SPECIAL REPORT 190

RELATIVE LIKELIHOOD FOR THE PRESENCE OF NATURALLY OCCURRING ASBESTOS IN PLACER COUNTY, CALIFORNIA

2006

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California Geological Survey

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RELATIVE LIKELIHOOD FOR THE PRESENCE OF NATURALLY OCCURRING ASBESTOS IN PLACER COUNTY, CALIFORNIA

By

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EXECUTIVE SUMMARY

Naturally occurring asbestos (NOA) is known to be present in Placer County. To help identify areas in the county that may contain NOA, the California Department of Conservation, California Geological Survey (CGS), has prepared a 1:100,000-scale map (Plate 1) of relative likelihood for the presence of naturally occurring asbestos in Placer County. The map and accompanying report were prepared for the Placer County Air Pollution Control District under Interagency Agreement No. 1004-001R.

The map divides the county into different areas based on the relative likelihood of encountering NOA. These areas are defined as: most likely, moderately likely, and least likely to contain NOA. In addition, areas of faulting and shearing are highlighted where they exist in areas most likely or moderately likely to contain NOA; these represent localities of increased likelihood for the presence of NOA beyond that of the surrounding areas. The presence of NOA is possible within all of these areas, but it is more likely to be present in some areas than others. The areas that are most likely or moderately likely to contain NOA are found mainly in the west-central part of the county (Auburn-Dutch Flat-Foresthill region) within the lower elevations of the Sierra Nevada. Areas least likely to contain NOA are distributed throughout the county.

The purpose of the map is to provide information to government agencies and the public about the likelihood of encountering NOA within Placer County. The available information used to create the map is not sufficient to determine if NOA will be found at a specific location within the county. A site-specific geologic investigation is required to verify the presence of NOA.

The presence of asbestos in nature is related to the chemistry of rocks in an area and the different geologic processes that have acted on those rocks through time. Conditions favorable for the formation of NOA may be present in a variety of geologic settings, but are more common in some settings than in others. The geology of Placer County is complex, characterized by a variety of igneous, metamorphic, and sedimentary rocks, many of which have been faulted or sheared. The geologic diversity in Placer County provides many settings that are favorable for the presence of NOA.

The map produced during this project is based primarily on geologic information compiled and interpreted from published and unpublished geologic and soil maps available at the time of the study. Limited fieldwork was conducted to check the accuracy of the geologic maps used. The accuracy of the map also is dependent on the quality of the original geologic and soil data that were used. Overall, available information suggests that the accuracy of the boundaries of the areas of relative likelihood for the presence of NOA shown on the map is better than plus or minus 1,000 feet.

INTRODUCTION

Naturally occurring asbestos (NOA) is known to be present in Placer County. To help identify areas in the county that may contain NOA, the California Department of Conservation, California Geological Survey (CGS), has prepared a map and report for the Placer County Air Pollution Control District under Interagency Agreement No. 1004-001R.

This study is based on research of published and unpublished geologic documents, limited interpretation of airborne and spaceborne imagery, limited fieldwork, and laboratory analyses. Geologic information related to rocks, faults, and soil in Placer County was compiled from a number of previously existing geologic and soil maps. The 1:100,000-scale (1" = 1.6 miles) map produced in this study is a result of the interpretation this geologic information to identify areas of relative likelihood for the presence of naturally occurring asbestos. To facilitate the evaluation, and to aid in preparation of the accompanying map, data was compiled in a computerized geographic information system (GIS). The approach of this study built upon that developed by Churchill and others (2000) for El Dorado County, which adjoins Placer County to the south.

This report provides background information about NOA, the supporting geologic assumptions on which the map is based, the relative likelihood for NOA presence in Placer County, information on map accuracy, and guidance on map usage and limitations. Additional information on study methodology, the geology and mineralogy of NOA, Placer County geology, Placer County soils, and map accuracy is presented in Appendices A through E. A glossary is available starting on page 16 of this report.

Background on Naturally Occurring Asbestos

"Asbestos" is a commercial term used to identify a group of six silicate minerals (chrysotile, crocidolite, amosite, tremolite, actinolite, anthophyllite) of fibrous or asbestiform habit, which have the properties of high tensile strength, flexibility, chemical resistance, and heat resistance. These properties have made these minerals useful in many manufactured products and industrial processes during the Twentieth Century. A few examples of the many uses of asbestos include brake and clutch linings, insulation, fireproof textiles, and filtration products. The use of asbestos in manufactured goods and processes in the United States has significantly decreased over the last 30 years because of health concerns related to asbestos exposure.

Asbestos is classified as a known human carcinogen by state, federal, and international agencies. State and federal health officials consider all types of asbestos to be hazardous. Information on the health effects of asbestos can be found in the *Toxicological Profile for Asbestos* by the Agency for Toxic Substances and Disease Control (2001).

"Naturally Occurring Asbestos" (NOA) is the term applied to the natural geologic occurrence of any of the six types of asbestos. The presence of asbestos in nature is related to the chemistry of rocks in an area and the different geologic processes that have acted on those rocks through time. Formation of asbestos requires certain chemical conditions (available silica, magnesium, calcium, iron, sodium and water) and physical conditions (appropriate temperature, pressure, and possibly stress). These conditions may be present in a variety of geologic settings, but are more common in some settings than in others. In addition to the six asbestos minerals listed above, other asbestiform amphiboles such as richterite and winchite are known or suspected of posing a health risk (Wylie and Verkouteren, 2000). Further discussion of the mineralogy and geology of asbestos can be found in Appendix B and in Clinkenbeard and others (2002).

GEOLOGIC SETTING OF PLACER COUNTY

Placer County is situated in the Sierra Nevada and Great Valley geologic provinces (Figure 1). The part of the county within the Sierra Nevada province is underlain by a wide variety of metamorphic and igneous rocks. These rocks were emplaced on the western edge of North America through a complicated series of plate-tectonic processes that were active from about 100 million to more than 300 million years ago (Paleozoic and Mesozoic Eras). During the Cenozoic Era, from about 66 million years ago to the present, volcanic and sedimentary rocks were deposited on top of this basement of older rocks. Most of the Cenozoic rocks have been removed by erosion, but extensive exposures of Cenozoic rocks still remain in the higher elevations of the Sierra Nevada. The older basement rocks have been variously deformed by several episodes of folding and faulting. The overlying Cenozoic deposits show little or no deformation.

The western part of the county that lies within the Great Valley province mostly is underlain by Cenozoic sedimentary deposits. These deposits are composed of material eroded from the Sierra Nevada and carried westward by a system of rivers. They show little or no deformation. The westernmost exposures of the metamorphic and plutonic rocks of the basement complex also terminate in the valley where they are overlain by the Cenozoic deposits. Additional details and references on the geology of the county pertinent to NOA are presented in Appendix C.

NOA can form in several types of geologic settings depending on the rock types and geologic history of an area. Placer County has many settings that are favorable for the presence of NOA because of its complex geology. This complexity is characterized by the variety of older metamorphic and igneous rocks and by the multiple episodes of deformation that many of these rocks have undergone.

Geologic and Soil Mapping of the County

To evaluate the geology of Placer County and the likelihood of the presence of NOA, information on geologic units and soils units previously identified by other geologists and soil scientists was reviewed. These units were then grouped into a broader set of more generalized geologic units based on rock type and structural characteristics. These broader geologic units are listed here with their assigned abbreviations and are described in Appendix C. Their distribution in the county is shown in Figure 2.

Auriferous Gravels (ag)

Basaltic Rocks (b)

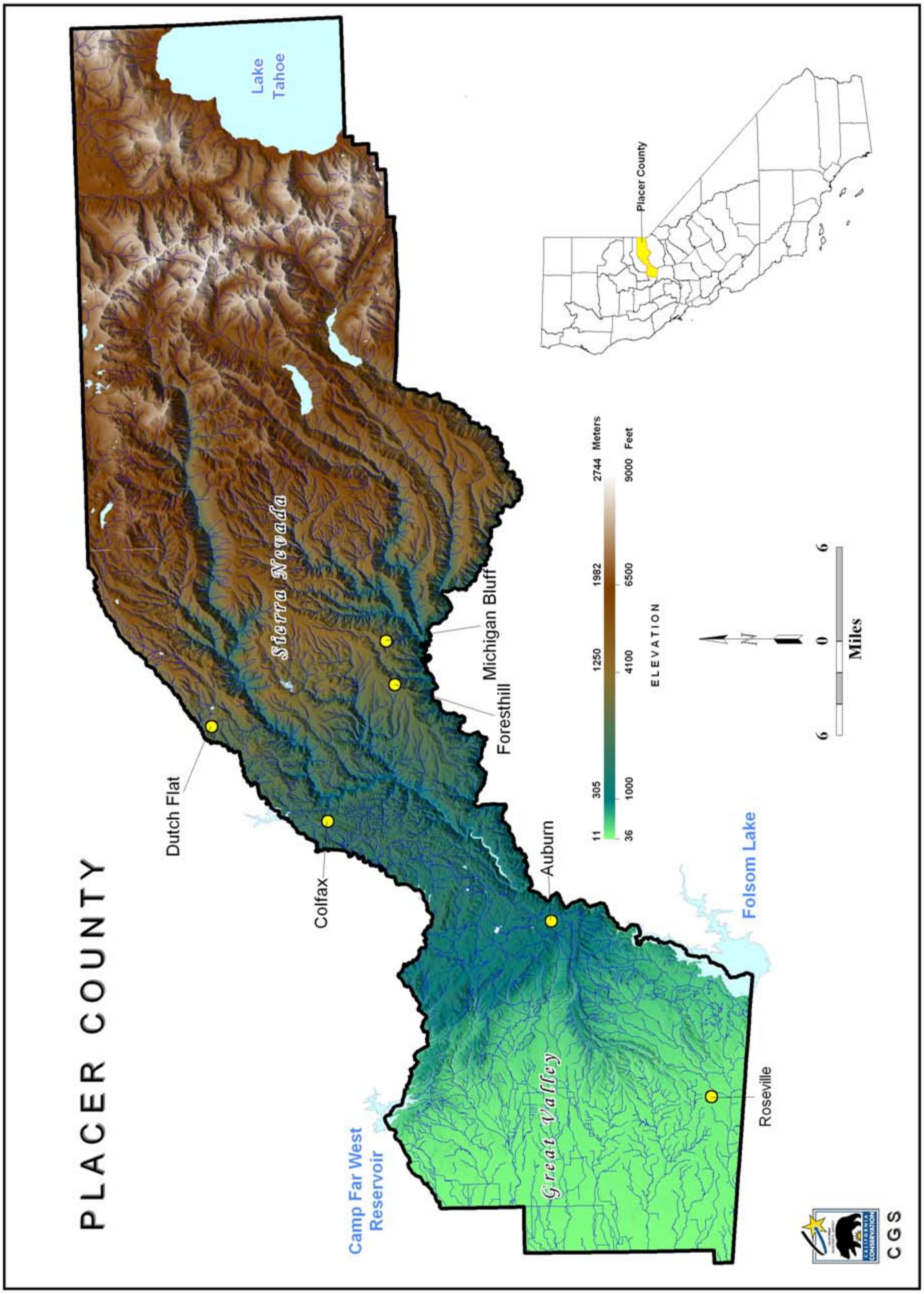

Figure 1. Location Map of Placer County.

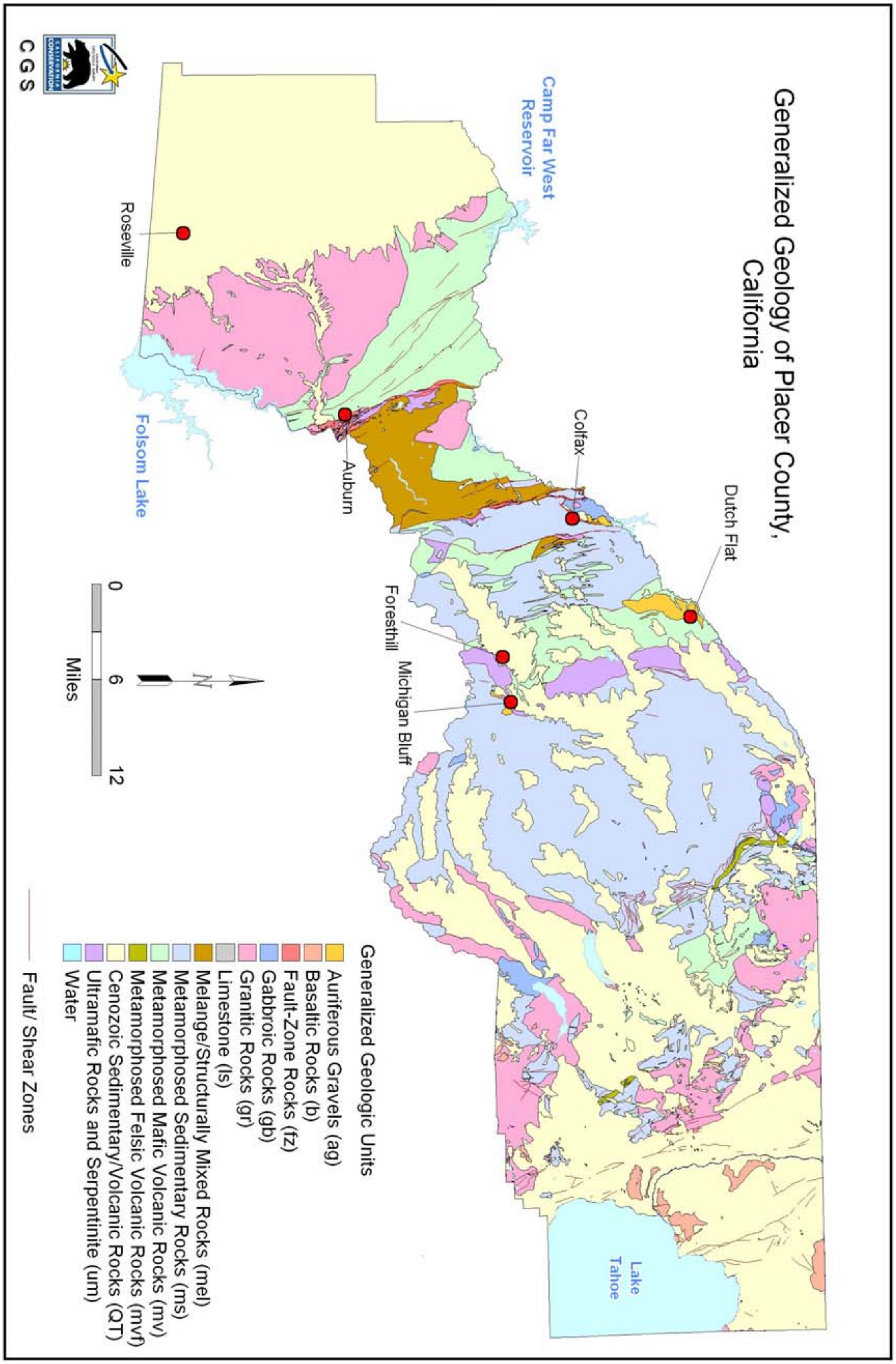

Figure 2. Generalized Geologic Map of Placer County.

Cenozoic Sedimentary and Volcanic Rocks (QT)

Fault-Zone Rocks (fz)

Gabbroic Rocks (gb)

Granitic Rocks (gr)

Limestone (ls)

Melange/Structurally Mixed Rocks (mel)

Metamorphosed Felsic Volcanic Rocks (mvf)

Metamorphosed Mafic Volcanic Rocks (mv)

Metamorphosed Sedimentary Rocks (ms)

Ultramafic Rocks and Serpentinite (um)

Soils derived from asbestos-bearing rocks may contain free asbestos. Soils derived from ultramafic rocks and serpentinite commonly are distinctive; they often are identified in soils studies as serpentine- or ultramafic- related soils. In Placer County, the Dubakella, Forbes, and Henneke soils were identified as being derived (at least in part) from serpentinite or ultramafic rocks. These soil units are described in Appendix D.

Reported Geologic Occurrences of NOA in Placer County

Occurrences of chrysotile asbestos and amphibole asbestos have been reported from several locations in western Placer County. Photographs of some examples of NOA from Placer County are shown in Figures 3 through 6. These are most commonly found in areas of ultramafic rocks and serpentinite and in areas of faulting and shearing.

Both chrysotile asbestos and amphibole asbestos have been mined or prospected in Placer County. About a dozen mines and prospects for asbestos are recorded in digital databases of the California Geological Survey and U.S. Geological Survey. Waring (1918), Logan (1927), Rice (1957), and Wiebelt and Smith (1959) described deposits of slip-fiber tremolite asbestos near Iowa Hill, which is about five miles east of Colfax. Wiebelt and Smith (1959) reported an occurrence of amphibole asbestos at one deposit near Iowa Hill that could be traced for a distance of 150 feet and contained fibers up to eight inches long. They also reported veins of cross-fiber chrysotile asbestos and sheets of slip-fiber tremolite asbestos at the Morgan Mine, about three miles southeast of Dutch Flat. Logan (1927) reported chrysotile asbestos northeast of Dutch Flat and also in the area southwest of Lake Valley Reservoir. Chandra (1961) reported a few asbestos prospects at Iowa Hill and several prospect pits for amphibole asbestos at Burnt Flat, east of Colfax. Production of asbestos in the county through the 1950s is estimated to be no more than a few hundred tons (Wiebelt and Smith, 1959).

In addition to reports of mines and prospects for asbestos, geologists also have made basic geologic observations of chrysotile asbestos and amphibole asbestos in different parts of western Placer County. The economic geology reports cited above indicated that chrysotile asbestos and amphibole asbestos were observed either within bodies of serpentinite or along their contacts with other types of rock. Commonly, the contacts are faulted or sheared. Also, the U.S. Bureau of Reclamation (1977) reported small veinlets of chrysotile asbestos along many joints in serpentinite in the large fault zone southeast of Auburn (Plate 1). Chandra (1961), in describing serpentinite in the Colfax area as “widely distributed” and “usually present along fault zones,” stated that the sheared form of the rock is “often cut by veinlets of asbestos.” Lindsay (1996) observed fibrous chrysotile in the serpentinite exposed along Mosquito Ridge Road southeast of Foresthill.

Other observations of NOA have been reported during various construction projects in serpentinite bodies along State Highway 49 where it passes through Placer County (Todd Nishikawa, personal communication, 2005). In adjacent counties (El Dorado, Sacramento), geologic investigations for construction activities have revealed local occurrences of chrysotile and amphibole asbestos in ultramafic rocks, serpentinite, mafic metavolcanic rocks, and in metamorphosed or altered gabbro.

Several geologists have reported the presence of the minerals actinolite and tremolite in metamorphic rocks and shear zones in Placer County and adjacent counties. These reports generally do not give specific locations for these occurrences; consequently, field verification of them is difficult. While it is not known if these occurrences are asbestos, the presence of the minerals tremolite and actinolite indicate that at least some of the conditions necessary to form tremolite-asbestos or actinolite-asbestos occurred in these areas. Additionally, use of terms such as “fibrous” and “feathery” by geologists in describing these minerals indicates that they could be asbestos. Xenophontos (1984) reported “fibrous actinolite” in parts of the Smartville Complex in Nevada County just to the north of Placer County. Springer (1981) reported actinolite along the Spenceville-Deadman Fault Zone. Lindgren (1894b) observed “abundant light green fibrous hornblende (sic)” in mafic metavolcanic rocks west of Auburn (possibly actinolite). Olmsted (1971) described an occurrence of “feathery actinolite” in greenschist facies metavolcanic rocks a few miles southeast of Auburn in El Dorado County. The U.S. Bureau of Reclamation (1977) reported actinolite in chlorite schist along the large fault zone southeast of Auburn. Tuminas (1983) observed actinolite in the Lake Combie Complex north of Auburn. Chandra (1961) reported actinolite and tremolite associated with the mafic metavolcanic rocks of the Calaveras Complex in central Placer County; he also described tremolite-schist in these rocks as “fibrous.” Harwood (1983) observed actinolite in calcareous quartzite beds in the Shoo Fly Complex near the southern edge of Placer County, southeast of Michigan Bluff.

Figure 3. Veins of serpentinite in ultramafic rock from the Emigrant Gap area. Small bands of chrysotile are present within the veins.

Figure 4. Chrysotile asbestos south of Foresthill Road between Auburn and Foresthill.

Figure 5. Amphibole asbestos from northeast of Colfax. Sample is about four inches long.

Figure 6. Amphibole asbestos in sheared metamorphic rock west of Auburn.

MAP OF AREAS OF RELATIVE LIKELIHOOD FOR THE PRESENCE OF NOA IN PLACER COUNTY

Plate 1 is a map of areas of relative likelihood for the presence of NOA in Placer County. The map divides the county into different areas based on the relative likelihood of encountering NOA within each area. These areas are:

- AREAS MOST LIKELY TO CONTAIN NOA
- AREAS MODERATELY LIKELY TO CONTAIN NOA
- AREAS LEAST LIKELY TO CONTAIN NOA
- AREAS OF FAULTING OR SHEARING

NOA occurrences are typically small and irregularly distributed, located wherever the geologic conditions required for asbestos formation and preservation were present. NOA is possible within all of the listed areas. Areas of faulting and shearing may have an increased likelihood for the presence of NOA beyond that of the surrounding areas.

The available information used to create the map is not sufficient to determine if asbestos occurs at a specific location within these areas. A site-specific geologic investigation is required to verify if NOA is present. However, available geologic information is sufficient to identify areas where NOA is more or less likely to be present in Placer County. Thus, based on current information, areas indicated by the map as “most likely to contain NOA” are expected to have more instances of NOA than areas indicated as “moderately likely to contain NOA.” Additionally, available geologic information indicates that NOA deposits are expected to be much less common or absent in areas indicated as “least likely to contain NOA.” The areas of relative likelihood for the presence of NOA in the county, along with their component rock units, are described in more detail below.

Areas Most Likely to Contain NOA

These areas contain ultramafic rocks and serpentinite (um), and their associated soils. Typically, they are found as linear belts along major fault zones in the western part of the county. The areas, as shown on Plate 1, represent a composite of both the areas of ultramafic rocks and serpentinite and the areas of soil derived from these rocks.

Serpentinite and partially serpentinized ultramafic rocks often can contain chrysotile asbestos. These rocks may also host amphibole asbestos, typically tremolite, actinolite, or anthophyllite. Also, soils derived from weathering of ultramafic rocks and serpentinite may contain NOA. Soil maps of Placer County prepared by the U.S. Department of Agriculture’s Natural Resources Conservation Service and Forest Service include the following ultramafic- and serpentinite-related soils series: Dubakella, Henneke, and Forbes. These soils are described in more detail in Appendix D.

As described above, chrysotile asbestos and amphibole asbestos are known to be present in ultramafic rock and serpentinite in Placer County. Occurrences of each have been reported in the geologic literature cited above or were observed during fieldwork for this study.

Small bodies of rock, which may not contain NOA, may be present within areas of ultramafic rocks and serpentinite. Typically, these are too small to show on the map. Also, the locations of all such rocks are not mapped at this time.

Areas most likely to contain NOA are distributed principally in the west-central part of the county, mainly from Auburn to the Dutch Flat-Foresthill region. Most of the areas are sparsely populated, but some are in population centers, including that along the City of Auburn-State Highway 49 corridor.

The California Geological Survey did not evaluate deposits of unconsolidated sediment along rivers and creeks below areas of ultramafic rocks and serpentinite for their likelihood to contain NOA. Such deposits may contain NOA if some of the sediment was derived from ultramafic rocks or serpentinite. No studies of NOA in such sediment in Placer County were identified during research for this mapping project. Many of these deposits may be too small to depict on the map.

Areas Moderately Likely to Contain NOA

These areas contain one or more of the following rock types: metamorphosed mafic volcanic rocks (mv); mafic intrusive rocks and metamorphosed mafic intrusive rocks (gb); and several structurally complex assemblages (fz, mel) in which metamorphic rocks of different origins are mixed together. The structurally complex assemblages are broadly referred to as “structurally mixed or disrupted rocks.”

The rocks in these areas generally have a lower relative likelihood for the presence of NOA than those in the areas described above as most likely to contain NOA. Nonetheless, these rocks have chemical and/or physical characteristics that are favorable for the presence of NOA.

NOA is known to be present in the geologic units that comprise these areas, either in Placer County or in similar rocks in nearby counties. Occurrences of amphibole asbestos have been reported in the geologic literature and were observed during fieldwork for this study.

The most likely settings for NOA in these areas are in fault zones and shear zones that contain slivers of serpentinite and/or talc-chlorite schists. According to Clark (1964), small sheets and slivers of serpentinite too small (some are less than a foot thick) to show on geologic maps are widely distributed in shear zones in the Sierra Nevada Foothills as part of the Western Sierra Nevada Metamorphic Belt. Also, Clark and Huber (1975) show several small bodies of serpentinite along rivers that cut through melange belts and mafic metavolcanic rocks in Placer County. These serpentinite bodies may have associated NOA. Other possible settings for NOA include contacts with igneous dikes. Both chrysotile asbestos and amphibole asbestos are known to be present in such settings.

Areas moderately likely to contain NOA are distributed mostly in the west-central part of the county; a few areas are also present in the eastern half of the county. They include moderately populated regions of the lower elevations of the Sierra Nevada such as around Auburn and along the Interstate 80 corridor between Auburn and Colfax.

Fault-Zone Rocks (fz) - The unit includes a variety of undifferentiated metamorphic rocks present in major fault zones in the western half of the county. Aside from being metamorphosed, their exposure to shearing and potential alteration in the fault zones makes this unit favorable for the presence of NOA. Component units locally can include serpentinite and mafic metavolcanic rocks.

Gabbroic Rocks (gb) - The unit includes gabbro, metagabbro, and diabase. It is present mainly in the Lake Combie and Emigrant Gap areas, and in a few other localities in the eastern half of the county. NOA may be present where some of these rock types have been metamorphosed or deformed.

Melange/Structurally-Mixed Rocks (mel) - The unit includes categories of rocks termed “melange” and other types of structurally mixed rocks that are distributed from Auburn to Colfax. It has high chemical and physical variability because of its origin. Two characteristics of this unit make it a favorable setting for the presence of NOA. First is the local presence of included blocks of mafic metavolcanic rocks, gabbro, and serpentinite. Second is the pervasive fracturing and shearing present in the rocks, a result of its complex deformational and metamorphic history.

Metamorphosed Mafic Volcanic Rocks (mv) - The unit consists of metamorphosed mafic volcanic and volcaniclastic rocks and dikes. The degree of metamorphism of these rocks ranges generally from greenschist facies to amphibolite facies, which indicates favorable temperature and pressure conditions for the formation of actinolite and tremolite. All of these rocks have undergone deformation. Of note is the large area of metavolcanic rocks west of State Highway 49 that extends from Camp Far West Reservoir to Auburn. These are known locally to contain small bodies of serpentinite, dikes, and zones of faulting and shearing (Xenophontos, 1984; Springer, 1981; Woodward-Clyde, 1977), which may be potentially favorable sites for the presence of NOA.

Areas Least Likely to Contain NOA

These areas contain one or more of the following rock types: metamorphosed sedimentary rocks (ms, ls), metamorphosed felsic volcanic rocks (mvf), granitic rocks (gr), volcanic rocks (QT, b), sedimentary rocks (QT), alluvial deposits (QT, ag), and glacial deposits (QT).

The review of geologic documents and fieldwork did not reveal the presence of NOA in any of these rock types in Placer County. As cited above, the mineral actinolite has been reported at a few localities in the metamorphosed sedimentary rocks, but whether or not it is asbestos was not reported; in general, non-asbestiform actinolite is much more common than actinolite asbestos in the Sierra Nevada.

Based on the available information, the relative likelihood for the presence of NOA in these areas is lower than that in areas identified as most likely or moderately likely to contain NOA. The chemical and physical conditions that make other areas more likely to contain NOA are less likely to be present in these rocks.

Although research did not reveal any reported NOA in the rocks in these areas, current geologic knowledge is not sufficient to completely eliminate the possibility that NOA may be present in these areas. Small bodies of rock or soil with moderate or higher likelihood for the presence of NOA may occur within some of these areas. Such occurrences could be as yet undiscovered, or may have been too small to show at the scale of the geologic maps used in this study. Examples of the latter situation are present in the area between the Weimar Fault Zone and the Foresthill Fault Zone (Plate 1). Here, small dikes of metamorphosed mafic igneous rocks and small bodies of mafic metavolcanic rocks occur in a large unit of metasedimentary rocks. Future detailed study of these rocks, particularly those that are metamorphosed, may reveal localized deposits of NOA where chemical and physical conditions were favorable for its formation.

Areas least likely to contain NOA are distributed throughout the county, but are most extensive in its westernmost part and eastern half. They include the most populated region of the county (Roseville-Rocklin-Lincoln) and the sparsely to moderately populated regions of the higher elevations of the Sierra Nevada, including the Lake Tahoe Basin.

Auriferous Gravels (ag) - The unit consists of early Cenozoic-age conglomerates that are limited to a few areas in the vicinity of Colfax and Dutch Flat. The generally variable composition and lack of metamorphism of this geologic unit make it less likely to host NOA. Isolated clasts of ultramafic rocks or serpentinite may be present locally in this unit.

Basaltic Rocks (b) - The unit consists of Cenozoic-age volcanic rocks (basalt) deposited in the easternmost part of the county, mostly in the Lake Tahoe Basin. Although these rocks are mafic in composition, they are generally not metamorphosed or deformed and are less likely to contain NOA than similar rocks that have undergone metamorphism.

Cenozoic Sedimentary and Volcanic Rocks (QT) - The unit consists of undifferentiated Cenozoic-age sedimentary and volcanic rocks, which are distributed throughout the county. These deposits are not metamorphosed, and they show little or no deformation, although some of the volcanic rocks are cut by faults. The generally variable composition and lack of metamorphism of the geologic unit make it less likely to host NOA. Locally, the sedimentary deposits may contain isolated clasts of ultramafic rocks or serpentinite.

Granitic Rocks (gr) - The unit consists of plutonic rocks of intermediate to felsic chemical composition (containing less iron and magnesium and more aluminum and silicon than mafic or ultramafic rocks). They are distributed in the westernmost and eastern parts of the county. These rocks typically show little or no metamorphism, and are relatively undeformed. Of note is their capability to produce zones of contact metamorphism in surrounding rocks, which can lead to the formation of NOA. These zones may form at the boundaries where granitic rock has intruded into surrounding rocks. Heat and fluids from the intrusion can cause chemical reactions to take place between the intrusion and the surrounding rocks. As a result, these contact zones can contain assemblages of alteration minerals. Tremolite is an example of such a mineral that may form where plutonic rocks intrude a carbonate rock such as limestone.

Limestone (ls) - The unit includes isolated areas of metamorphosed carbonate rocks present in the melange belt near Auburn and in the eastern part of the county in the higher elevations of the Sierra Nevada. By themselves, these rocks are not favorable settings for NOA, but they may become more favorable for the presence of NOA where intruded by igneous rocks as discussed above.

Metamorphosed Felsic Volcanic Rocks (mvf) - This unit consists of limited areas of metavolcanic rocks in the eastern part of the county. Although these rocks have been metamorphosed and deformed, their chemical composition generally is not favorable for the formation of NOA.

Metamorphosed Sedimentary Rocks (ms) - The unit consists of metasedimentary rocks that are widely distributed in the central and eastern parts of the county. They are metamorphosed and deformed, but their chemical composition generally is not favorable for the formation of NOA.

Areas of Faulting or Shearing

These areas are linear belts of fractured and deformed rocks that are highlighted by stippling on Plate 1 where they exist in areas most likely or moderately likely to contain NOA. The western half of Placer County contains many mapped fault and shear zones, some of which contain NOA, or are potentially favorable environments for its presence. These areas may have an increased likelihood for the presence of NOA beyond that of the surrounding area.

The stippled areas of faulting or shearing are distributed mostly in the west-central part of the county; there are also a few of these areas in the eastern half of the county. They extend through various population centers in the lower elevations of the Sierra Nevada, including the City of Auburn-State Highway 49 corridor.

Both chrysotile asbestos and amphibole asbestos are present in fault and shear zones in Placer County. Occurrences of chrysotile asbestos and amphibole asbestos in fault and shear zones have been reported in the geologic literature or were observed during fieldwork for this study.

Amphibole asbestos has also been observed in fault zones and shear zones where serpentinite is not apparent. Examples are in zones of chlorite schist within mafic metavolcanic rocks.

The stippling on the map is intended to draw attention to these areas as localities with increased likelihood for the presence of NOA above that of unfaulted or unsheared areas. For example, an area of faulting or shearing shown within an area mapped as moderately likely to contain NOA would be expected to have a higher relative likelihood for the presence of NOA than that of the surrounding moderately-likely area by itself.

The widths of the stippling shown on the map are not intended to precisely depict the actual width of a fault or shear zone at any particular location. Detailed information on the width of fault zones is largely unavailable for Placer County. Observed fault zones in the Sierra Nevada Foothills are seldom less than two hundred feet wide and may be several thousand feet wide or more (Clark, 1960; 1964). Also, the width of a fault zone commonly varies along its length.

Faults and shear zones also strike across areas least likely to contain NOA. The more prominent ones are shown on the map as lines without stippling. While these features may have an increased likelihood for the presence of NOA beyond that of the surrounding area, in general, the overall likelihood is still low because of the chemical compositions and physical conditions of many of the underlying rocks. Each of these faults would have to be investigated on a case-by-case basis to determine if the likelihood for the presence of NOA is increased.

LIMITATIONS AND USE OF THE MAP

Plate 1 indicates areas of relative likelihood for the presence of naturally occurring asbestos in Placer County. It is based on a compilation of geologic information and soil data from various published and unpublished sources available at the time of the study and on limited geologic fieldwork by CGS staff. The purpose of the map is to provide information to local, state and federal agencies and the public as to where naturally occurring asbestos is more likely to be found in Placer County. It does not indicate whether NOA minerals are present or absent in bedrock or soil associated with a particular parcel of land. The determination of the likelihood of NOA presence or absence within a parcel can only be made during a detailed site-specific examination of the property. Consequently, no representations or warranties as to the actual presence or absence of natural occurrences of asbestos at specific locations within the area covered by this map can be made.

Scale

The scale of the map is 1:100,000 (one inch = 1.6 miles). The map is intended for use and interpretation at that scale.

Accuracy of Boundaries

The boundaries of the NOA areas shown on the map were derived principally from geologic boundaries shown on the geologic maps used for this study. Consequently, the accuracy of the boundaries of the NOA areas is dependent on the accuracy of the previously mapped geologic boundaries. Geologic boundaries from maps of various scales, from 1:100,000 (one inch = 1.6 miles) to 1:4,800 (one inch = 400 feet) were used in the compilation of this map. Typically, the mapped boundaries shown on the different geologic maps were located within 0 to 1,000 feet of each other. The greatest difference noted was 2,900 feet. Overall, available information suggests that the accuracy of the boundaries of the areas of relative likelihood for the presence of NOA shown on the map is better than plus or minus 1,000 feet. A distance of 1,000 feet on the ground is equal to a distance of 0.12 inches (about 1/8th of an inch) on the map.

Possibilities exist for the presence of unmapped (previously undiscovered) areas of particular types of rocks, such as serpentinite. Possibilities also exist for areas currently mapped as particular rock types to have been misidentified. The chance of these situations generally decreases with increasing size of the exposure, but they cannot be entirely eliminated.

Use of the Map by Local Government Agencies

The map is intended to aid cities, counties, special districts, and state agencies in determining where they may wish to consider actions to minimize generation of and exposure to dust that may contain NOA. The map also contains an index to published and unpublished geologic maps at more detailed scales that agencies and geoscientists may wish to consult when investigating particular areas for NOA.

Uncertainties regarding the locations of boundaries between areas of relative likelihood for the presence of NOA and the widths of fault and shear zones may be addressed in one or more ways. Concerning the areas of relative likelihood for the presence of NOA, one approach would be to use the mapped boundaries of the areas as is, without the addition of buffer zones. Another possible approach might be to apply whatever investigation requirements are adopted to a specified buffer zone of some width (1,000 feet, for example) around the area. Such an approach will increase the odds of finding small or poorly exposed bodies of rock, such as serpentinite, where mitigation could prove beneficial. Similar approaches could be used to address uncertainties regarding the areas of faulting and shearing.

Finally, continuing excavation activities in Placer County undoubtedly will lead to the identification of additional occurrences of asbestos-bearing rock and soil. This information will provide opportunities to refine the locations of the boundaries shown on the map. Regulations involving maps related to NOA should allow for such map modifications so that decisions will always be made based upon the best geologic information available at the time.

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GLOSSARY

The following sources were consulted during development of the definitions provided below: Bates and Jackson, 1987; Campbell and others, 1979; Churchill and others, 2000; Clinkenbeard and others, 2002; Deer and others, 1966; Ernst, 2000; Environmental Systems Research Institute, Inc., 1990; Gradstein and others, 2004; Hyndman, 1972; Neuendorf and others, 2005; Press and Siever, 1982; Press and Siever, 1994; and Rice, 1957.

Accretionary terrane: A mass of continental or oceanic material added to the margin of a continent by collision and welding.

Acicular: The shape of an extremely slender crystal with small cross-sectional dimensions (a special case of the prismatic form). Acicular crystals may be blunt-ended or pointed. The term “needlelike” refers to an acicular crystal with pointed termination at one or both ends.

Actinolite: A common rock-forming mineral of the amphibole mineral group that commonly occurs in prismatic or acicular form and less commonly in fibrous (asbestos) form. Actinolite is similar to tremolite, but contains iron in place of some of the magnesium in the composition - $Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$. Actinolite asbestos is green, with fibers that are weak and somewhat brittle. It is similar to tremolite in occurrence and has always been of little commercial significance.

Amosite: A commercial term for cummingtonite-grunerite asbestos.

Amphibole asbestos: The asbestiform varieties of the following amphibole minerals—tremolite-actinolite, riebeckite (crocidolite), cummingtonite-grunerite (amosite), and anthophyllite are collectively referred to as amphibole asbestos.

Amphibolite: A metamorphic rock composed chiefly of an amphibole mineral, most often hornblende.

Amphibolite facies: A metamorphic facies in which mafic rocks are represented mainly by the minerals hornblende and plagioclase (feldspar). The metamorphic conditions consist of moderate to high pressures and temperatures in the range of 450°-700°C.

Anthophyllite: A Fe-Mg-Mn-Li amphibole having the formula $(Mg,Fe)_7Si_8O_{22}(OH)_2$. Anthophyllite sometimes crystallizes in the asbestiform habit and is one of the regulated asbestos minerals.

Antigorite: A serpentine group mineral having a formula close to $Mg_3Si_2O_5(OH)_4$. Small amounts of Fe^{2+} may substitute for Mg in antigorite.

Asbestiform: A specific type of mineral fiber that occurs in bundles and possesses high tensile strength and flexibility. “Asbestiform” and “asbestos” are essentially synonymous in current usage. The length to width ratio for asbestos fibers is typically large, usually greater than five to one.

Asbestos: The term asbestos is used to identify a group of six commercially important silicate minerals of fibrous or asbestiform habit having properties of high tensile strength, flexibility, chemical resistance, and heat resistance. These properties have made these minerals useful in many manufactured products and industrial processes during the twentieth century. The six types of asbestos are chrysotile, crocidolite (asbestiform riebeckite), amosite (asbestiform cummingtonite-grunerite), asbestiform tremolite, asbestiform actinolite, and asbestiform anthophyllite. The term is also sometimes used for manufactured products containing one of these six minerals.

Carcinogen: Any substance that produces cancer.

Cenozoic: Interval of geologic time from about 66 million years ago to the present.

Chlorite: One of a group of minerals with a layered structure, which somewhat resemble micas. They are magnesium-iron-aluminum hydrous silicates in composition and are most often green to brown in color. Their principal occurrences are in lower temperature metamorphic rocks, in hydrothermally altered (metamorphosed by reactions with hot water) igneous rocks, and in clay-rich sediments.

Chrysotile: A white, gray, or greenish mineral of the serpentine group, magnesium silicate hydroxide in composition. It is a highly fibrous, silky variety of serpentine. Commercially it is the most important type of asbestos.

Clinopyroxene: Any of a group of monoclinic calcium-rich silicate minerals of the pyroxene group, such as diopside, hedenbergite, clinoenstatite, clinohypersthene, clinoferrosilite, augite, acmite, pigeonite, spodumene, jadeite and omphacite.

Contact: The boundary between two types or ages of rock.

Contact metamorphism: A local process of thermal metamorphism taking place in rocks at or near their contact with a body of igneous rock at the time the igneous rock was emplaced.

Crocidolite: A varietal term used in the past for riebeckite-asbestos.

Cross-fiber (asbestos): Occurrences of asbestos in veins where the long direction of the fibers is oriented perpendicular to the vein walls.

Country rock: The rock enclosing or hosting a mineral deposit, mineral occurrence or an igneous intrusion.

Cummingtonite: A Fe-Mg-Mn-Li amphibole having the formula $(Mg,Fe)_7Si_8O_{22}(OH)_2$. It is part of the Cummingtonite-Grunerite series. Cummingtonite-Grunerite (Amosite) sometimes crystallizes in the asbestiform habit and is one of the regulated asbestos minerals.

Digitizing: The process of creating a digital GIS file of the locations of geographic features by using special equipment to convert their positions on a map into a series of x,y Cartesian coordinates that can be stored in computer files.

Dike (igneous): A tabular igneous intrusion that cuts across the bedding or foliation of the country rock.

Dolomite: A common rock-forming mineral composed of calcium, magnesium and carbonate. The name is also used for a carbonate sedimentary rock of which more than 50 percent by weight or by areal percentages under the microscope consists of the mineral dolomite. The term also may be used to refer to a variety of limestone or marble rich in magnesium carbonate.

Dunite: A plutonic igneous rock composed almost entirely of the mineral olivine.

Facies (metamorphic): Characteristic assemblages of minerals in metamorphic rocks that are indicative of the range of pressures and temperatures experienced during metamorphism

Fault: A fracture or a zone of fractures along which there has been displacement of the rocks on one side relative to the other.

Fault zone: A fault that is expressed as a zone of numerous small fractures.

Felsic: An adjective used to describe a light-colored igneous rock that is poor in iron and magnesium and contains abundant feldspars and quartz.

Fibrous: The occurrence of a mineral in bundles of fibers, resembling organic fibers in texture, from which the fibers can usually be separated (for example, chrysotile asbestos). Fibrous is a more general term used to describe all kinds of minerals that crystallized in habits resembling organic fibers, including asbestos minerals. The term "**fiber**" is not limited to asbestos. However, it is distinct from the term "**acicular**" because it requires the resemblance to organic fibers. Until recently, the term "**asbestiform**" was never used for fibrous mineral habits other than asbestos.

Foliated: A term for a planar arrangement of textural or structural features in any rock type; especially the planar structure that results from flattening of the constituent grains of a metamorphic rock.

Gabbro: A dark colored intrusive igneous rock principally composed of plagioclase and calcium magnesium iron silicate minerals (clinopyroxene, with or without orthopyroxene and olivine). The extrusive igneous (volcanic) rock basalt is approximately equivalent in chemical composition to gabbro.

GIS: Geographical Information System--An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (maps).

Granitic: A general term applied to any light-colored coarse-grained intrusive igneous rock containing quartz, feldspar and lesser amounts of mafic (dark colored iron-magnesium) minerals.

Greenschist facies: A metamorphic facies in which mafic rocks are represented by the minerals albite, epidote, chlorite, and actinolite. The metamorphic conditions consist of relatively low pressures and low temperatures (300^{o}-$500^{o}C$).

Grunerite: A Fe-Mg-Mn-Li amphibole having the formula $(Fe,Mg)_7Si_8O_{22}(OH)_2$. It is part of the Cummingtonite-Grunerite series. Cummingtonite-Grunerite (Amosite) sometimes crystallizes in the asbestiform habit and is one of the regulated asbestos minerals.

Hydrothermal alteration: Alteration (change in chemistry or mineralogy) of rocks or minerals by reaction with hot aqueous fluids.

Igneous rocks: Rocks that formed by the solidification of molten or partly molten material (magma).

Intrusive rocks: Igneous rocks formed by the solidification of magma that has moved into pre-existing rock.

Limestone: A sedimentary rock composed chiefly of calcium carbonate (the mineral calcite).

Lizardite: A serpentine group mineral with the formula $Mg_3Si_2O_5(OH)_4$. Lizardite is one of the rock forming serpentine minerals.

Mafic: An adjective used to describe an igneous rock rich in silicate and oxide minerals that contain iron and magnesium.

Marble: A metamorphic rock consisting predominantly of fine- to coarse-grained recrystallized calcite and/or dolomite. (Metamorphosed limestone or dolomite.)

Melange: A body of rock that consists of a chaotic, heterogeneous mixture of rock fragments and blocks embedded in a fragmental matrix of finer-grained material. Such bodies have typically undergone a complex history of deformation.

Mesozoic: Interval of geologic time from about 251 million years ago to 66 million years ago.

Metamorphic rock: Any rock derived from a pre-existing rock by mineralogical, chemical, and/or structural changes in response to heat, pressure, shearing stress, and chemical environment, generally at depth in the crust of the earth.

Metamorphism: The changes of mineralogy and texture imposed on a rock by pressure and temperature in the Earth's interior.

Metavolcanic: Shortened term for "metamorphosed volcanic."

Mylonite: A very fine-grained metamorphic rock commonly found in major thrust faults and produced by shearing and rolling during fault movement

Oblique-fiber (asbestos): Asbestos occurrences where the orientation of the long axis of the fibers is at an angle to the vein walls.

Olivine: A magnesium-iron silicate mineral or group of minerals, common in many igneous rocks that tend to crystallize at higher temperatures, such as ultramafic and mafic rocks. Olivine is also found in some metamorphic rocks and volcanic rocks.

Orthopyroxene: One of several magnesium-iron silicate minerals of the pyroxene group, common in many igneous rocks that crystallize at relatively high temperatures. For example, these minerals are common constituents of some ultramafic and mafic rocks. These minerals may also occur in some metamorphic rocks.

Paleozoic: Interval of geologic time from about 542 million years ago to 251 million years ago.

Peridotite: A coarse-grained plutonic igneous rock chiefly composed of olivine with or without other mafic (dark colored, magnesium-iron) minerals such as pyroxenes, amphiboles, or micas, and containing little or no feldspar. Peridotite is commonly altered to serpentinite.

Plutonic rock: Igneous rocks that form at great depths below the surface of the earth.

Pyroxene: A group of dark colored rock-forming silicate minerals commonly containing magnesium, iron and calcium, with or without manganese, aluminum, or chromium. They tend to crystallize as short prismatic shaped crystals. Pyroxene minerals are common constituents of igneous rocks including ultramafic and mafic rocks. Because of differences in crystal structure and related properties among the pyroxene minerals, they are often subdivided into two groups, orthopyroxene and clinopyroxene.

Quartz: A common rock-forming mineral composed of crystalline silica (silicon dioxide—SiO_2), widely distributed in igneous, metamorphic and sedimentary rocks.

Riebeckite: A sodic amphibole having the formula $Na_2(Fe^{2+}{}_3,Fe^{3+}{}_2)Si_8O_{22}(OH)_2$. Riebeckite sometimes crystallizes in the asbestiform habit and is one of the regulated asbestos minerals (crocidolite). It is sometimes referred to by the varietal name crocidolite when asbestiform.

Richterite: A sodic-calcic amphibole having the formula $Na(Ca,Na)Mg_5Si_8O_{22}(OH)_2$. Richterite sometimes crystallizes in the asbestiform habit.

Schist: A strongly foliated crystalline rock, formed by dynamic metamorphism, that can be readily split into thin flakes or slabs. This splitting characteristic is due to well-developed parallelism of more than 50 percent of the minerals present in the schist, particularly minerals with platy or elongate prismatic habits, such as mica or amphibole minerals.

Sedimentary rock: A water deposited rock formed by the consolidation and compaction of loose sediment or by chemical precipitation.

Serpentine: A group of common rock-forming minerals composed primarily of magnesium, silica and water. Serpentines have a greasy or silky luster, a slightly soapy feel, and a conchoidal fracture (a fracture producing a smooth curved surface). They are usually compact but may be granular or fibrous, and are commonly green, greenish yellow, or greenish gray and often veined or spotted with green and white. Serpentines are always secondary minerals, derived by alteration (metamorphism) of magnesium-rich silicate minerals. The most common serpentine minerals are lizardite, chrysotile, and antigorite. These minerals all have approximately the composition $Mg_3[Si_2O_5](OH)_4$.

Serpentinite: A rock consisting mainly of serpentine-group minerals, often formed by the metamorphism of magnesium rich intrusive igneous rocks such as peridotite or dunite.

Serpentinization (process): The process of hydrothermal alteration (metamorphism) by which magnesium-rich silicate minerals such as olivine, pyroxenes, and/or amphiboles in ultramafic rocks are converted into or replaced by serpentine minerals.

Shear zone: A zone of rock that has been crushed and brecciated by many parallel fractures due to shear strain.

Silica: The chemical compound silicon dioxide. Silica is an essential component of many other minerals such as olivine, pyroxene, amphibole, mica, clay, and feldspar.

Skarn (deposit): A mining term referring to rocks where metamorphic processes have caused silicate minerals such as amphiboles, pyroxene, and garnet to replace limestone and dolomite (carbonate rocks).

Slate: A compact, fine-grained metamorphic rock that possesses slaty cleavage, meaning that it can be split into thin plates.

Slip-fiber (asbestos): Asbestos occurrences where the orientation of the long axis of the fibers is parallel to the vein walls.

Talc-chlorite schist: A metamorphic rock (schist) composed primarily of the minerals talc and chlorite.

Terrane: A fault-bounded body of rock of regional extent, characterized by a geologic history different from that of contiguous terranes. Informally, a region where a particular rock or group of rocks predominates.

Tremolite: A white to dark-gray mineral of the amphibole group, principally composed of calcium, magnesium, silica, and hydroxide - $Ca_2Mg_5Si_8O_{22}(OH)_2$. It contains varying amounts of iron and may contain manganese and chromium. Tremolite occurs in long blade-shaped or short stout prismatic crystals and in columnar, fibrous (asbestos) or granular masses or compact aggregates, generally in metamorphic rocks such as dolomitic marble and talc schists. Tremolite asbestos is the most common variety of amphibole asbestos. Tremolite asbestos occurs most commonly as slip fiber veins in fault zones. It is found in a variety of host rocks, both igneous and metamorphic, although most of the commercial deposits have been in serpentinite. Historically in California, a commercial deposit consisted of a single steeply dipping vein, typically a few inches wide and less than 100 feet long. Some veins contained pockets up to several feet in width.

Tremolite/actinolite: Tremolite and actinolite are closely related amphibole minerals and this term is used to jointly refer to them or in situations where it is uncertain which one is present.

Ultramafic rock: an igneous rock composed chiefly of mafic (dark colored iron-magnesium) minerals such as olivine, augite, or hypersthene. Dunite, peridotite and pyroxenite are examples of ultramafic rock types. Asbestos minerals may form in ultramafic rock when it undergoes metamorphism.

Vein: The mineral filling in a fracture or fault in a host rock.

Volcanic rock: A fine-grained rock that formed by the crystallization of magma at or near the surface of the earth (an extrusive igneous rock).

Winchite: A sodic-calcic amphibole having the formula $(Ca,Na)(Mg_4Al)Si_8O_{22}(OH)_2$. Winchite sometimes crystallizes in the asbestiform habit.

X-ray diffraction: A mineral identification method that uses characteristic interference patterns of X-rays. These patterns are obtained when pulverized mineral samples are exposed to X-rays and relate to the three dimensional arrangement of atoms in minerals.

APPENDIX A

Study Methodology

Research of Geologic Documents

This study is based on a review and interpretation of numerous published and unpublished reports and maps on the geology and soils of Placer County. The vintage of these documents ranges from the end of the Nineteenth Century to 2005. Scales of the maps range from small (1: 316,800, or one inch = 5 miles) to large (1:4,800, or one inch = 400 feet). The purposes of the mapping ranged from descriptions of basic geology and soils to the potential for mineral resources.

The literature and databases on the distribution of mineral deposits that are known to be commonly associated with ultramafic rocks and serpentinite in California, and thus NOA, were researched. These included the mineral commodities asbestos, chromite, magnesite, nickel, and talc.

In addition, geologists familiar with the geology of the northern Sierra Nevada were interviewed.

Use of Remote-Sensing Imagery

Limited use was made of both aerial imagery (black and white, color, color infrared) and satellite imagery (ASTER) for interpretation of selected geologic features in the county. Imagery was used both during fieldwork and in the office.

Compared to surrounding areas of non-serpentinized rock, serpentinized rock is commonly characterized by vegetation cover that is: 1) unique in type; 2) less in amount; 3) stunted in growth; or 4) all of the above. The extent and boundaries of such rock can thus sometimes be determined through analysis of remote-sensing imagery. In Placer County, however, areas of ultramafic rock that are not strongly serpentinized can sometimes be difficult to distinguish from surrounding areas of non-ultramafic rock because the differences in vegetation cover are not readily apparent.

Fieldwork

Approximately 15 days of fieldwork were conducted during the project. Most of the fieldwork was carried out in the western half of the county between the foothills west of the Auburn area to the mid-elevations of the Sierra Nevada in the vicinity of Dutch Flat and Michigan Bluff. The purpose of the fieldwork was to:

- Observe and verify the character of rocks and structures of the major rock units in the county as previously mapped by other geologists.

- Evaluate the accuracy of the boundaries of previously mapped areas of the rock units in the county
- Collect rock and mineral samples for laboratory analysis.

Access for fieldwork was limited by the prevalence of private property in western Placer County. Therefore, fieldwork was conducted in areas such as road cuts along public roads, other areas of non-private ownership, or areas where permission for access could easily be obtained.

Laboratory Analyses

Identification of fibrous mineral material collected during fieldwork was made by X-ray diffraction, limited microscopic examination, and/or analysis at a commercial laboratory by California Air Resources Board (CARB) method 435 and/or EPA Method 600/R-93-116.

Map Preparation

This map was developed through use of a geographic information system (GIS). The geologists and GIS specialists obtained or prepared various digital layers by scanning and digitizing information from a variety of sources. This information included:

- Base data (cultural and geographic features)
- Geologic information (rock units, faults)
- Soil data (soil data related to ultramafic rocks/serpentinite)

This information was evaluated and combined to develop the final composite map that is presented as Plate 1.

Base Map Information

The map base for this project was compiled from various sources including the following: Roads and hydrography are from the Placer County Planning Department; Public Land Survey System is from the California Department of Conservation, Division of Oil and Gas and Geothermal Resources; and political boundaries are from the California Department of Forestry and Fire Protection. GIS specialists at the CGS labeled map features such as roads, water bodies, and population centers. The scale of the base map is 1:100,000 (one inch = 1.6 miles). This scale was chosen because the entire county can be displayed as a hard-copy document of reasonable size and because features the size of city-blocks can be resolved at this scale.

APPENDIX B

Mineralogy and Geology of Naturally Occurring Asbestos

This section provides a brief introduction to the mineralogy and geology of asbestos. A more detailed discussion of the mineralogy and geologic occurrence of asbestos can be found in Clinkenbeard and others (2002).

NOA is the term applied to the natural geologic occurrence of any of the six types of asbestos, which include chrysotile, crocidolite (fibrous riebeckite), amosite (fibrous cummingtonite-grunerite), tremolite (when fibrous), actinolite (when fibrous), and anthophyllite (when fibrous). The terms "crocidolite" and "amosite" are varietal or trade names rather than formal mineral names and represent fibrous riebeckite and fibrous cummingtonite-grunerite, respectively. Minerals with closely related crystal structures and compositions can be considered to be members of the same mineral "group." Chrysotile is the most common asbestos mineral in California and belongs to the serpentine mineral group. The remaining asbestos minerals belong to the amphibole mineral group.

Asbestos minerals can occur in a variety of geologic environments. Formation of asbestos requires the correct chemical components, the right physical conditions (temperature and pressure), and possibly stresses in the rock that encourage the growth of fibers rather than other crystal forms.

Chrysotile is a magnesium silicate, and amphiboles are typically iron-magnesium silicates with varying amounts of sodium and calcium. It is much easier to form asbestos if the rock already contains these chemical components than in rocks that lack one or more necessary components. Any rock that ordinarily has the correct chemical composition to contain amphibole or serpentine minerals has the potential to contain amphibole asbestos or serpentine asbestos. However, the non-asbestiform habits of these minerals are much more common than the asbestiform habits (Clinkenbeard and others, 2002).

Asbestos minerals form during a process called metamorphism, in which the mineralogy of the rock is changed in response to changing chemical and physical (temperature and pressure) conditions. Asbestos minerals can form under a wide range of metamorphic conditions within the earth's crust.

The physical conditions that lead to the crystallization of asbestos fibers are not well understood. In many cases, a condition of stress in the rock that encourages the growth of a mineral crystal mostly in one direction appears to be required to make asbestos. Stress may also encourage fiber growth by increasing permeability and fluid flow so space and materials are available for crystal growth. Stress conditions leading to fiber growth may be present during faulting, shearing, or folding of rocks, or where differences in temperature occur in the geologic environment.

Asbestos and Ultramafic Rocks

The asbestos minerals are most commonly associated with ultramafic rocks (also called "ultrabasic" rocks in older terminology) and their metamorphic derivatives, including serpentinite (serpentine rock). Ultramafic rocks are those igneous rocks composed mainly of iron-magnesium silicate minerals, such as olivine and pyroxene. They include the rock types dunite, peridotite, pyroxenite, and hornblendite. Ultramafic rocks form in high-temperature and high-pressure environments deep beneath the earth's surface. By the time they are exposed at the earth's surface, ultramafic rocks have typically undergone a type of metamorphism known as serpentinization, a process that alters the original iron-magnesium minerals to one or more water-bearing magnesium silicate minerals (lizardite, antigorite, chrysotile) that belong to the serpentine mineral group. The mineral chrysotile is often present as asbestos in the resulting rock. Metamorphism of ultramafic rocks and serpentinite may also lead to the formation of amphibole asbestos minerals. Conditions favorable for asbestos formation may occur repeatedly during the metamorphic process and, consequently, it is very common for at least a small quantity of asbestos to be present in metamorphosed ultramafic rock bodies.

Asbestos in Other Geologic Environments

Asbestos minerals may also form in other geologic settings. While generally associated with ultramafic rocks and serpentinite, chrysotile asbestos may less commonly occur in other rocks that originally contained the minerals olivine and pyroxene. These include metamorphosed mafic plutonic rocks (such as gabbro) or mafic volcanic rocks (such as basalt) that are commonly associated with ultramafic rocks or serpentinite. Chrysotile asbestos may also form in metamorphosed carbonate rocks (magnesium-rich limestones and dolomites). The amphibole asbestos minerals are most commonly found in metamorphosed ultramafic rocks, including serpentinite, and in metamorphosed mafic plutonic rocks, metamorphosed mafic volcanic rocks, metamorphosed iron-rich chert, and metamorphosed ironstones. Amphibole asbestos may also form in metamorphosed carbonate rocks (magnesium-rich limestones and dolomites) and less commonly in metamorphosed granitic rocks.

In many of these geologic environments, asbestos may be more likely to be found where changes in the geology occur (near geologic contacts, along dike boundaries, or near inclusions of different rocks) or in fault or shear zones where fluid flow has been enhanced.

Asbestos in Sedimentary Rocks, Stream Sediments, and Soils

Asbestos minerals may also be found in sedimentary rocks, stream sediments, or soils derived from parent materials that contain asbestos. Alluvial deposits that contain asbestiform materials are likely to be found in any watershed that drains ultramafic rocks. In fact, waters in many California rivers that drain such watersheds contain asbestos fibers (Hayward, 1984).

Soils derived from parent materials that contain chrysotile asbestos and amphibole asbestos may also contain asbestos fibers and are an important potential source of airborne asbestos. Weathering and leaching reduce the amounts of asbestos in soils over time, yet little is known about the rates of weathering and leaching of asbestos in soil environments. Available information suggests that substantial reductions in the amount of chrysotile may take hundreds or thousands of years, depending on the soil environment, and somewhat longer for amphibole asbestos (Clinkenbeard and others, 2002).

NOA in California

Chrysotile is the most common type of asbestos mineral found in California. The amphibole-group asbestos minerals also occur, but are less common. California has commercially produced significant amounts of chrysotile asbestos, small amounts of tremolite asbestos, and possibly some anthophyllite asbestos in the past. Currently, there are no operating asbestos mines in the state. While economic deposits of the asbestos minerals are rare, and usually limited to a few geographic locations, small non-economic occurrences of chrysotile and amphibole asbestos are present in a variety of rock types and geologic settings around the state.

Serpentinite, the host rock for chrysotile asbestos, is widely distributed in California, and mostly derived from peridotite. Veins of chrysotile asbestos can be found in many of the serpentinite masses in California (Rice, 1957).

Tremolite/actinolite asbestos is probably the most common amphibole-group asbestos found in California. Tremolite asbestos has been found in most of the counties of the Sierra Nevada and Klamath Mountains, where it most frequently occurs as slip-fiber veins associated with fault or shear zones in serpentinite (Rice, 1957). Tremolite/actinolite asbestos also occurs along serpentinite contacts with other metamorphic rocks such as amphibolite, slate, and schist in the Sierra Nevada foothills and other parts of the state (Rice, 1957; Wiebelt and Smith, 1959; and reports of the State Mineralogist between 1900 and 1957).

APPENDIX C

Geologic Units and Structural Features in Placer County

INTRODUCTION

The geology of Placer County is complex and still not completely understood by geologists. Tuminas (1983), for example, describes the northern region of the Sierra Nevada geologic province as containing a "staggering variety" of rocks. There remains disagreement among geologists on origins, ages, and relationships of some of the geologic units that comprise the metamorphic belts in the Sierra Nevada Foothills. Also, according to Day and Bickford (2004), the main faults that cut the metamorphic terranes of the lower elevations of the Sierra Nevada are complex, incompletely mapped, and still poorly understood. There has evolved a complicated set of unit names for the rocks as well as significant differences among geologic maps that cover the Western and Central Metamorphic Belts in Placer County. Various regional interpretations of the geology of Placer County can be found in Clark (1976), Day (1992a, 1992b); Day and Bickford (2004), Edelman and Sharp (1989), Graymer (2005), Graymer and Jones (1994), Harwood (1988, 1992), Jones and others (1997), Loyd (1995), and Schweickert and others (1999). These papers also include extensive reference lists.

It was not possible to prepare a comprehensive geologic map of Placer County that incorporates all of the various interpretations developed by geologists. To confront this problem, two main approaches were used in developing a geologic picture of the county that could be applied to interpretation of NOA: 1) Base the geology on mapped rock types ("lithology") and structures; and, 2) generally follow the geologic interpretations as shown on the two CGS 1:250,000-scale geologic atlas sheets (Saucedo and Wagner, 1992; Wagner and others, 1981) that cover Placer County. These maps are readily available to the public compared to other geologic maps and they present comprehensive views of the regional geology.

GEOLOGIC OVERVIEW

Placer County is underlain by a basement complex that consists of northerly-trending belts of metamorphic rocks intruded by younger plutonic rocks. This basement complex extends from Plumas County to Mariposa County. Most of the metamorphic rocks originally formed on the seafloor as sedimentary and volcanic rocks of various types. Some geologists believe that these rocks were then attached as "accretionary terranes" to the western margin of the North American continent at various times when an oceanic plate was sliding under the continental plate. These episodes of accretion included deformation and metamorphism, or recrystallization, of the rocks to produce what is termed the "Western Sierra Nevada Metamorphic Belt," which ranges in age from about 150 to more than 300 million years old (Schweickert and others, 1999). Also during this time, bodies of ultramafic rocks and serpentinite were emplaced, mainly along fault zones. Some geologists have divided the metamorphic belt into three smaller, northerly trending belts, which are separated by two major fault zones. These are the Western Metamorphic Belt, Central Metamorphic Belt, and Eastern Metamorphic Belt. In Placer County, the Wolf Creek Fault Zone separates the Western Belt from the Central Belt, while the Feather River Peridotite Belt separates the Central Belt from the Eastern Belt. In Placer County, the three metamorphic belts are composed of the following geologic units:

Western Metamorphic Belt

Smartville Complex (mafic metavolcanic rocks)
Other mafic metavolcanic rocks in the vicinity of Auburn, which may be part of the Copper Hill Volcanics

Central Metamorphic Belt

Lake Combie Complex (mafic metavolcanic rocks, gabbro, diabase)
Colfax sequence (metasedimentary rocks)
Logtown Ridge Formation (mafic metavolcanic rocks)
Calaveras Complex (mafic metavolcanic rocks, melange, and metasedimentary rocks) – Schweickert and others (1999) classified these rocks as part of what they termed an unnamed “high-strain phyllite-greenschist-metachert belt”
Structurally mixed or disrupted rocks (melange and fault-zone complexes)

Eastern Metamorphic Belt

Shoo Fly Complex (metasedimentary rocks)
Emigrant Gap Complex (mafic and ultramafic rocks)
Tuttle Lake Formation (mafic metavolcanic rocks)
Reeve Formation (mafic metavolcanic rocks)
Taylor Formation (mafic metavolcanic rocks)
Sailor Canyon Formation (metasedimentary rocks)
Sierra Buttes Formation (felsic metavolcanic rocks)
Peale Formation (felsic metavolcanic rocks and metasedimentary rocks)
Lake Tahoe sequence (metasedimentary rocks)

The bodies of plutonic rocks that intrude the Western Sierra Nevada Metamorphic Belt are small to moderately large, have a range of compositions, and range in age from approximately 100-160 million years old (Wagner and others, 1981; Saucedo and Wagner, 1992). They are mainly distributed in the Rocklin-Auburn area and in the eastern half of the county.

The Cenozoic deposits in the county include both sedimentary and volcanic rocks. The sedimentary rocks are older alluvial deposits (ag) deposited before eruption of the volcanic rocks, younger alluvium and glacial deposits (QT) in the Sierra Nevada, and alluvial deposits (QT) in the westernmost part of the county. The volcanic rocks (QT) are dominantly andesite with lesser amounts of rhyolite. Very limited areas of basalt (b) are present in the eastern part of the county, mostly in the Lake Tahoe Basin.

GEOLOGIC UNITS DEVELOPED FOR THE NOA MAP

Because of the lack of agreement on names and definitions for the various rock units of the basement complex, the geologic units described in the previous section were reinterpreted and grouped into twelve “lithologic” units. This section gives a brief overview of each of these units. The units were used to prepare a generalized geologic picture of the county (Figure 2), which became the basis for deriving the areas of relative likelihood for the presence of NOA in Placer County.

Auriferous Gravels (ag) - The unit consists of sedimentary rocks deposited by streams in the early Cenozoic. It consists in part of clasts of older igneous and metamorphic rocks that form the basement complex; isolated fragments of ultramafic rocks or serpentinite may be present locally. The deposits are present at a few locations in the central section of the county.

Basaltic Rocks (b) - The unit consists of volcanic rocks (basalt) deposited in the late Cenozoic as lava flows and shallow intrusions in the easternmost part of the county, mostly in the Lake Tahoe Basin. These rocks are mafic in chemical composition, but they are generally not metamorphosed.

Cenozoic Sedimentary and Volcanic Rocks (QT) - The unit consists of a variety of undifferentiated sedimentary and volcanic rocks that were deposited from the early Cenozoic to the present. They are distributed throughout the county. This unit is common in the eastern part of the county where it consists mainly of intermediate to felsic volcanic rocks and young glacial deposits. It also covers the westernmost part of the county where it consists mainly of alluvial deposits. These deposits are not known to be metamorphosed, and they show little or no deformation, although some of the volcanic rocks in the Sierra Nevada are cut by faults. Locally, the sedimentary deposits may contain isolated fragments of ultramafic rocks or serpentinite.

Of special note are deposits of unconsolidated alluvium present along rivers and creeks throughout the Sierra Nevada in Placer County. Because of their generally narrow extent and the small scale of the map, they are not shown separately on the map.

Fault-Zone Rocks (fz) - The unit consists of a mixture of undifferentiated pre-Cenozoic metamorphic rocks distributed within large fault zones. They can include, but are not necessarily limited to, metavolcanic, metasedimentary, ultramafic rocks and serpentinite. Rock types can include those derived from the country rock on either side of the fault zone in question. The unit is shown on the map along the Wolf Creek, Weimar, Colfax, and Gillis Hill Fault Zones. These rocks commonly are sheared or deformed.

Gabbroic Rocks (gb) - The unit consists of mafic plutonic rocks (gabbro), some of which are metamorphosed. It also includes diabase, which is a shallow intrusive equivalent to gabbro. These pre-Cenozoic rocks are locally distributed within the Lake Combie Complex and Emigrant Gap Complex (near Lake Valley Reservoir), and as a few other isolated bodies in the eastern half of the county. Where metamorphosed, the degree of metamorphism is reported to be greenschist facies.

Granitic Rocks (gr) - The unit consists of various plutonic rocks that are intermediate to felsic in chemical composition. It includes the Penryn, Rocklin, and Hotaling (north of Auburn) plutons in the western part of the county and various unnamed plutonic rocks in the eastern half of the county. These rocks were emplaced during the Mesozoic, subsequent to the episodes of regional metamorphism that affected older rocks in the county. Contact metamorphic features may be present locally at the boundaries of these plutons where they intrude older metamorphic or igneous rocks or where younger plutonic rocks intrude them.

Limestone (ls) - The unit consists of small, isolated bodies of limestone within melange-type rocks near Auburn and small bodies in metasedimentary units in the higher elevations of the Sierra Nevada. The melange-type rocks contain blocks of limestone locally, but these are too small to show at the scale of this map.

Melange/Structurally-Mixed Rocks (mel) - The unit consists of complex assemblages of pre-Cenozoic metamorphic rocks distributed over a large area between Auburn and Colfax. Along with the Fault-Zone Rock unit (fz) described above, it is part of what is broadly referred to in this report as "structurally mixed or disrupted rocks."

Some geologists have mapped the main component of this unit as a "melange," which is an incoherent assemblage of metamorphic blocks embedded in a matrix of metamorphic rock that is strongly sheared or disrupted. Belts of melange form either from material that was scraped off onto the edge of an over-riding tectonic plate (tectonic mélange) or by chaotic deposition of rock materials on the ocean floor through submarine landslides (sedimentary mélange). Graymer and Jones (1994) mapped the area near Auburn as a mixture of sedimentary melange (their "American River Terrane") and disrupted seamount deposits (their "Cool Quarry Terrane"). The most common types of blocks in the melange here are chert, mafic metavolcanic, and limestone; locally, blocks of serpentinite may be present, but they generally are too small to show at the scale of the map. Furthermore, the locations of all serpentinite blocks are not known at this time. The serpentinite blocks may represent material emplaced along faults in the melange belt.

Another part of this unit, in the vicinity of Colfax, was mapped by Tuminas (1983) as a highly complex, structurally (tectonically) mixed mass of two separate rock units (Clipper Gap tectonic unit and Colfax sequence), which he named the Clipper Gap-Colfax Transition Unit. It also includes small areas of what he defined as his Clipper Gap tectonic unit, a structurally disrupted sequence of interbedded chert and shale/argillite. Tuminas (1983) defined his Colfax sequence as a disrupted assemblage of marine debris slides and turbidites with very little volcanic material. Day and Bickford (2004) later interpreted the Clipper Gap and Colfax units to be part of the Fiddle Creek Complex.

The remaining part of this unit is a smaller area of melange mapped by Tuminas (1983) along the east side of the Gillis Hill Fault Zone. He placed these rocks in his Cape Horn Unit, but other geologists have placed them in the Calaveras Complex.

Metamorphosed Felsic Volcanic Rocks (mvf) - The unit consists of deformed metamorphosed submarine volcanic rocks of felsic composition that form subunits within the Paleozoic Sierra Buttes Formation and Peale Formation. These rocks are sparsely distributed in the eastern half of county.

Metamorphosed Mafic Volcanic Rocks (mv) - The unit consists of metamorphosed mafic volcanic, volcaniclastic, and dike rocks that were deposited generally in marine conditions during the Paleozoic and Mesozoic. Included within this unit are rocks that entirely or partially compose the Smartville Complex, Lake Combie Complex, Logtown Ridge Formation, Calaveras Complex (high-strain belt of Schweickert and others, 1999), Tuttle Lake Formation, Reeve Formation, and Taylor Formation. Mafic metavolcanic rocks assigned to the Smartville Complex have been mapped north of the 39°00'00" latitude line and west of the Wolf Creek Fault Zone (Plate 1; Day and Bickford, 2004). South of this line, Wagner and others (1981) mapped some of these rocks south to El Dorado County as possibly equivalent to the Copper Hill Volcanics.

This unit is mainly present in the western half of the county. The degree of metamorphism of these generally deformed metavolcanic rocks ranges from greenschist facies to amphibolite facies.

Metamorphosed Sedimentary Rocks (ms) - The unit consists mostly of deformed metamorphosed sedimentary rocks that were originally deposited in marine conditions during the Paleozoic and Mesozoic. Included within the unit are rocks that entirely or partially compose the Colfax sequence, Calaveras Complex (high-strain belt of Schweickert and others, 1999), Shoo Fly Complex, Sailor Canyon Formation, Peale Formation, and Lake Tahoe sequence. (The Colfax sequence has been designated by different researchers as Fiddle Creek Complex, Cosumnes Formation, and Mariposa Formation.) These rocks are present in the central and eastern parts of the county. These metasedimentary rocks are mainly greenschist facies.

Except for the bodies of ultramafic rocks and serpentinite, the area between the Gillis Hill Fault Zone and the Foresthill Fault Zone is mapped as Calaveras Complex. Schweickert and others (1999) interpreted this area to be part of what they termed a "high-strain phyllite-greenschist-metachert belt," which differs from rocks mapped farther south of Placer County as Calaveras Complex. This area consists of a mixture of metasedimentary rocks (mainly metachert and phyllite), mafic metavolcanic rocks, and melange-type rocks. It is shown on Figure 2 as largely metasedimentary (ms) with smaller areas of mafic metavolcanic rocks (mv) and melange/structurally-mixed rocks (mel). It is important to note that small areas of mafic metavolcanic rocks are present in the metasedimentary unit, but such areas either are too small to show on the map, or have not been previously mapped.

Ultramafic Rocks and Serpentinite (um) - The unit consists largely of pre-Cenozoic ultramafic rocks and serpentinite, which are present as large and small bodies mainly in the western half of the county. (The unit also may contain locally bodies of other types of rocks, such as metagabbro, which are too small in size or too complexly intermixed with the ultramafic rocks and serpentinite to show them on the map.) Ultramafic rocks and serpentinite are commonly found along the large fault zones that bound the main geologic units of the Western and Central Metamorphic Belts, but they also are known to be locally present within individual metamorphic complexes, particularly along smaller faults.

Soils developed on the ultramafic rocks and serpentinite in the county include the Dubakella, Henneke, and Forbes units, which are described in Appendix D.

MAJOR GEOLOGIC STRUCTURES IN THE COUNTY

The structural framework of western Placer County is dominated by a group of major north- to north-northwest-trending fault zones, which mark the boundaries of different packages of rocks within the basement complex described above. These fault zones, listed here from west to east and labeled on Plate 1, include the Spenceville-Deadman, Wolf Creek, Weimar, Gillis Hill, Foresthill, and the large faults that bound each side of the Feather River Ultramafic Belt. These fault zones locally can be characterized by long bands and isolated lenses of serpentinite, talc-chlorite schist, quartz-vein complexes, and highly sheared country rock. In addition, a shorter northeast-trending fault zone, the Colfax Fault, is present near the town of Colfax between the Weimar and Gillis Hill Fault Zones. Each of these zones is briefly described below. Other faults and shear zones are present throughout most of the county, some of which are shown on Plate 1.

Spenceville-Deadman Fault Zone - The northwest-trending fault zone extends from Nevada County southward through the area west of Auburn, and continues south across the American River into El Dorado County where it is mapped as a branch of the Bear Mountains Fault Zone. In the northern part of Placer County, the Spenceville-Deadman Fault Zone forms a major structural boundary between subunits of the metamorphosed volcanic, volcaniclastic, and dike rocks of the Smartville Complex. Where it crosses into Placer County along the Bear River, Clark and Huber (1975) mapped this feature as a shear zone about 1,500 feet wide. Springer (1981) mapped this feature as both a fault and as a shear zone about 1,000 feet wide.

Just west of the Spenceville-Deadman Fault Zone in Nevada County and Placer County, Lindgren (1894a) and Lindgren and Turner (1895) described a broad zone of sheared metavolcanic rocks, which ranges from about 1 to 3 miles wide. Xenophontos (1984) also described a zone of sheared metavolcanic rocks in this same region, but his study did not extend into Placer County. Also, he did not show the areal extent of these rocks on his geologic map. In contrast, detailed geologic mapping by Springer (1981) and Clark and Huber (1975) in northern Placer County did not show the rocks west of the Spenceville-Deadman Fault Zone as part of a shear zone. Rather, their mapping in this region showed shear zones to be restricted to the very narrow belt of rocks associated with the fault zone as described above. The stippled area of faulting and shearing shown on Plate 1 for this region is based on the interpretations of Springer (1981) and Clark and Huber (1975).

Wolf Creek Fault Zone - The north-trending fault zone extends from Nevada County, generally following State Highway 49 southward through the City of Auburn, where it continues south into El Dorado County. Its width varies considerably, but the zone's outer boundaries are not well established. Parts of this zone were included in the Fault-Zone Rocks (fz) unit described above. Bodies of ultramafic rocks and serpentinite are present along its length. The zone forms the major structural boundary between the Western and Central Metamorphic Belts. Juxtaposed along the zone are mafic metavolcanic rocks of the Lake Combie Complex and melange-type rocks to the east, and mafic metavolcanic rocks (including those of the Smartville Complex) to the west.

Weimar Fault Zone - The north-trending fault zone extends from Nevada County and splits into two north-trending branches southwest of Colfax (Plate 1). The eastern branch crosses Placer

County and continues into El Dorado County. The western branch, which was mapped by Tuminas (1983), is shown on Plate 1 to stop at the 39°00'00" latitude line because his study area terminated at that line. The widths of the two branches vary and are not well established because of their complexity. The zone is complex, and parts of the eastern branch are included in the Fault-Zone Rocks (fz) unit described above. Bodies of ultramafic rocks and serpentinite are present along the main eastern branch, while one small body is present at the southern end of the western branch. The eastern branch of this zone forms a major structural boundary between rocks of the Colfax sequence (Fiddle Creek Complex) to the east and rocks of the previously described melange/structurally mixed unit to the west.

Gillis Hill Fault Zone - The north-trending zone extends from Nevada County to the east of Colfax and continues southward into El Dorado County. Its width varies, and is not well mapped because of its complexity. Parts of it were included in the Fault-Zone Rocks (fz) unit described above. Bodies of ultramafic rocks and serpentinite are present along its length. The zone forms a major structural boundary between a subunit of mixed mafic metavolcanic and metasedimentary rocks of the Calaveras Complex to the east and rocks of the Colfax sequence to the west.

Colfax Fault Zone - The northeast-trending zone extends between the Weimar and Gillis Hill Fault Zones northwest of Colfax. The zone is complex, and parts of it were included in the Fault-Zone Rocks (fz) unit described above. Although no bodies of ultramafic rocks or serpentinite were mapped by Tuminas (1983) or Chandra (1961) along its length, the zone does contain mafic metavolcanic rocks of the Lake Combie Complex and melange-type rocks of the Clipper Gap tectonic unit of Tuminas (1983). The Clipper Gap unit is known to contain blocks of serpentinite elsewhere in the county. The Colfax Fault Zone forms a structural boundary between rocks of the Lake Combie Complex to the north and rocks of the Colfax sequence to the south.

Foresthill Fault Zone - The north-trending zone extends from the vicinity of Dutch Flat southward to Foresthill where it continues into El Dorado County. Its width is not well established. Linear bodies of ultramafic rocks and serpentinite are present along the fault zone in the Iowa Hill area about 7 miles south of Dutch Flat. The zone forms a major structural boundary between a subunit of mafic metavolcanic rocks of the Calaveras Complex to the east and another subunit of mixed mafic metavolcanic and metasedimentary rocks of the Calaveras Complex to the west.

Feather River Ultramafic Belt - The north-trending belt includes the largest masses of ultramafic rocks and serpentinite in the county. The belt extends well north and south of Placer County and is up to two miles wide. It is bounded to the east and west by unnamed fault zones. The widths of these zones are not well established, although Redmond (1966) described a 2,500-foot wide belt of mylonite present along the east-bounding fault zone. Historically, some geologists (e.g., Clark, 1960) named this belt the Melones Fault Zone, as a northern continuation of the fault zone of the same name south of Placer County. Other geologists are not convinced of this continuation. The belt forms the main structural boundary between the Central and Eastern Metamorphic Belts. Juxtaposed along the zone are metasedimentary rocks of the Shoo Fly Complex to the east and mafic metavolcanic rocks of the Calaveras Complex to the west.

Other Geologic Structures and Settings - Various plutonic rocks are intruded into older metamorphic and plutonic rocks in the western and eastern parts of the county. Zones of contact metamorphism of uncertain extent can in places characterize the boundaries between the younger plutonic rocks and the older rocks. In these zones, the heat and fluids from the pluton caused chemical reactions to take place between the pluton and the older rocks. As a result, these zones can contain assemblages of alteration minerals. Where chemical and physical conditions are favorable, such as where a granitic rock intrudes a carbonate rock (particularly magnesium-rich ones such as dolomite or dolomitic limestone or magnesian limestone), amphiboles such as tremolite may form. Under the right circumstances, the tremolite may be asbestiform.

Contact metamorphism along the intrusive contacts in western Placer County has not been described in detail in the geologic literature. Tuminas (1983) briefly described the Hotaling pluton (north of Auburn) as containing a narrow (<100 m), but not mappable, discontinuous zone of contact metamorphism of hornblende-hornfels facies where it intrudes the Lake Combie Complex. Also associated with this pluton, Kohler (1984) described a small contact-metamorphic skarn deposit of iron ore at the site of Hotaling.

Review of technical documents did not reveal reports of asbestos associated with zones of contact metamorphism in the county. Nonetheless, such zones cannot be ruled out as possible sites for the presence of NOA.

Finally, numerous small igneous dikes are present in rocks of the basement complex of the county. These are generally too small and irregularly distributed to show on geologic maps, but their contacts with the rocks they intrude may represent possible local sites where NOA may be present.

APPENDIX D

Soils Units in Placer County

The soils in Placer County, with the exception of those in the Lake Tahoe Basin, were mapped under three main surveys. Rogers (1980) mapped the western part of the county, while Hanes and others (1982) mapped that portion of the county in Tahoe National Forest. A small area at the southern edge of the county is within Eldorado National Forest, which was mapped by Mitchell and others (1985).

Soils derived from asbestos-bearing parent materials may contain asbestos. Because soils derived from ultramafic rocks and serpentinite are commonly distinctive, they are often identified in soils studies as serpentine or ultramafic related soils. Both Rogers (1980) and Hanes and others (1982) mapped soil units derived from ultramafic rocks and serpentinite. Mitchell and others (1985) did not observe any soils associated with ultramafic rocks and serpentinite.

In the soil studies used here, the relationship between parent material and soil was not as clearly defined for other rock types as it was for ultramafic rocks and serpentinite. Consequently, only those soils associated with ultramafic rock/serpentinite were used in compiling Plate 1.

Overall, the locations of mapped soils and mapped geologic units related to ultramafic rock and serpentinite agree reasonably well. There are, however, a few small isolated areas of soil in the Auburn area that do not have corresponding mapped areas of ultramafic rocks and serpentinite.

Soil Units of Rogers (1980)

Rogers (1980) mapped soils associated with ultramafic rocks and serpentinite as belonging to the following units:

<u>Dubakella (Map Unit 143)</u>

The unit is derived from serpentinite bedrock. Natural vegetation is brush, stunted (scrub) conifer, and annual grasses. Depth to bedrock is about 31 inches. Erosion is moderate to high.

<u>Henneke/Rock Outcrop (Map Unit 148)</u>

The unit is derived from serpentinite bedrock. Natural vegetation is conifer-hardwood forest. Depth to bedrock is about 18 inches. Erosion is high. The unit is found in a discontinuous belt from Auburn north to Orr Creek (just north of Florence Road) east of State Highway 49.

<u>Rock Outcrop (Map Unit 179)</u>

We could not use the “Rock Outcrop” unit for the NOA map of Placer County because the definition of this unit also included rock types other than ultramafic rocks and serpentinite. In other words, the unit was not differentiated according to each underlying parent-rock material.

Soil Units of Hanes and Others (1982)

Hanes and others (1982) mapped soils associated with ultramafic rocks and serpentinite as belonging to the following units:

Dubakella-Dubakella Variant-Rock Outcrop (Map Unit DUE)

The unit is derived from serpentinitic bedrock on 2-30% slopes. Depth to bedrock is 0-32 inches. Erosion is high.

Dubakella-Dubakella Variant-Rock Outcrop (Map Unit DUF)

The unit is derived from serpentinitic bedrock on 30-50% slopes. Depth to bedrock is 0-32 inches. Erosion is high.

Forbes-Dubakella Complex (Map Unit ISE)

The unit forms in residuum weathered from ultramafic rocks on 2-30% slopes. Vegetation is semi-dense to dense mixed conifers. Depth to bedrock is 0-61 inches.

Forbes-Dubakella Complex (Map Unit ISE5)

The unit is associated with ultramafic rocks on 2-30% slopes that underlie tree plantations; the soils have been artificially disturbed. Depth to bedrock is up to 51 inches on Forbes and up to 31 inches on Dubakella. This complex includes rock outcrop.

Forbes-Dubakella Complex (Map Unit ISF)

The unit forms on 30-50% slopes. Vegetation is mixed conifer. Depth to bedrock is up to 61 inches on Forbes and up to 32 inches on Dubakella. This complex includes rock outcrop.

Rock Outcrop-Dubakella-Dubakella Variant Complex (Map Unit RDE)

The unit forms on 2-40% slopes. Vegetation includes manzanita-Jeffrey Pine series/barren-manzanita series. Depth to bedrock is 32 inches on Dubakella and 13 inches on Dubakella Variant.

Rock Outcrop-Dubakella-Dubakella Variant Complex (Map Unit RDG)

The unit has the same characteristics as the RDE unit except that it forms on 40-75% slopes.

APPENDIX E

Map Accuracy

The accuracy of a geologic (rock-type) boundary shown on a geologic map is dependent upon many factors. Some of these factors directly related to geology are:

1. The amount of a geologic boundary, or "contact," exposed for observation.
2. The extent of rock exposures in the area and the distances between them.
3. The regularity and consistency in the occurrence of geologic units within an area.
4. Whether the geologic unit is sufficiently consistent in appearance to be properly identified throughout the map area.
5. Whether the geologic unit is homogeneous or is intimately or complexly associated with occurrences of other rock types that cannot be readily separated at the scale of mapping.
6. Whether an exposure of the geologic unit is sufficient in size to show at the scale of mapping.

The accuracy of the base map upon which geologic boundaries are plotted is another factor, particularly for older geologic maps. Geologic units originally plotted on obsolete base maps commonly cannot be precisely located onto modern base maps. The mapping style of the geologist can also affect map accuracy. Because geologic mapping is an art as well as a science, mapping styles of individual geologists will vary depending upon the skill and experience of the individual. Some styles may work better in one area, but not another. Finally, the original purpose of a geologic map can affect both the level of detail and number of geologic boundaries shown on a given map. With the large number of geologic maps utilized in the compilation of the NOA map for Placer County, the accuracy of the boundaries of the areas of relative likelihood for the presence of NOA are probably influenced by all of the above factors.

In many instances, soil, vegetation, and development can obscure geologic boundaries. Consequently, locations of boundaries must be interpolated between available exposures of rock units. Limited field observations suggest uncertainties of a few to several hundred feet for rock units are common in these situations in Placer County.

To minimize uncertainty in locations of the areas of relative likelihood for the presence of NOA, the most detailed, appropriate, geologic mapping available for each portion of the county was used. Field checking was done in selected areas where access was possible. Overall, available information suggests that the accuracy of the boundaries of the rock units used to define the areas of relative likelihood for the presence of NOA are within 1,000 feet of their true locations (0.12 inches on the map equals 1,000 feet on the ground).

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RELATIVE LIKELIHOOD FOR THE PRESENCE OF NATURALLY OCCURRING ASBESTOS IN PLACER COUNTY, CALIFORNIA

By

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2006

RELATIVE LIKELIHOOD FOR THE PRESENCE OF NATURALLY OCCURRING ASBESTOS IN PLACER COUNTY

Natural occurrences of chrysotile asbestos and amphibole asbestos are known to be present in some parts of Placer County. On this map, the County is divided into areas according to the relative likelihood for the presence of naturally occurring asbestos (NOA) in different geologic units. The presence of faulting or shearing may locally increase the likelihood for the presence of NOA in some geologic units. The presence of NOA is possible within all of these areas, but it is more likely to be present in some areas than others.

This map is based on compilation and interpretation of geologic and soil data from various published and unpublished sources available at the time of the study. Users are encouraged to read the accompanying report for further details about this map.

Based on existing information, determination of the presence or absence of NOA at specific sites on this map is not possible. Determination of whether NOA is present or absent at a specific site will require a detailed geologic investigation of that site.

Areas of Relative Likelihood for the Presence of NOA

Areas Most Likely to Contain NOA: These areas include ultramafic rock and serpentinite (serpentine rock), and associated soils, which are most likely to contain NOA.

Areas Moderately Likely to Contain NOA: These areas include these metamorphic and igneous rocks that are moderately likely to contain NOA.

Areas Least Likely to Contain NOA: These areas include those metamorphic, igneous, and sedimentary rocks that are least likely to contain NOA.

Areas of Faulting or Shearing: These areas are zones of faulted or sheared rock that may locally increase the relative likelihood for the presence of NOA within or adjacent to areas moderately or most likely to contain NOA. The solid lines represent mapped traces of fault and shear zones; question marks indicate uncertainty regarding the continued extent of the traces.

Mapped trace of fault or shear zone. These features may locally increase the likelihood for the presence of NOA within areas least likely to contain NOA. The presence of NOA along these features is more likely within areas mapped as most likely or moderately likely to contain NOA as described above.

EXPLANATION OF THE AREAS OF RELATIVE LIKELIHOOD FOR THE PRESENCE OF NOA

This section provides more information on the characteristics of each of the NOA areas shown on the map of Placer County. Additional details are presented in the report that accompanies this map.

Areas Most Likely to Contain NOA:

These areas contain ultramafic rock and serpentinite, and their associated soils. Serpentinite and partially serpentinized ultramafic rock commonly contain chrysotile asbestos. These rocks may also host amphibole asbestos, typically the following varieties: tremolite, actinolite, or anthophyllite. Soils derived from ultramafic rock and serpentinite may contain NOA. These soils are commonly designated as "ultramafic soils" or "serpentine soils" on soil maps. Soil maps of Placer County by the U.S. Department of Agriculture's Natural Resources Conservation Service and the U.S. Forest Service include the following ultramafic- and serpentinite-related soils series: Dubakella, Henneke, and Forbes.

The California Geological Survey did not evaluate deposits of unconsolidated sediment along rivers and creeks below areas of ultramafic rock and serpentinite for their likelihood to contain NOA. Such deposits may contain NOA, but no studies of NOA in such sediment in Placer County were identified during research for this mapping project. Many of these deposits are too small to depict on this map.

Areas Moderately Likely to Contain NOA:

These areas contain one or more of the following rock types: metamorphosed mafic volcanic rocks, metamorphosed mafic intrusive rocks, non-metamorphosed mafic intrusive rocks, and several structurally complex assemblages in which metamorphic rocks of different origins are mixed together. Geologic units in Placer County comprised partly or entirely of one or more of these rock types include the Smartville Complex, Lake Combie Complex, Logtown Ridge Formation, Calaveras Complex, Emigrant Gap Complex, Tuttle Lake Formation, Reeve Formation, and Taylor Formation. The structurally complex assemblages are broadly referred to as "structurally mixed or disrupted rocks."

The rocks in these areas generally have a lower relative likelihood for the presence of NOA than those in the areas described as most likely to contain NOA. Nonetheless, NOA is known to be present in these rock types either in Placer County or in similar rocks in nearby counties. The most likely settings for NOA in these rocks are in fault zones and shear zones that contain slivers of serpentinite and/or high concentrations of the minerals talc and chlorite. Both chrysotile asbestos and amphibole asbestos are known to occur in such environments.

Areas Least Likely to Contain NOA:

These areas contain one or more of the following rock types: metamorphosed sedimentary rocks, metamorphosed non-mafic volcanic rocks, granitic rocks, volcanic rocks, alluvium, and glacial deposits. Geologic units in Placer County comprised partly or entirely of one or more of the metamorphic rock types include the Colfax sequence (Fiddle Creek Complex), Calaveras Complex, Shoo Fly Complex, Sailor Canyon Formation, Sierra Buttes Formation, Peale Formation, and Lake Tahoe sequence. The granitic rocks include the Rocklin and Penryn plutons.

The technical documents reviewed during compilation of this map did not indicate the presence of NOA in any of these rock types within Placer County. The mineral actinolite has been reported at a few localities in the metamorphosed sedimentary rocks, but whether or not it is asbestos was not reported; in general, non-asbestiform actinolite is much more common than actinolite-asbestos in the Sierra Nevada. Based on the available information, the relative likelihood for the presence of NOA in these areas is lower than that in areas identified as most likely or moderately likely to contain NOA. Small bodies of rock or soil with moderate or higher likelihood for the presence of NOA may occur within some of these areas, but they remain undiscovered or are too small to depict on this map.

Areas of Faulting or Shearing:

The western half of Placer County contains many mapped fault and shear zones, some of which contain NOA, or are potentially favorable environments for its presence. These are linear belts of highly fractured and deformed rocks, highlighted by stippling on the map where they overlap areas most likely or moderately likely to contain NOA. These areas may have an increased likelihood for the presence of NOA beyond that of the underlying area.

The stippling on the map is intended to draw attention to these areas as localities with increased likelihood for the presence of NOA above that of unfaulted or unsheared areas. For example, an area of faulting or shearing shown within an area mapped as moderately likely to contain NOA would be expected to have a higher relative likelihood for the presence of NOA than that of the moderately-likely area by itself. The widths of the stippled areas shown on the map are not intended to precisely depict the actual width of a fault or shear zone at any particular location. Fault zones in the Sierra Nevada Foothills are seldom less than two hundred feet wide and may be several thousand feet wide or more. The width of a fault zone commonly varies along its length. Detailed information on the width of fault zones is largely unavailable for western Placer County.

NOA in Other Geologic Environments

NOA can be associated with many different rock types in a variety of geologic environments. The geologic environments for NOA discussed on this map are those known or strongly suspected to contain NOA in Placer County. The research for this mapping project did not reveal occurrences of NOA in other geologic settings in the county. However, the possibility that additional occurrences will be discovered in the future cannot be ruled out. These less-common possibilities for the presence of NOA are discussed in the accompanying report.

USE AND LIMITATIONS OF MAP

Chrysotile and tremolite/actinolite asbestos are known to occur in Placer County. Other varieties of NOA may also be present within the county.

The purpose of this map is to provide information to local, state and federal agencies, and the public as to areas where naturally occurring asbestos is most likely to be found in Placer County. This information includes locations of major mapped faults and fault zones, as well as certain rock and soil types with potential for containing naturally occurring asbestos.

This map is based on a compilation of geologic data and soil data from various published and unpublished sources available at the time of the study. These sources are identified on the map and in the accompanying report. This map is also based on limited geologic fieldwork by staff of the California Department of Conservation, California Geological Survey.

The scale of this map is 1:100,000 (one inch = 1.6 miles). This map is intended for use in conjunction with the companion report. The report provides detailed information on the underlying geologic assumptions for the map, map compilation procedures, map accuracy, and guidance on map usage and limitations.

This map should not be used to determine whether bedrock or soil on a particular parcel of land contains naturally occurring asbestos. A detailed site-specific investigation is required to make such a determination.

California Geological Survey Web Site: http://www.consrv.ca.gov/cgs/

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(These cover all or large parts of Placer County)

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DISCLAIMER

The State of California and the California Department of Conservation, California Geological Survey make no representations or warranties as to the actual presence or absence of natural asbestos at specific sites. Further, the State and the Department make no representations or warranties regarding the accuracy of the data from which these maps were derived. Neither the State nor the Department shall be liable under any circumstances for any direct, indirect, special, incidental or consequential damages with respect to any claim by any user or any third party on account of or arising from the use of this map.

FRAMEWORK DATA

Base map data for hydrography and roads were provided by Placer County Planning Department; Public Land Survey (PLSS) by California Department of Conservation, Division of Oil, Gas, and Geothermal Resources; and political boundaries by California Department of Forestry and Fire Protection.

Cartographic design and GIS development by Milton Fonseca