SPECIAL REPORT 192

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

2006

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California Geological Survey

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By

Chris T. Higgins and John P. Clinkenbeard

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EXECUTIVE SUMMARY

Naturally occurring asbestos (NOA) is known to be present in eastern Sacramento County. To help identify areas in the county that may contain NOA, the California Department of Conservation, California Geological Survey (CGS), has prepared a 1:62,500-scale map (Plate 1) of relative likelihood for the presence of NOA in eastern Sacramento County. The map and accompanying report were prepared for the Sacramento Metropolitan Air Quality Management District under Interagency Agreement No. 1004-019R.

The map divides the eastern part of the county into different areas based on the relative likelihood of encountering NOA. These areas are defined as: moderately likely and least likely to contain NOA. In addition, areas of faulting and shearing are highlighted where they exist in areas 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 moderately likely to contain NOA are found along a northerly trending region that extends from Folsom Lake to the Cosumnes River. These areas include parts of the communities of Folsom and Rancho Murieta. Areas least likely to contain NOA are present in this region also, and they comprise the remainder of the study area west of this region.

The purpose of the map is to provide information to government agencies and the public about the likelihood of encountering NOA within eastern Sacramento 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 and concentration 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 eastern Sacramento County is characterized by a variety of igneous, metamorphic, and sedimentary rocks, some of which have been faulted or sheared. The geologic diversity in eastern Sacramento County provides some 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 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 eastern Sacramento 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 Sacramento Metropolitan Air Quality Management District under Interagency Agreement No. 1004-019R.

This study is based on research of published and unpublished geologic documents, interpretation of airborne and spaceborne imagery, limited fieldwork, and laboratory analyses. Geologic information related to rocks and faults in eastern Sacramento County was compiled from a number of previously existing geologic maps. The 1:62,500-scale (1” = 1 mile) map produced in this study is a result of the interpretation of 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 were compiled in a computerized geographic information system (GIS). The approach of this study built upon those developed by Higgins and Clinkenbeard (2006) and Churchill and others (2000) for similar investigations in Placer and El Dorado counties, which adjoin eastern Sacramento County to the north and east.

This report provides background information about NOA, the supporting geologic assumptions on which the map is based, the relative likelihood for NOA presence in eastern Sacramento County, information on map accuracy, and guidance on map usage and limitations. Additional information on study methodology, the geology and mineralogy of NOA, eastern Sacramento County geology, and map accuracy is presented in Appendices A through D. A glossary is available starting on page 14 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 EASTERN SACRAMENTO COUNTY

Eastern Sacramento County is within the Great Valley geologic province**,** adjacent to the western edge of the Sierra Nevada geologic province (Figure 1). It is underlain by a variety of igneous, metamorphic, and sedimentary rocks that range in age from the recent to more than 150 million years old.

The oldest rocks are metamorphosed volcanic, sedimentary, and intrusive rocks, at least some of which formed in a volcanic-arc setting about 150-160 million years ago. These rocks are exposed as a northwest-trending belt along the eastern edge of the county. About 130 million years ago igneous rock bodies intruded these rocks in the Folsom Lake area. Together, all of these rocks form a "basement" complex, which was emplaced on the western edge of North America through plate-tectonic processes. Folding and faulting have variously deformed the metamorphic rocks, while the igneous rock bodies are less deformed.

Beginning about 100 million years ago, and continuing to the present, sedimentary and volcanic rocks were deposited on top of the basement complex. The sedimentary rocks are composed mainly of material eroded from the Sierra Nevada Mountains to the east, and carried westward by a system of streams and rivers. The volcanic rocks were derived from volcanoes in the Sierra Nevada and possibly from volcanoes farther to the east. The sedimentary and volcanic rocks show little or no deformation or metamorphism. Additional details and references on the geology of the eastern part 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. Eastern Sacramento County has some settings that are favorable for the presence of NOA because of its geology. These settings are typically associated with metamorphic and igneous rocks that have undergone episodes of deformation.

Geologic and Soil Mapping of the County

To evaluate the geology of eastern Sacramento 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. In earlier studies of NOA by the CGS (Churchill and others, 2000;

Higgins and Clinkenbeard, 2006), soils reports were used primarily to identify mapped locations of soils associated with ultramafic rock and serpentinite. In the present study, review of the soils reports that cover eastern Sacramento County (Cole and others, 1954; Tugel and others, 1993) did not indicate the presence of these types of soils. Furthermore, it was not possible to use soils units as defined in these reports to aid mapping of other rock types in the study area. Therefore, soils units were not used further to evaluate areas for the relative likelihood of the presence of NOA in eastern Sacramento County.

The geologic units evaluated from previous geologic mapping were grouped into a broader set of more generalized geologic units by rock type and structural characteristics. These generalized geologic units are listed here with their assigned abbreviations and are described in Appendix C. Their distribution in eastern Sacramento County is shown in Figure 2.

Gabbroic Rocks (gb)

Granitic Rocks (gr)

Metamorphosed Intrusive Rocks (mi)

Metamorphosed Mafic Volcanic Rocks (mv)

Metamorphosed Sedimentary Rocks (ms)

Sedimentary Rocks (s)

Tailings from Gold Dredging (t)

Volcanic Rocks (v)

Reported Geologic Occurrences of NOA in Eastern Sacramento County

Occurrences of amphibole asbestos have been reported from several locations in eastern Sacramento County. To date, these occurrences have been found in areas mapped as metamorphosed mafic volcanic rocks in the Folsom area (Figure 1).

Based on research of mine databases, mining records, and reports on mining activity (Carlson, 1955; Logan, 1925; Loyd, 1984), no asbestos mines or prospects have been found in eastern Sacramento County.

No reports of naturally occurring asbestos in eastern Sacramento County were found in a review of published geologic literature. There are a few published reports of the presence of the amphibole minerals tremolite, actinolite, and anthophyllite, either in eastern Sacramento County proper or in regional rock units that are known to extend into the county. These reports do not

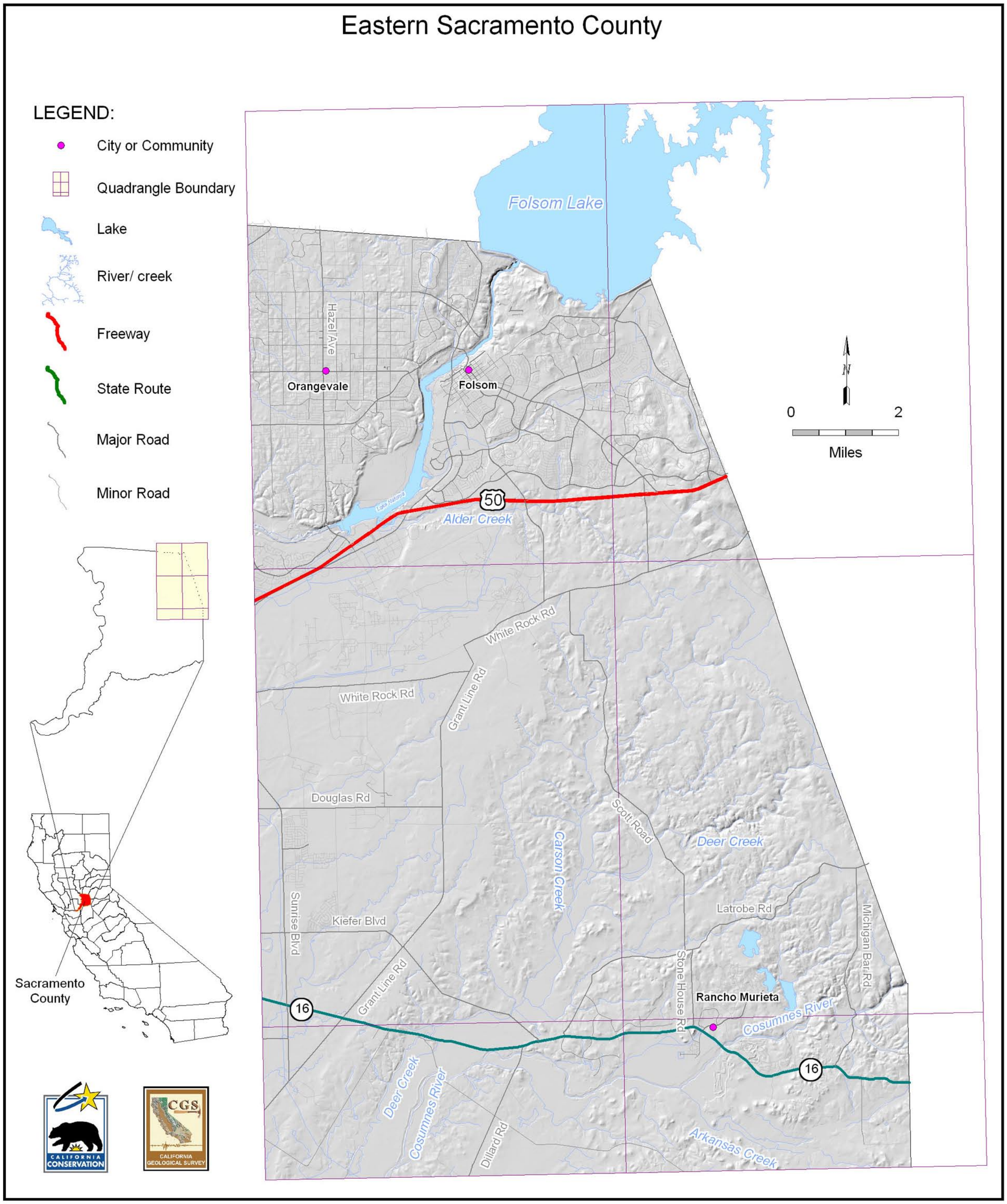

Figure 1. Location Map of Eastern Sacramento County.

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, actinolite, and anthophyllite indicate that at least some of the conditions necessary to form amphibole asbestos occurred in these areas. Clark (1964) reported that metamorphism “has produced abundant epidote, albite, and tremolite and some chlorite in most of the rocks of the Gopher Ridge volcanics…” Kiersch and Treasher (1955) reported the presence of “tremolite schist” in the weathered metamorphic rock that underlies the Mormon Island Dam, which is on the south edge of Folsom Lake. Tierra Engineering Consultants (1983) reported that actinolite is present in the metavolcanic rocks south of Folsom Lake. Swanson (1970) reported the presence of anthophyllite a few meters from the contact between the Rocklin Pluton and Copper Hill volcanics. He also observed tremolite in small clots in the metavolcanic rocks within a few tens of meters of the contact.

The presence of NOA in metamorphic rock is mentioned in several unpublished consulting reports related to construction projects in the Folsom area that are on file with the Sacramento Metropolitan Air Quality Management District. Most of these NOA occurrences, some of which were identified as actinolite asbestos, were in rocks mapped as Copper Hill volcanics by Loyd (1984) and by Wagner and others (1981). However, one set of occurrences was in rocks mapped as Gopher Hill volcanics by Loyd (1984) and by Wagner and others (1981).

AREAS OF RELATIVE LIKELIHOOD FOR THE PRESENCE OF NOA

The likelihood for the presence of NOA in an area is related to the geology (rock types, geologic structures, geologic processes, and geologic history) of the area. The CGS has previously used this relationship to define areas of relative likelihood for the presence of NOA in El Dorado and Placer counties (Churchill and others, 2000; Higgins and Clinkenbeard, 2006). In general, areas can be divided into four different categories of relative likelihood of encountering NOA based on geology. These categories are:

- 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. *Such areas are not known to be present in eastern Sacramento County.*

- AREAS MODERATELY LIKELY TO CONTAIN NOA: These areas include those metamorphic, igneous, and sedimentary 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 are zones of faulted or sheared rock that may locally increase the likelihood for the presence of NOA within or adjacent to areas moderately likely or most likely to contain NOA.

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 categories. Areas of faulting and shearing may have an increased likelihood for the presence of NOA beyond that of the surrounding areas.

MAP OF AREAS OF RELATIVE LIKELIHOOD FOR THE PRESENCE OF NOA IN EASTERN SACRAMENTO COUNTY

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

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

Note that the category of “Areas Most Likely to Contain NOA” discussed in the previous section is not included. Ultramafic rock and serpentinite, the rock types with which NOA is most commonly associated in California, are not currently known to be present in eastern Sacramento County.

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 eastern Sacramento County. Thus, based on current information, areas indicated by the map as “moderately likely to contain NOA” are expected to have more instances of NOA than areas indicated as “least 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 Moderately Likely to Contain NOA

These areas contain one or more of the following rock types: metamorphosed mafic volcanic rocks (mv); metamorphosed intrusive rocks (mi); and gabbroic (mafic intrusive) rocks (gb). These rock types, which are described below, have a higher likelihood for the presence of NOA than other rock types within eastern Sacramento County because of their chemical and/or physical characteristics. Occurrences of amphibole asbestos in these rock types have been reported in several consulting reports prepared for construction activities in eastern Sacramento County or are known to be present in similar rocks in nearby counties.

Gabbroic Rocks (gb) – The unit consists of a body of gabbro mapped near the south end of Folsom Lake. NOA may be present where such rock has been metamorphosed or deformed.

Metamorphosed Intrusive Rocks (mi) – The unit includes metamorphosed plutonic to shallow intrusive rocks of mafic to intermediate composition. They are distributed in the east-central part of the study area from just north of US Highway 50 to the vicinity of Deer Creek.

Metamorphosed Mafic Volcanic Rocks (mv) – The unit consists mainly of metamorphosed volcanic breccias and lesser amounts metamorphosed flow rocks. They are present as a northwest-trending belt along the eastern edge of the county. The unit may locally contain metamorphosed sedimentary rocks, such as slate, and metamorphosed intrusive rocks, but the locations of these rocks are not known in sufficient detail to map them separately. Compositions of the volcanic rocks are dominantly mafic, but felsic rocks are present locally. The degree of metamorphism of these rocks is generally greenschist facies, which indicates favorable temperature and pressure conditions for the formation of actinolite and tremolite. All of these rocks have been deformed.

Within these areas, NOA is most likely to occur 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. Such bodies have been mapped in similar rocks and geologic settings in adjacent counties and sometimes contain NOA. Although ultramafic rocks and serpentinite are not known to be present in eastern Sacramento County, based on research for this study, such rocks could be present in this geologic setting and may be discovered in the future. Another possible geologic setting for NOA is near contacts with igneous dikes. Both chrysotile asbestos and amphibole asbestos occur in such settings in other California counties.

Areas moderately likely to contain NOA are located in the easternmost part of the county along a northerly trending belt extending from Folsom Lake to the Cosumnes River area. These areas include parts of the communities of Folsom and Rancho Murieta. Outside of these communities, areas classified as moderately likely to contain NOA are currently sparsely populated.

Areas Least Likely to Contain NOA

These areas contain one or more of the following rock types: metamorphosed sedimentary rocks (ms); granitic rocks (gr); volcanic rocks (v); sedimentary rocks (s); unconsolidated alluvium (s); and tailings from gold dredging (t). These rock types, which are described below, have a lower relative likelihood for the presence of NOA than the other rock types in eastern Sacramento County because of their chemical and/or physical characteristics.

Granitic Rocks (gr) – The unit consists of plutonic igneous rocks of intermediate chemical composition (i.e., containing less iron and magnesium and more aluminum and silicon than mafic rocks). They occur at the northern end of eastern Sacramento County, adjacent to Folsom Lake. 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 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. NOA can form in contact metamorphic environments if the chemical and physical conditions are right, but such occurrences are not known at this time in Sacramento County.

Metamorphosed Sedimentary Rocks (ms) – The unit consists of metamorphosed sedimentary rocks that are dominantly slate with small amounts of metamorphosed sandstone and conglomerate. They are distributed in a northwest-trending belt along the eastern edge of the county. The unit may locally contain metamorphosed volcanic rocks, but the locations of these are not known in sufficient detail to map them separately. The degree of metamorphism of these rocks is generally greenschist facies, and all of these rocks have been deformed. Despite their metamorphism and deformation, their chemical composition makes them less favorable for the presence of NOA than that of the metamorphosed mafic volcanic rocks.

The metamorphosed sedimentary rocks in eastern Sacramento County are composed mainly of black sericite slate (Clark, 1964; Tierra Engineering Consultants, 1983). Compositionally, this slate is not as favorable as the metamorphosed mafic volcanic rocks and metamorphosed intrusive rocks for the presence of NOA. In some localities, the metasedimentary rocks are known to be hydrothermally altered, contain quartz veins, or are intruded by igneous dikes (Logan, 1925; Loyd, 1984). Also, these rocks may be locally faulted and sheared. Finally, there may be small lenses of metavolcanic rocks within the areas mapped as metasedimentary rocks. Any of these conditions may locally increase the potential for the presence of NOA. As a whole, however, these conditions do not appear to be common in the metasedimentary rocks in the area.

Sedimentary Rocks (s) – The unit consists of sedimentary rocks including claystone, siltstone, sandstone, and conglomerate, and their unconsolidated equivalents. These rocks are found mainly in the western two-thirds of the study area, but are also present in the easternmost part. These deposits are not metamorphosed, and they show little or no deformation. Because of their composition and lack of metamorphism, these deposits are generally less likely to contain NOA. Locally, they may contain isolated clasts of ultramafic rock or serpentinite, which could contain NOA.

Tailings from Gold Dredging (t) – The unit includes rock debris left behind during historic dredging for gold, mainly in sedimentary deposits associated with the American River and Cosumnes River and their tributaries. Dredge tailings are distributed largely in the west-central part of the study area, particularly south of US Highway 50. They typically consist of clay, silt, sand, and gravel derived from local sedimentary rocks as described above. Locally, they may contain isolated clasts of ultramafic rock or serpentinite, which could contain NOA.

Volcanic Rocks (v) – The unit includes volcanic rocks of intermediate to felsic composition as well as interbedded sedimentary rocks composed principally of these volcanic materials. These rocks are found mainly in the southern half of the study area. They are not metamorphosed, and they show little or no deformation. Because of their composition and lack of metamorphism, these deposits are generally less likely to contain NOA. Locally, the interbedded sediments may contain isolated clasts of ultramafic rock or serpentinite, which could contain NOA.

Review of published geologic documents and fieldwork for this study did not identify the presence of NOA in any of these rock types in eastern Sacramento County. One unpublished consulting report for a proposed construction project in the Folsom area indicated the presence of trace amounts of NOA in a few samples of rocks identified as metamorphosed sedimentary rocks; these rocks are associated with metamorphosed volcanic rocks, but the relationship between them is not fully understood at this time. The site of this project was mapped by Loyd (1984) as part of the Gopher Ridge volcanics and was thus assigned in the present NOA study to the “mv” geologic unit. Correspondingly, the location of the rocks in which the trace amounts of NOA were detected falls in an area on Plate 1 that is “moderately likely “ to contain NOA. The reported presence of trace amounts of NOA in a few samples of metamorphosed sedimentary rocks is not considered to be sufficient justification to include all of the metamorphosed sedimentary rocks in the study area into the category of moderately likely to contain NOA at this time.

Regarding the areas identified on Plate 1 as least likely to contain NOA, current geologic knowledge is not sufficient to completely rule out 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.

Areas least likely to contain NOA are present within the western two-thirds of the study area. They include parts of the communities of Folsom and Orangevale, and populated areas along the US Highway 50 corridor, all of which are in the northern part of the study area. To the south, with the exception of the community of Rancho Murieta, this portion of Sacramento County is rural with a low population density.

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 moderately likely to contain NOA. Eastern Sacramento County contains two mapped fault or shear zones, which are potentially favorable environments for the presence of NOA. 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 situated at or near the eastern edge of the county, one in the community of Folsom (termed the “Mormon Island Fault Zone”) and the other near the Cosumnes River. Both trend north-northwesterly and are within rocks mapped as metamorphosed mafic volcanic rocks (mv) associated with either the Copper Hill volcanics or Gopher Ridge volcanics.

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 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. Detailed information on the width of fault zones is largely unavailable for eastern Sacramento 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.

Although there are only a few areas of faulting and shearing identified in eastern Sacramento County in areas moderately likely to contain NOA, there is the possibility that additional areas of faulting and shearing will be discovered in the future. This possibility is based both on reconnaissance studies of lineaments identified on remote-sensing imagery and on the presence of fault and shear zones in similar rocks and geologic settings in adjacent counties. In eastern Sacramento County, many lineaments have been documented that are parallel or subparallel to the general north-northwest-trending structural grain of the foothills metamorphic belt (Tierra Engineering Consultants, 1983; Hodges, 1979). Although there can be many possible causes of these lineaments, some may be faults or shear zones, which may be favorable settings for the presence of NOA.

Research of documents did not identify naturally occurring asbestos in fault and shear zones in eastern Sacramento County. Fieldwork in these areas was hindered by development and poor exposure of these zones. Nonetheless, the absence of reported evidence does not mean that NOA is not present in such zones. For example, NOA is present in fault and shear zones in similar rocks in adjacent counties (Churchill and others, 2000; Higgins and Clinkenbeard, 2006). In the Bear Mountains Fault Zone just to the east in El Dorado County, NOA is associated with serpentinite in the fault zone (Tierra Engineering Consultants, 1983). At one location along the Mormon Island Fault Zone in El Dorado County, about 1-1/2 miles from the Sacramento County line, small seams of serpentinite were reported to be present within the fault zone (Tierra Engineering Consultants, 1983). NOA is most commonly associated with ultramafic rocks and serpentinite (see Appendix B).

Faults and shear zones may also occur within areas least likely to contain NOA. Based on the geologic mapping reviewed for this study, a few fault and shear zones have been reported in the granitic rock at Folsom Lake, but these are of very limited extent and are not shown on Plate 1. While such features may increase the likelihood for the presence of NOA beyond that of the surrounding area, in general, the overall likelihood for the presence of NOA is still low within areas least likely to contain NOA because the chemical compositions and physical conditions of many of the underlying rocks are not favorable for NOA formation.

LIMITATIONS AND USE OF THE MAP

Plate 1 indicates areas of relative likelihood for the presence of naturally occurring asbestos in eastern Sacramento County. It is based on a compilation of geologic information 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 NOA is more likely to be found in eastern Sacramento 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 1:62,500 (one inch = 1 mile). 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 contacts 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 contacts. Geologic contacts from maps of various scales, from 1:62,500 (one inch = 1 mile) to 1:12,000 (one inch = 1,000 feet) were used in the compilation of this map. Typically, the mapped contacts shown on the different geologic maps were located within 0 to 1,000 feet of each other. The greatest difference noted was 2,800 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 0.19 inches (about 3/16^{ths} 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. Another possible approach might be to create a specified buffer zone of some specified width (1,000 feet, for example) around the area. Including a buffer will increase the likelihood of identifying bodies of rocks that may contain NOA by addressing potential uncertainties in geologic-unit boundaries. Similar approaches could be used to address uncertainties regarding the areas of faulting and shearing.

Finally, continuing excavation activities in eastern Sacramento 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; Environmental Systems Research Institute, Inc., 1990; Ernst, 2000; Gradstein and others, 2004; Hyndman, 1972; Neuendorf and others, 2005; Press and Siever, 1982, 1994; Rice, 1957; and Sabins, 1997.

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.

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.

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

Cretaceous: Interval of geologic time from about 145 million years ago to 66 million years ago.

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

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: Geographic 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^oC).

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).

Lineament: A mappable linear or curvilinear feature on the ground whose parts align in a straight or slightly curved fashion. Such features can be natural or artificial, but in some cases may be the expression of a fault or other line of weakness.

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.)

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.”

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.

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.

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

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.

Schist: A strongly foliated crystalline rock, formed by dynamic metamorphism, which 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.

Sericite: A potassium-rich mica mineral that occurs as an alteration product of clay minerals or certain other silicate minerals. It is commonly a major component of fine-grained metamorphic rocks such as slate.

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.

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.

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 breccia: A volcanic rock composed of large angular fragments embedded in a matrix of smaller material.

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 eastern Sacramento County. The vintage of these documents ranges from the end of the Nineteenth Century to 2006. Scales of the maps range from small (1: 316,800, or one inch = 5 miles) to large (1:12,000, or one inch = 1,000 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.

Use of Remote-Sensing Imagery

Limited use was made of both aerial imagery (black and white, and color) and satellite imagery (Advanced Spaceborne Thermal Emission and Reflection Radiometer, or ASTER) for interpretation of selected geologic features in the county. Imagery was used both during fieldwork and in the office.

Fieldwork

Approximately 10 days of fieldwork were conducted during the project. Most of the fieldwork was carried out in the part of the county where basement rocks are present. 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 eastern Sacramento 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 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)

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: Hydrography was provided by the Sacramento Area Council of Governments Mapping Center and U.S. Geological Survey; Roads by the Sacramento Area Council of Governments Mapping Center; 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. GIS specialists at the CGS labeled map features such as roads, water bodies, and population centers.

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 Eastern Sacramento County

INTRODUCTION

The geology of eastern Sacramento County is somewhat complex, with parts of it still not completely understood by geologists. There remains some disagreement among geologists on origins, ages, and relationships of the metamorphic rocks along the eastern edge of the county. Also, according to Day and Bickford (2004), the main faults that cut metamorphic rocks in this region are complex, incompletely mapped, and still poorly understood. Finally, regarding the metamorphic rocks exposed in the Great Valley and adjacent Sierra Nevada, there has evolved both a complicated set of unit names for the rocks as well as significant differences in how they have been portrayed on geologic maps of the region.

Various regional interpretations of the geology of the region, which includes eastern Sacramento County, can be found in Behrman (1978), Clark (1964, 1976), Day (1992), Day and Bickford (2004), Dupras (1999), Edelman and Sharp (1989), Graymer (2005), Graymer and Jones (1994), Helley and Harwood (1985), Jones and others (1997), Loyd (1984), and Schweickert and others (1999). These papers also include extensive lists of references.

It was not possible to prepare a comprehensive geologic map of eastern Sacramento 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 CGS 1:250,000-scale geologic atlas sheet (Wagner and others, 1981) that covers eastern Sacramento County. The map is readily available to the public compared to other geologic maps and it presents a comprehensive view of the regional geology.

GEOLOGIC OVERVIEW

Eastern Sacramento 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 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 eastern Sacramento County, only rocks of the Western Metamorphic Belt are present, which geologists generally interpret to have formed in association with an island arc. Here, the belt is composed of the following geologic units:

Copper Hill volcanics (metamorphosed mafic volcanic rocks)

Gopher Ridge volcanics (metamorphosed mafic volcanic rocks)

Salt Spring slate (metamorphosed sedimentary rocks)

Unnamed intrusive rocks (metamorphosed intrusive rocks)

The plutonic rocks that intrude the Western Metamorphic Belt in eastern Sacramento County are part of the Rocklin and Penryn plutons, which are exposed along the southwestern edge of Folsom Lake. This plutonic complex has been radiometrically dated at about 130 million years old (Swanson, 1978; Wagner and others, 1981).

Overlying the basement complex in eastern Sacramento County are various sedimentary and volcanic rocks that range from Cretaceous to recent in age. The sedimentary rocks consist of both marine and non-marine deposits, while the volcanic rocks consist mainly of non-marine andesitic volcaniclastic deposits with lesser amounts of rhyolitic volcaniclastic deposits. The sediments and sedimentary rocks have been dredged locally for gold, a process that has left extensive tailings in places.

GEOLOGIC UNITS DEVELOPED FOR THE NOA MAP

The geologic units described in the previous section were reinterpreted and grouped into eight “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 study area (Figure 2), which became the basis for deriving the areas of relative likelihood for the presence of NOA in eastern Sacramento County.

Gabbroic Rocks (gb) – The unit consists of a body of rock mapped just south of Folsom Lake among rocks assigned by various geologists to the Copper Hill volcanics. Loyd (1984) mapped this body as ultramafic rock, whereas Kiersch and Treasher (1955) mapped it as gabbro. Most of the body is now concealed beneath a housing development, which hindered direct observation to help resolve this discrepancy. Rock exposed in a road cut at the north edge of this body as mapped by Loyd (1984) was interpreted during fieldwork to be a metamorphosed complex of volcanic and dike rocks similar to those of the Copper Hill volcanics. Also, a detailed aeromagnetic map (U.S. Geological Survey, 1986) that covers this area does not show any positive anomaly, which would likely be present if this body was composed of ultramafic rocks. Consequently, based on this evidence and the mapping by Kiersch and Treasher (1955), this body is shown as gabbro on Figure 2. Whether it has been partly or entirely metamorphosed is not known. The age of the body is Mesozoic.

Granitic Rocks (gr) – The unit consists of plutonic rocks that are intermediate in composition. Swanson (1970, 1978) mapped these rocks as part of the Rocklin and Penryn plutons, which are exposed on the west side of Folsom Lake in Sacramento and Placer counties. These rocks were emplaced during the Cretaceous about 130 million years ago, subsequent to the episodes of regional metamorphism that affected the older rocks in the eastern part of the county. Contact-metamorphic features are present locally at the boundary of this plutonic complex where it intrudes the older metamorphic rocks.

Metamorphosed Intrusive Rocks (mi) – The unit consists of several bodies of metamorphosed Mesozoic intrusive rocks interpreted to be mafic to intermediate in composition. The bodies have been variously interpreted as originally gabbro (Loyd, 1984), diabase (Lindgren, 1894), and diorite (Howard Day, 2006, written communication). They are all altered, with actinolite reported in at least one body (Howard Day, 2006, written communication). These rocks are present within the north-northwest-trending belt of metavolcanic and metasedimentary rocks along the eastern edge of the county. The degree of metamorphism is probably greenschist facies overall.

Metamorphosed Mafic Volcanic Rocks (mv) – The unit consists predominantly of metamorphosed volcanic, volcaniclastic, and dike rocks originally deposited mainly under marine conditions during the Mesozoic. Included within this unit are rocks that comprise the Copper Hill volcanics and Gopher Ridge volcanics. Most of the rocks are mafic to intermediate in composition, although felsic compositions are present locally. Pyroclastic (tuff and breccia) rocks are dominant, with minor amounts of flow rocks. Metasedimentary rocks, generally slate, may be present locally. The unit is present within the north-northwest-trending belt of metamorphic rocks along the east edge of the county. These rocks have been folded and faulted, and the degree of metamorphism is mainly greenschist facies.

Clark (1964) originally defined the Copper Hill volcanics and Gopher Ridge volcanics as separate geologic units within the Western Metamorphic Belt. He interpreted the Copper Hill to be younger, separated depositionally from the Gopher Ridge by a middle metasedimentary unit he termed the Salt Spring slate. Behrman (1978) later combined the Copper Hill and Gopher Ridge into a single “Volcanic Unit.” Recently, Springer and Day (2005) concluded that the Copper Hill is simply a repeated section of the Gopher Ridge based on the lithologic similarity of the units.

Metamorphosed Sedimentary Rocks (ms) – The unit consists mostly of deformed metamorphosed sedimentary rocks that were originally deposited under marine conditions during the Mesozoic. Included within this unit are rocks that comprise the Salt Spring slate. Rock types are dominantly sericite slate and argillite, with minor amounts of metagraywacke and conglomerate. Locally, metavolcanic rocks or igneous dike rocks may be present, but the locations of these are not known in sufficient detail to map them separately. The unit is present within the north-northwest-trending belt of metamorphic rocks along the east edge of the county. The degree of metamorphism is mainly greenschist facies.

Sedimentary Rocks (s) – The unit consists of a variety of marine and non-marine sedimentary rocks that range in age from Cretaceous to recent. It includes rocks that compose the Chico Formation, Ione Formation, Laguna Formation, Turlock Lake Formation, South Fork Gravels, Riverbank Formation, and Modesto Formation. It also includes undifferentiated deposits of unconsolidated alluvium and tailings from gold dredging. Typical deposits consist of claystone, siltstone, sandstone, and conglomerate, and their unconsolidated equivalents. These deposits are not known to be metamorphosed, and they show little or no deformation. The unit is distributed mostly in the western two-thirds of the study area, but is also present in the easternmost part.

Tailings from Gold Dredging (t) – The unit consists of debris left behind from dredging of gold-bearing Cenozoic sedimentary rocks (s) and unconsolidated alluvium (s) as described above. These materials are not metamorphosed nor are they deformed. They are distributed mainly in the Folsom area south of US Highway 50, but smaller areas are also found along the Cosumnes River.

Volcanic Rocks (v) – The unit consists of intermediate to felsic volcaniclastic rocks deposited mainly during the middle Cenozoic. Included in this unit are rocks that comprise the Mehrten and Valley Springs formations. They represent distal deposits of volcanic material originally erupted from volcanoes to the east. These rocks are not metamorphosed, and they are only slightly deformed. They are found mainly in the southern half of the study area.

MAJOR GEOLOGIC STRUCTURES IN THE COUNTY

The structural framework of eastern Sacramento County is composed of two regimes. A north-northwest-trending structural grain defined by steeply dipping foliation and folds dominates the metamorphic rocks of the basement complex. The overlying Cretaceous-Cenozoic sedimentary and volcanic rocks are either undeformed or only gently tilted to the southwest.

Only one major fault zone, the Mormon Island Fault Zone (Plate 1), is known to be present in eastern Sacramento County based on the geologic mapping reviewed for this study. This fault zone is described briefly below. Also, a northerly trending fault was mapped by Clark (1964) in metavolcanic rocks near the Cosumnes River (Plate 1). This fault may extend farther north and south than shown on Plate 1. Kiersch and Treasher (1955) also reported faults and shear zones in the basement complex at the site of the Folsom Dam project. Other fault and shear zones may be present within the basement complex, but these are not yet documented. Studies of remote-sensing imagery of eastern Sacramento County (Tierra Engineering Consultants, 1983; Hodges, 1979) indicated an abundance of lineaments. Although lineaments can have a variety of causes, many are aligned with the structural grain of the metamorphic belt, and some of these may represent faults or shear zones.

Mormon Island Fault Zone – This north-northwest-trending fault zone subparallels the county line southeast of Folsom Lake (Plate 1). The mapped trace of this zone extends for about two miles in Sacramento County before it crosses the county line into El Dorado County to the east near US Highway 50 (Tierra Engineering Consultants, 1983). Rocks cut by this fault zone have been mapped as Copper Hill volcanics. In places, the zone is reported to follow strongly foliated and sheared greenstone that lies between more massive rock to the east and west. Also, small seams of serpentinite oriented parallel to shears along the fault zone were reported to be present in a trench excavated across the zone in adjacent El Dorado County, about 1-1/2 miles from the Sacramento County line (Tierra Engineering Consultants, 1983). Although the width of the fault zone was not precisely estimated because of poor exposure, Tierra Engineering Consultants (1983) reported that the width probably ranges from 500 to 1,000 feet. Tierra Engineering Consultants (1983) also evaluated the zone for earthquake activity and concluded that it has not undergone displacement during the last 65,000 to 70,000 years at minimum, and probably has not been the locus of large displacements since the late Mesozoic.

Other Geologic Structures and Settings – The Rocklin and Penryn plutons are intruded into older metavolcanic and metasedimentary rocks in the vicinity of Folsom Lake. 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, amphiboles such as tremolite may form. Under the right circumstances, the tremolite may be asbestiform.

Swanson (1970, 1978) described contact-metamorphic effects at unspecified locations along the contact between the Rocklin-Penryn plutonic complex and the metamorphic rocks in the Folsom area. He observed hornfelsic textures at these locations in addition to assemblages of alteration minerals. Within a few tens of meters of the contact, the metavolcanic rocks in places contained small clots of minerals that included tremolite. Within a few meters of the contact, these rocks also contained anthophyllite. However, neither the tremolite nor anthophyllite were reported to be asbestiform.

Review of other technical documents did not indicate the presence of NOA associated with zones of contact metamorphism in the study area. Nevertheless, 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

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 accurately located onto modern base maps. The mapping style of the geologist can also affect map accuracy. Geologic mapping is an art as well as a science, and 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 number of geologic maps utilized in the compilation of the NOA map for eastern Sacramento 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 eastern Sacramento 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 areas of relative likelihood for the presence of NOA are within 1,000 feet of their true locations (0.19 inches on the map equals 1,000 feet on the ground).

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