01 the numerical estimates of the number of undiscovered deposits at the 90th, 50th, and 10th percentile confidence levels are 1, 3, and 5, respectively (table 1) (Slack, 1996). That is, the assessment team estimated that the probability of less than one undiscovered deposit at a depth of 1 km or less in tract SA01 was very low; they considered it likely that 3 undiscovered deposits exist, and unlikely that there were more than 5 undiscovered deposits. From this analysis, it is concluded that there is a relatively high probability of the occurrence of one of more undiscovered massive sulfide deposits in tract SA01 Estimates for the other tracts indicate that the probability of undiscovered massive sulfide deposits is high for SA03 and SA08 (Slack, 1996; Klein, 1996). No estimates were made for tracts SA02 and SA09 because the team considered the probability of undiscovered deposits to be less than one percent, but not negligible.

Continuing with the example, the severity of environmental hazards associated with massive sulfide deposits is then estimated. Geoenvironmental

Table 1. Numerical estimates of the number of undiscovered deposits in tracts that are permissive for massive sulfide deposits within the Southern Appalachians Man and the Biosphere region at 90th, 50th, and 10th percentile confidence levels. Estimates are for the number of undiscovered deposits in a tract at a depth of less than one kilometer. Estimates from the National Mineral Resource Assessment (Ludington and Cox, 1996).

Massive sulfide	Probability		
Tract	90%	50%	10%
SA01	1	3	5
SA02		No estimate	
SA03	1	3	5
SA08	2	5	10
SA09		No estimate	

models for mineral deposit types characterize the environmental signatures of rocks, soils, sediments, and waters prior to being mined (Plumlee and Nash, 1995). Geoenvironmental models also describe and predict the environmental effects likely to result from mining, that is, recovering the metals from such a deposit. Geoenvironmental models include factors such as the character and size of mine workings, the character and mass of waste products, and the processes of their interactions with the environment. The geoenvironmental model for massive sulfide deposits is the most likely of all deposit types to have associated environmental problems (Taylor and others, 1995). Drainage waters associated with massive sulfide deposits can be highly acid, can have extremely high dissolved metal contents, and are generally in host rocks that have low acid-buffering capacity. The deposits are most problematic in arid climates, but the iron- and base-metal sulfide minerals that are present in massive sulfide deposits are unstable under normal oxidizing conditions and represent potential sources of highly acid and metal-rich drainage in any environment.

In the geologic setting where massive sulfide deposits form, iron and base-metal sulfide-rich concentrations occur not only in mineral deposits where concentrations are sufficient to be mined, but in lateral extensions of these deposits and in concentrations that are not rich enough to mine, but can cause acidity and elevated level of metals in stream water flowing over undisturbed rock. Oxidation of pyrite (iron sulfide) releases Fe and trace metals along with SO_4^{2-} and H^+ and may increase acidity in ground and surface waters if not buffered. Disturbance of sulfide-rich zones through human activities increase the area of sulfide that are exposed to near surface conditions, which in turn increases the rate of the oxidation reaction and potential for acid production.

Therefore, the tracts identified as having high potential for massive sulfide deposits (SA01, SA03, and SA08) also have a high level of environmental risk associated with disturbance of pyrite-rich zones (fig. 2). For this example the areas with high potential for the occurrence of mineral deposits with high levels of environmental risk are assigned priority level of 1, and warrant a more detailed geologic evaluation. For the high priority areas, lithologic maps can be used to more closely delineate areas that have potential for generating acidic and metal-rich waters. Geologic and geochemical studies of areas with potential for development can be used to pinpoint sulfide-rich zones and to establish baseline data. For areas of lower potential for the occurrence of massive sulfide deposits (SA02 and SA09), the environment risk would be the same, but because the probability of occurrence of these deposits is low, the priority for more detailed studies is lower than for areas where probability of occurrence is high. For the purpose of this analysis, the environmental risk is considered moderate and the tract is assigned priority level of 2.

A large permissive tract for sedimentary exhalative deposits is partly within the SAMAB area (EC02, fig. 3). No estimate was made of the number of undiscovered deposits, because only a small part of the tract is within the SAMAB area and the assessment team considered the probability of undiscovered deposits to be low but not negligible based on the geologic environment (Clark, 1996). The mineralogic characteristics of sedimentary exhalative deposits are similar to those of massive sulfide deposits, so that if a deposit were to exist the environmental risk might be high (Kelley and others, 1995). Therefore, the overall level of potential environmental hazard is considered to be moderate and the tract is assigned a priority level of 2 (fig. 4).

The SAMAB area includes Appalachian zinc type deposits of the East Tennessee district. Three tracts (EC04, EC05, and EC06) that are considered permissive for the occurrence of undiscovered Appalachian zinc deposits are partly or mostly within the SAMAB area (fig. 5). The numerical estimates of the number of undiscovered deposits in tract EC06 at the 90th, 50th, and 10th percentile confidence levels are 3, 6, and 8, respectively (Table 3)(Clark and others, 1996). Therefore, for this analysis, there is a high probability of the occurrence of undiscovered deposits in tract EC06. Estimates for EC05 are less, but the assessment team estimated one undiscovered deposit at the 50 percent confidence level. Therefore, for these two tracts, the probability of the existence of at least one deposit is very likely. For tract EC04 the team considered the probability of undiscovered deposits to be less than one percent, but not negligible.

The potential impact of Appalachian zinc type deposits predicted by the geoenvironmental model differs significantly from the potential impact of massive sulfide deposits (Leach and others, 1995). The acid-generating potential is low because iron sulfides, which are the most common acid-generating minerals, are absent or present in minor amounts in Appalachian zinc deposits. Most of the deposits are low in lead; some are lead-free. In addition, the host rocks are carbonates, which have a high buffering capacity, so that even if acid drainage develops, it may be neutralized by the surrounding rocks. However, climatic conditions and soil properties (acidic vs. neutral) can interact to increase potential environmental problems. Even though the probablility of future mining is high in these tracts, the environmental impacts may be mainly related to physical disturbances with low to moderate geochemical risks from bedrock sources. For example, water

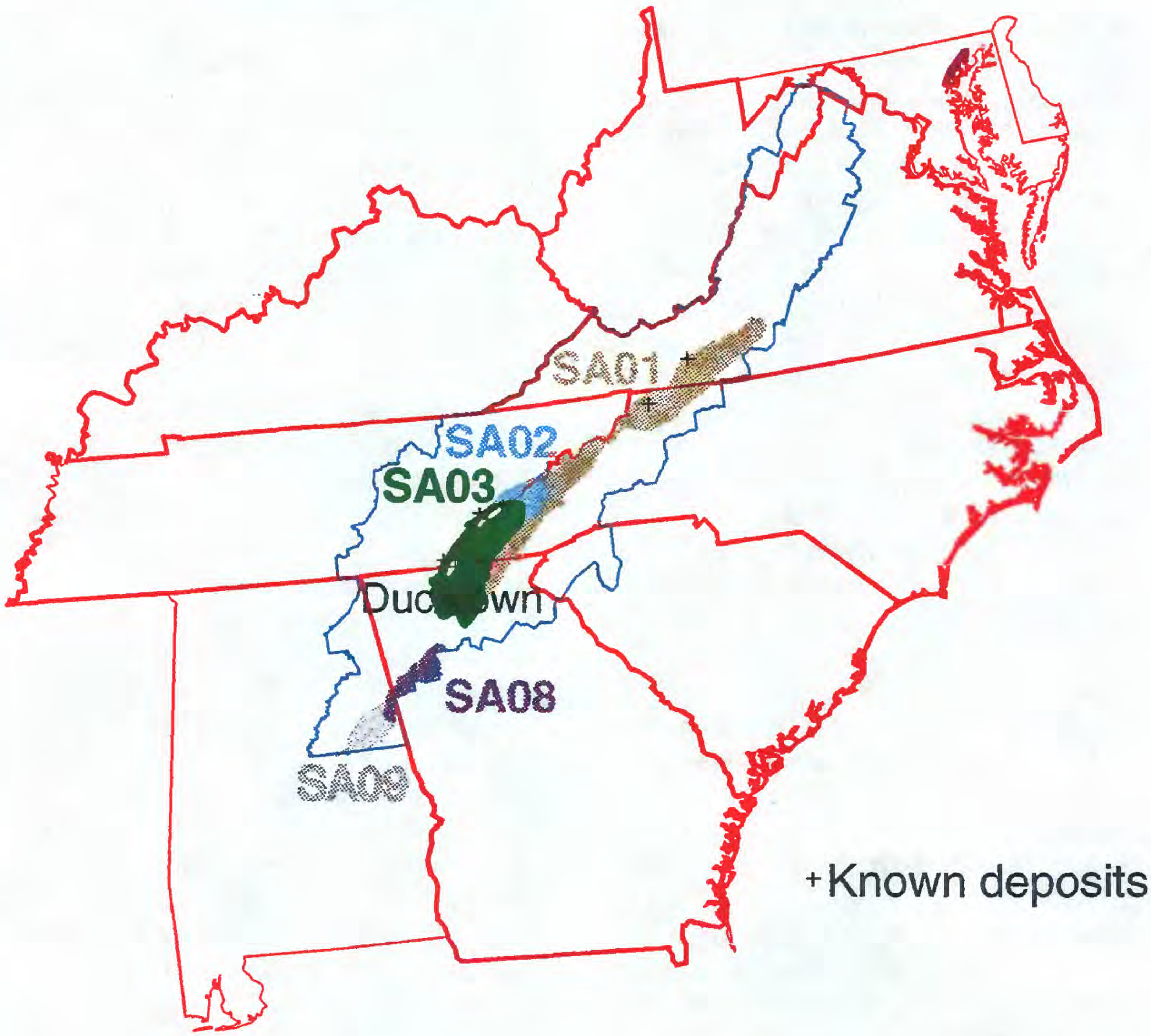
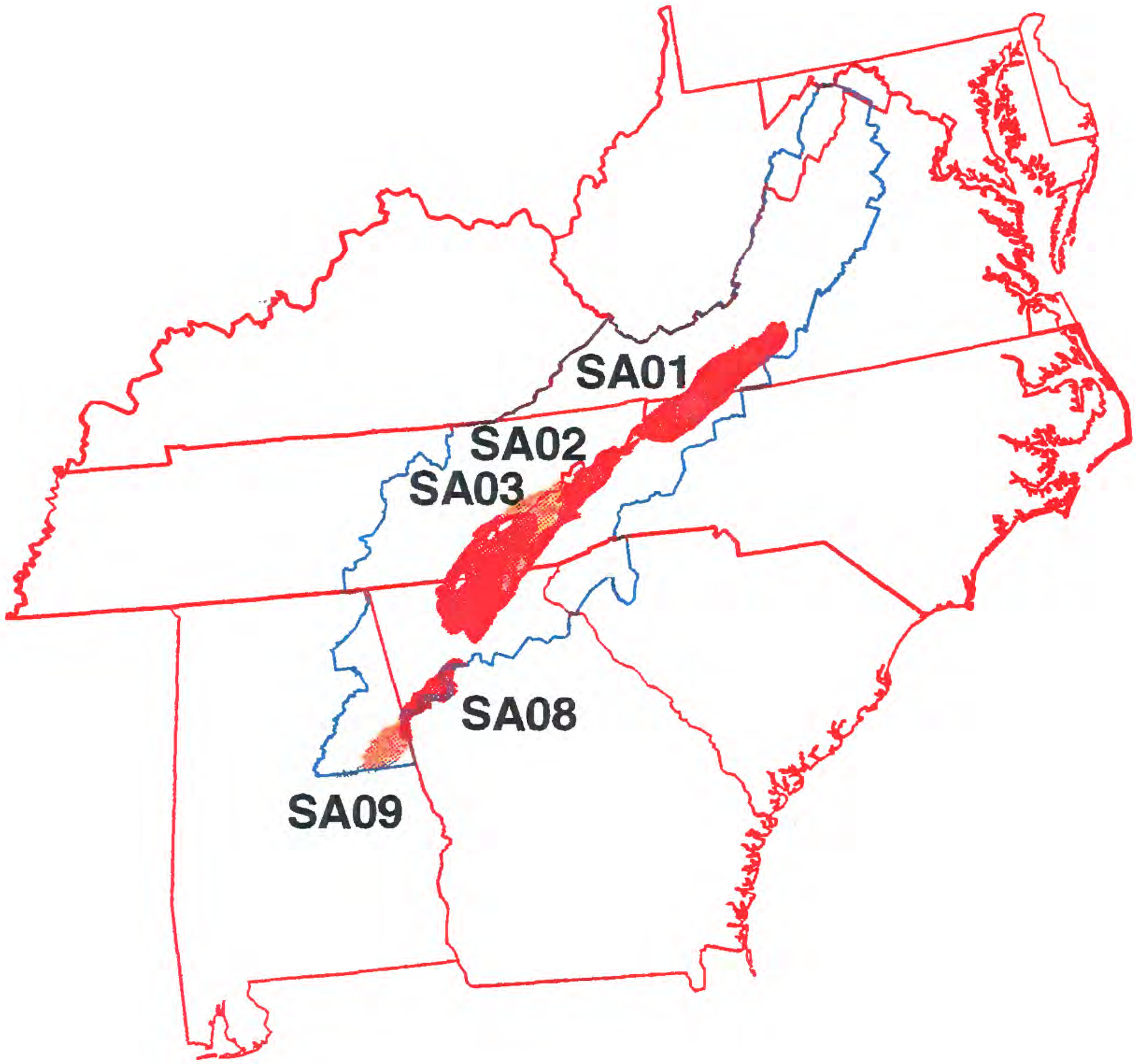


Figure 1. Permissive tracts for massive sulfide deposits in the SAMAB region.



Massive sulfide deposits

Tracts	Potential for:		Priority
	Undiscovered deposits	Environmental Hazards	
SA01, 03, 08	High	High	1
SA02, 09	Low	High	2

Figure 2. Priorities for further study of tracts with potential for massive sulfide deposits in the SAMAB region.

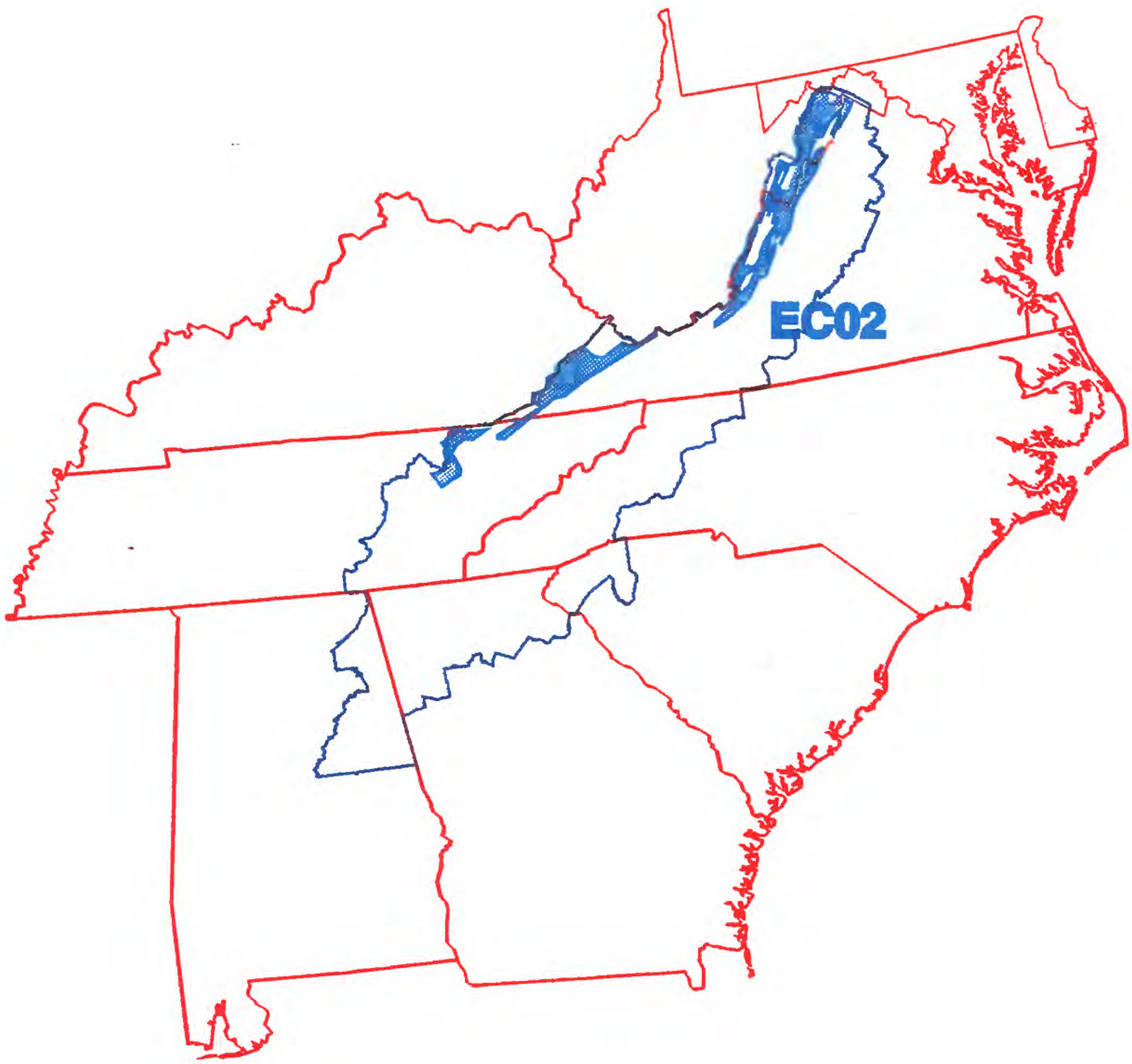


Figure 3. Permissive tracts for sedimentary exhalative lead-zinc deposits in the SAMAB region.

Sedimentary exhalative deposits

Tract	Potential for: Undiscovered deposits	Potential for: Environmental Hazards
EC02	Low	High

Priority

2

Figure 4. Priority for further study of tracts with potential for sedimentary exhalative deposits in the SAMAB region.

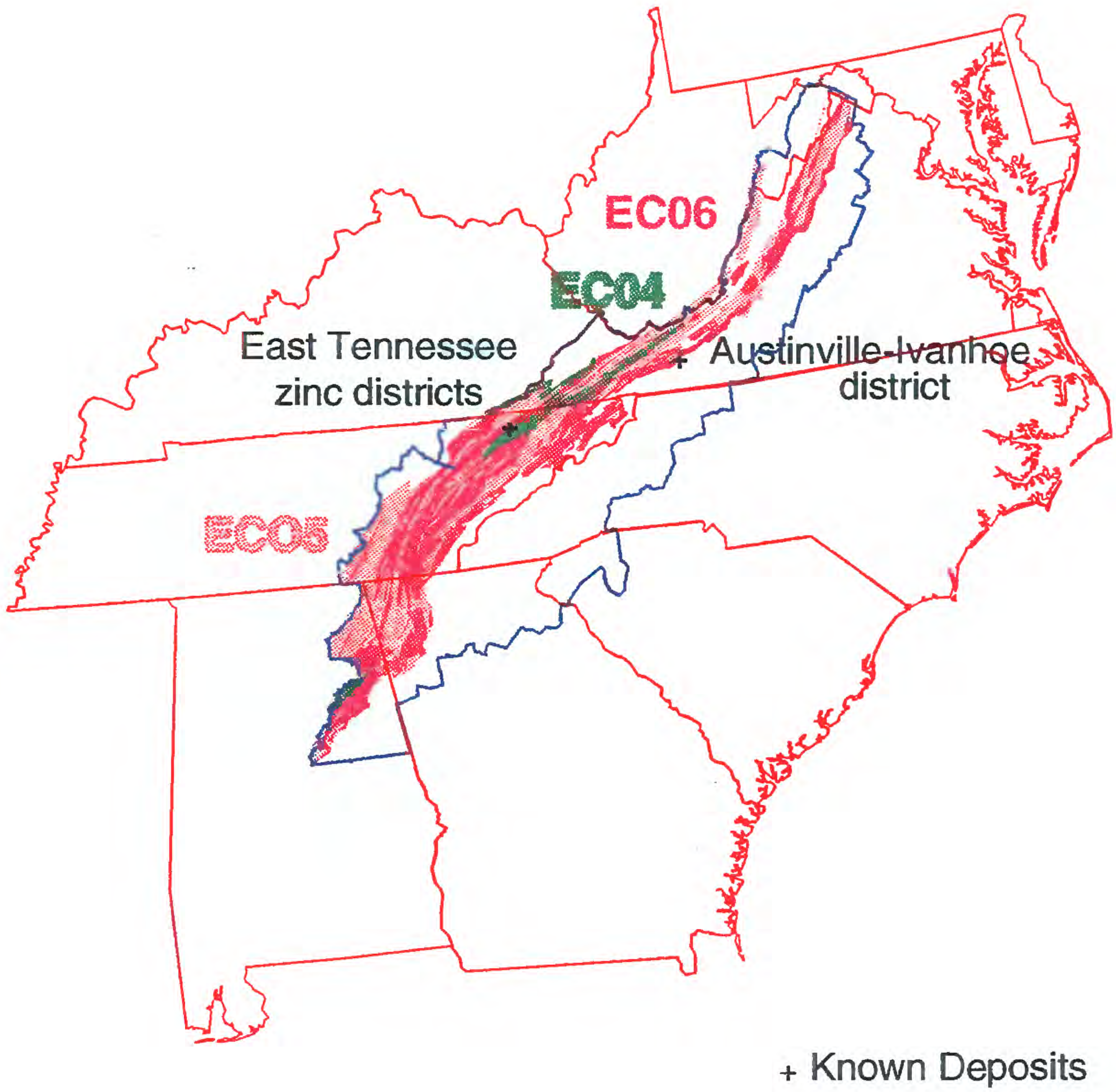
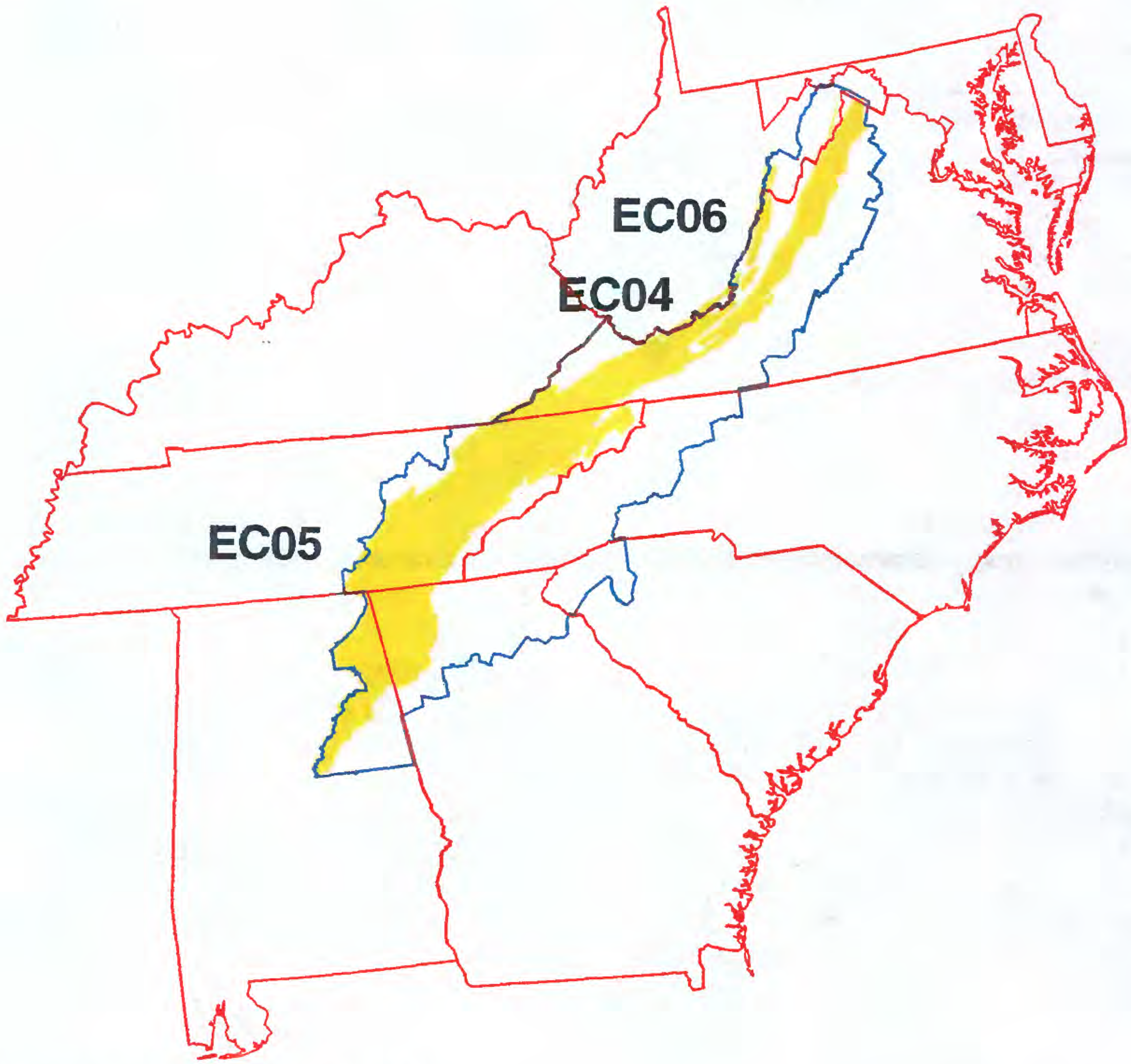


Figure 5. Permissive tracts for Appalachian-zinc deposits in the SAMAB region.



Appalachian-zinc deposits

Tract	Potential for: Undiscovered deposits	Potential for: Environmental Hazards
EC04	Low	Low
EC05	High	Low
EC06	High	Low

Priority

3

Figure 6. Priority for further study of tracts with potential for Appalachian-zinc deposits in the SAMAB region.

Table 2. Numerical estimates of the number of undiscovered deposits in tracts that are permissive for Appalachian zinc sulfide deposits within the Southern Appalachians Man and the Biosphere region at 90th, 50th, and 10th percentile confidence levels. Estimates are for the number of undiscovered deposits in a tract at a depth of less than one kilometer. Estimates from the National Mineral Resource Assessment (Ludington and Cox, 1996).

Appalachian zinc	Probability		
Tract	90%	50%	10%
EC04		No estimate	
EC05	0	1	3
EC06	3	6	8

quality problems in the New River of trace metals and locally acidification, may result in part from past mining activities in the Austinville-Ivanhoe district (Leach and others, 1995). The priority for additional information on environmental risk is considered to be lower than for the other areas, but not negligible, so tracts EC05 and EC06 are assigned a priority level of 3 (fig. 6).

The only other type of copper, lead, or zinc deposit for which permissive tracts are delineated in the SAMAB is sandstone-hosted lead-zinc. For this deposit type, the probability of undiscovered deposits is less that one percent, but not negligible (Slack and others, 1996). Known deposits contain lead sulfides, but do not usually contain iron sulfides, so the environmental risk of these deposits, if they occurred, would not be significant enough for further study in this analysis.

The results of the screening process are combined on a map showing the priorities for areas at risk for potential environmental hazards associated with the occurrence of undiscovered copper, lead, and zinc deposits or concentrations in the SAMAB region (fig. 7). Additional information on the deposits, both known and undiscovered, and on gold and silver deposits can be derived from the National Mineral Resource Assessment. Regional mineral resource investigations and site-specific studies can be used to provide additional information, including lithologic, geochemical, and geophysical maps and information about other types of mineral deposits. For high-priority areas with high potential for environmental hazards, if adequate information is not available, new geologic or geochemical baseline studies should be considered to provide adequate information for land use decisions and to develop guidelines for mitigation and remediation associated with potential mining or other disturbances to land and water.

SUMMARY

The preliminary screening process for environmental hazards from copper, lead, and zinc deposits is as follows:

1. Information on probability of the deposit types for which permissive tracts have been defined in the National Mineral Resource Assessment for the region under consideration are determined.
2. Layers for similar deposit types are combined.

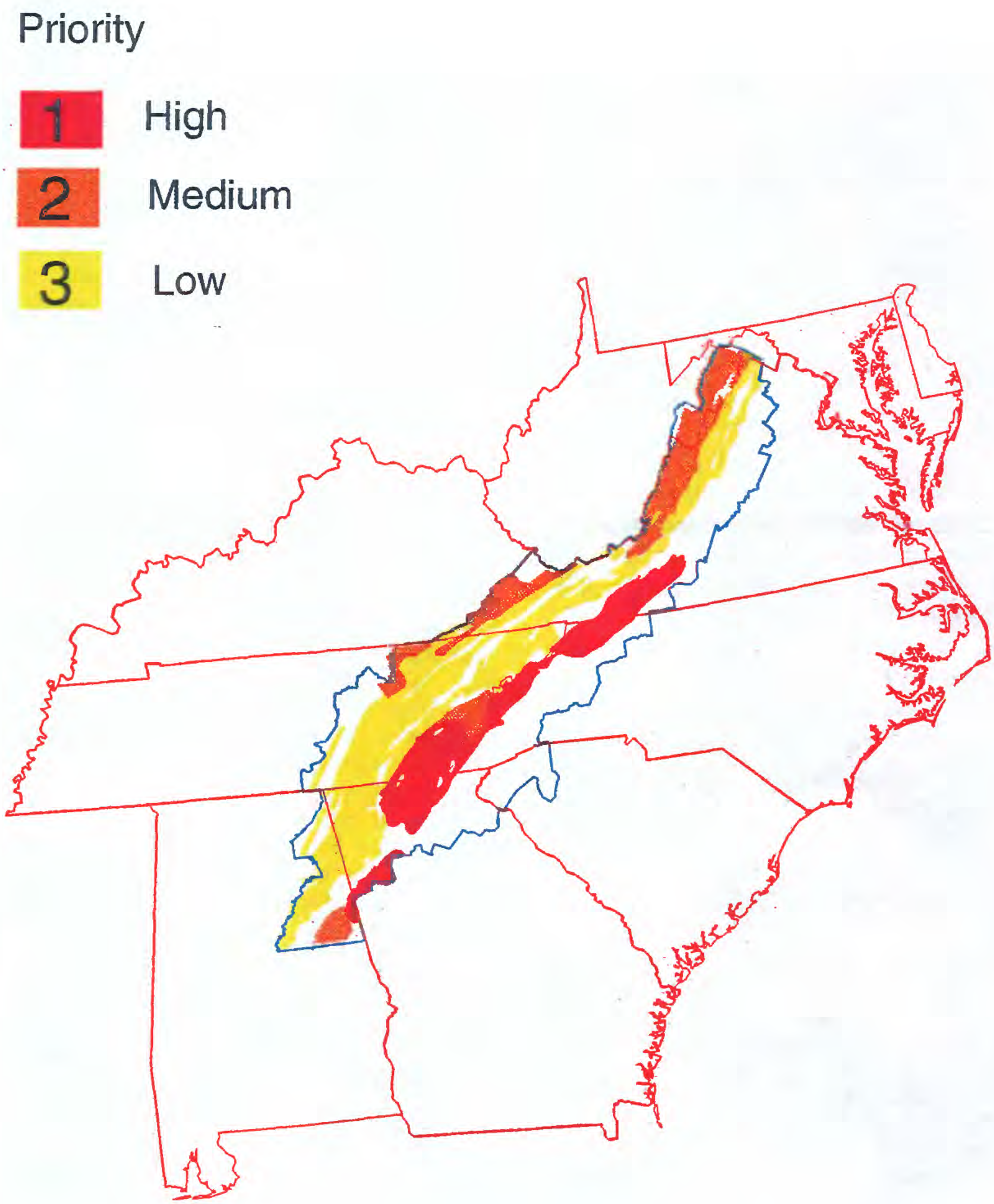


Figure 7. Results of the screening process for copper-lead-zinc deposits in the SAMAB region.

3. The number of undiscovered deposits estimated for each tract is used to evaluate the likelihood of occurrence of undiscovered deposits in the area under consideration.
4. Geoenvironmental models for each deposit type are examined to evaluate potential environmental impacts from mineral deposits or concentrations.
5. Information on probability of the occurrence of undiscovered deposits is combined with information on the level of potential environmental impact of deposits or metal concentrations to determine the priority of need for additional information.

Although the screening process is simple, it must be based on sound geological knowledge and expert judgment in order to provide a valid interpretation. The priorities set forth in this example are only preliminary. The process to determine where additional information is needed for land use planning requires further analysis and must incorporate knowledge and judgment of land managers with experience in the region.

REFERENCES CITED

Clark, S.H.B., 1996, Sedimentary exhalative Zn deposits, *in* Ludington, Steve, and Cox, D.P., eds., Database for a National mineral resource assessment of undiscovered deposits of gold, silver, copper, lead, and zinc--conterminous United States: U.S. Geological Survey open-file report 96-96, p. 133-135.

Clark, S.H.B., Briskey, J.A., Jr., and Cox, D.P., Mississippi Valley Deposits (Appalachian zinc), *in* Ludington, Steve, and Cox, D.P., eds., Database for a National mineral resource assessment of undiscovered deposits of gold, silver, copper, lead, and zinc--conterminous United States: U.S. Geological Survey open-file report 96-96, p. 139-145.

Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p.

Kelley, K.D., Seal, R.R. II, Schmidt, J.M., Hoover, D.B., and Klein, D.P., 1995, Sedimentary exhalative model, *in* Du Bray, E. A., ed., Preliminary compilation of geoenvironmental mineral deposit models: U.S. Geological Survey Open File Report 95-831, p. 225-233.

Klein, T.L., 1996, Massive sulfide deposits, Kuroko type, *in* Ludington, Steve, and Cox, D.P., eds., Database for a National mineral resource assessment of undiscovered deposits of gold, silver, copper, lead, and zinc--conterminous United States: U.S. Geological Survey open-file report 96-96, p. 433-436.

Plumlee, G.S., and Nash, J.T., 1995, Geoenvironmental models of mineral deposits--Fundamentals and applications, *in* Du Bray, E. A., ed., Preliminary compilation of geoenvironmental mineral deposit models: U.S. Geological Survey Open File Report 95-831, p. 1-9.

Leach, D.L., Viets, J.B., Foley-Ayuso, Nora, and Klein, D.P., 1995, Mississippi Valley-type Pb-Zn deposits, *in* Du Bray, E. A., ed., Preliminary compilation of geoenvironmental mineral deposit models: U.S. Geological Survey Open File Report 95-831, p. 234-243.

Ludington, Steve, and Cox, D.P., eds., 1996, Database for a National mineral resource assessment of undiscovered deposits of gold, silver, copper, lead, and zinc--conterminous United States: U.S. Geological Survey open-file report 96-96, 2037 p.

Taylor, C.D., Zierenberg, R.A., Goldfarb, R.J., Kilburn, J.E., Seal, R.R. II, and Kleinkopf, M.D., Volcanic-associated massive sulfide deposits, *in* Du Bray, E. A., ed., Preliminary compilation of geoenvironmental mineral deposit models: U.S. Geological Survey Open File Report 95-831, p. 137-144.

Slack, J.F., 1996 Massive sulfide deposits, Besshi type, *in* Ludington, Steve, and Cox, D.P., eds., Database for a National mineral resource assessment of undiscovered deposits of gold, silver, copper, lead, and zinc--conterminous United States: U.S. Geological Survey open-file report 96-96, p. 421-425.

Slack, J.F., Clark, S.H.B., Peper, J.D., and Pohn, H.A., 1996, Sandstone-hosted Pb-Zn deposits, *in* Ludington, Steve, and Cox, D.P., eds., Database for a National mineral resource assessment of undiscovered deposits of gold, silver, copper, lead, and zinc--conterminous United States: U.S. Geological Survey open-file report 96-96, p. 133-135.