NATURALLY OCCURRING HAZARDOUS MATERIALS

Final Report

SPR 686

RESEARCH

Oregon Department of Transportation

NATURALLY OCCURRING HAZARDOUS MATERIALS

Final Report

SPR 686

by

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for

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16. Abstract

The study of naturally occurring hazardous materials (NOHMs) was conceived as a proactive response to assure that the Oregon Department of Transportation (ODOT) maintenance and construction activities take the presence of NOHMs into account. The label of NOHM is given to certain elements, minerals, and materials of a varied geologic nature found in natural deposits or as contaminants that could have consequences on the well-being of those exposed to these earthy materials. Many elements, minerals (non-fuel and industrial minerals), and other rocks meet the NOHM criteria, particularly those that pose health hazards through their physical properties (e.g., size, shape, dissolutions traits). It is when such an occurrence is disturbed, crushed, or exposed to natural weathering and erosion, or to human activities that create dust that a potential risk may arise and possibly pose a human health or environmental concern.

Out of 42 possible NOHMs, ODOT's Technical Advisory Committee picked 16 for the project. Ten ODOT sites across Oregon were sampled for the presence (or absence) of any one of these NOHMs, from which 15 composited samples were collected. Of these, 4 samples were analyzed for multi-elements (35 analytes), 10 samples were examined for zeolite minerals with erionite being the mineral of interest, and 2 samples were examined for asbestos minerals. Five samples from four sites contained fibrous material in suspension. X-ray fluorescence diffraction (XRD) was unable to match the fibrous material with zeolite XRD pattern matching standards. However, Transmission Electron Microscopy (TEM) data of the fibrous material points to offretite's chemistry field, a zeolite species closely associated with erionite or possibly a Mg-poor erionite. The incongruity between the XRD and TEM results tends to confound analytical interpretation and the results are unfortunately inconclusive. At two ODOT sites, multi-element analysis by ICP-AEA with trace Hg by Cold Vapor/AAS revealed elevated levels of As and other analytes. Anthophyllite and chrysotile, both regulated asbestos minerals, were detected in two samples from the Chancellor quarry using NIOSH 9002 method (PLM/DS procedures).

A NOHM-GIS interpretative layer, called NGIL, is an important outcome of this project. It was developed to map where the 16 NOHMs picked for the project are likely to be encountered. To convey NOHM information to ODOT personnel, a relative NOHM hazard potential was assigned to geologic unit polygons held in the Oregon Digital Geologic Compilation. The relative NOHM hazard potential is expressed in qualitative terms of 'Most', 'Moderate', or 'Least' likely. To arrive at a hazard classification, various data rules were devised based on geological factors, expert knowledge, and databases either developed or enhanced for the project. NGIL is also linked to a database of the characteristics, hazards, analytical methods, and precautions that are associated with each NOHM.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
VOLUME				
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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1.0   INTRODUCTION

Naturally occurring hazardous materials (NOHMs) are found throughout Oregon and may be overlooked while doing environmental assessments and geologic investigations for specific projects. Asbestiform minerals are an example of a material of concern to the Oregon Department of Transportation (ODOT) as a public agency as well as to contractors, construction workers and the traveling public. Many other materials such as silica, mercury, arsenic, and pyrite may pose a concern. This report presents the results of an investigation into what naturally occurring materials should be of greatest concern to ODOT, where they are likely to occur in Oregon, and how to detect and deal with them.

1.1   PROBLEM STATEMENT

The label of naturally occurring hazardous material (NOHM) is given to certain elements, minerals, and materials of a varied geologic nature, e.g., coal, acid mine drainage, etc., found in natural deposits or as contaminants that could have consequences on the well-being of those exposed to these earthy materials. When an occurrence is disturbed, crushed, or exposed to natural weathering and erosion, or to human activities that create dust, a potential risk may arise and possibly pose a human health or environmental concern. A fundamental goal of this project is to provide a foundation for recognizing natural sources that are or could become human health hazards.

Oregon Department of Transportation (ODOT) excavation activities can avoid the disturbance and distribution of NOHMs. A NOHM analysis of a site can show conditions that might indicate the potential existence of NOHMs. Proper investigation and testing can then be applied to confirm or refute the actual existence of the NOHMs. This information can then be used to guide a variety of hazard mitigation or avoidance steps.

Recently, the North Dakota Department of Transportation has restricted the use of road construction aggregate containing erionite, a zeolite mineral (*Gendreau 2007*). Erionite is considered carcinogenetic and, in fact, the type locality for this mineral is near Durkee, Oregon. Erionite is just one NOHM in Oregon; there are many others, including asbestos. ODOT's biggest rock pit in southwestern Oregon is in serpentinized peridotite/dunite—a source of asbestos minerals.

Many elements, minerals (non-fuel and industrial minerals), and other rocks meet the NOHM criteria, particularly those that pose health hazards through their physical properties (e.g., size, shape, dissolution traits). While low levels of NOHMs (known as "background") seem to be of little consequence, when NOHMs have been concentrated or exposed to the accessible environment, the exposure may cause or pose a substantial present or potential hazard.

In response, ODOT has raised several questions regarding NOHMs. First, what are the NOHMs in Oregon that could pose environmental and health concerns related to ODOT's geologic

investigations and environmental assessment of projects, and potential pollution liability and construction and maintenance activities? Second, where are NOHMs located in the state and what is their relationship to state highway right-of-way including material sources, staging areas, and disposal and stockpile sties?

1.2   PURPOSE

The study of Naturally Occurring Hazardous Minerals was conceived as a proactive response to the need to locate and assess the risk of NOHMs that may impact ODOT operations. The outcome of the project is to produce a logical and practical interpretative GIS (Geographic Information System) layer, the result of which addresses the research efforts undertaken herein.

1.3   OBJECTIVES

The research objectives of this study are three-fold, and summarized below:

Identification and knowledge—Develop a list of NOHMs in Oregon that may plausibly occur, and tailor and query existing mineral and geologic databases to determine where such occurrences may intersect ODOT operations; setting priorities based on hazard assessment.

Detection—Develop tools such as digital maps that inform ODOT personnel of NOHMs in the ground using results of Objective 1 as a screening tool and build awareness of environmental and health impact.

Control and management—Provide tools and information that can be used to develop and implement policies or best management practices for identified NOHMs determined in Objective 1 and located through Objective 2.

1.4 WORK SCOPE

Ten tasks were developed to accomplish the above research objectives and as such constitute the project's scope of work:

1. **List of NOHM Candidates:** Through reviewing published literature and conferring with subject matter experts, a comprehensive list of NOHMs to be considered for mapping in Oregon was compiled. This comprehensive list was reduced to a list of NOHMs for inclusion in the research project through consultation with the Technical Advisory Committee (TAC) for this research project.

2. **Methods for Detecting NOHMs:** For the list of candidate NOHMs, the attributes for indicating the possible presence of NOHMs in the various geologic units in Oregon were determined. Emphasis was placed on attributes available in existing databases. Methods for analyzing for, or otherwise detecting, the various NOHMs were also assembled.

3. **Data Collection and Integration:** Information about the NOHMs was used to develop a model to enhance and integrate existing DOGAMI databases into one

NOHM GIS layer. MILO (Mineral Information Layer for Oregon) which shows distribution of mineralized zones, aggregate sources, and industrial minerals; GILO (Geoanalytical Information Layer for Oregon) which gives elemental geochemistry of volcanic rock; GTILO (Geothermal Information Layer for Oregon) which shows distribution of hot springs, and by their nature, associated with elevated levels metals; and OGDC (Oregon Geologic Data Compilation) which shows spatial distribution of rock units that might be expected to be sources for NOHMs were the principal data sources.

4. **Process Data to Tag NOHMs:** The GIS model above was used to associate Oregon geologic units with the occurrence of the various NOHMs.

5. **Develop Sampling and Detecting Procedures:** Based on the information about the attributes of the NOHMs, procedures for sampling and analyzing geologic materials to confirm or refute the inferred occurrence of each of the various NOHMs were developed.

6. **Exercise Sampling and Detecting Procedures:** The sampling and detecting procedures were exercised at 10 sites across Oregon. The sites tested focused on locations that were likely to result in a positive detection. Both right-of-way and aggregate source sites were included. While the majority of sites tested were selected with the expectation of a positive detection, a small number of sites were tested with a negative expectation.

7. **Catalog of Oregon NOHMs:** Finalize a data table of NOHMs identified in Task 1 with accompanying hazards, sampling methods, detection protocols, and references. NOHMs studied further in the project and those which were set aside are clearly differentiated in this table.

8. **Compile NOHM Database Files:** A final data table of NOHMs studied in this project, along with their corresponding hazards, sampling methods, detection protocols, and references was compiled. This database includes a description of the attributes used to flag geologic units.

9. **Develop NOHM GIS Interpretive Layer:** The principal product of this project is a NOHM-GIS data layer that can be used to convey to ODOT personnel NOHM awareness.

10. **Write Final Report:** This report documents the entire project's methods and results. This report is supported by the following electronic databases:

- Mineral Information Layer for Oregon (MILO-Release 2).

- Geoanalytical Information Layer for Oregon (GILO-Release 2).

- Geothermal Information Layer for Oregon (GTILO-Release 2).

- NOHM GIS Interpretative Layer (NGIL).

- Soda Springs database.

- Catalog of Oregon NOHMs.

- Electronic files of the results of laboratory analysis and copies of photographs and figures.

For the convenience of the reader, the report is divided into chapters as follows:

- Chapter 1 describes the scope and purpose of the project.

- Chapter 2 describes the GIS data layers assembled in this report.

- Chapter 3 provides a narrative that describes the NOHMs that have been subsequently included in the project and their geologic setting and exposure scenario.

- Chapter 4 describes the methods for detecting NOHMs and the sampling and analytical procedures.

- Chapter 5 describes the results of the laboratory analyses.

- Chapter 6 describes the development of the NOHM GIS Interpretive Layer.

- Chapter 7 is conclusions and recommendations.

2.0   DATA COLLECTION AND INTEGRATION

2.1   PROJECT DATA

The GIS data layers assembled and/or modified in this report are listed below, and the contents of each are described in greater detail in the subsections that follow:

- The Mineral Information Layer for Oregon (MILO-Release 2)

- The Geoanalytical Information Layer for Oregon (GILO-Release 2)

- The Geothermal Information Layer for Oregon (GTILO-Release 2)

- Soda Springs database

- The Oregon Geologic Data Compilation (OGDC-Release 5).

These data sets allow the user to build up a technical overview of an area and to undertake a desk study for the NOHMs included in the project. A brief description of each data layer is provided below.

2.1.1 The Mineral Information Layer for Oregon – Release 2

The Mineral Information Layer for Oregon (MILO-Release 2) is a published statewide geospatial database that stores and manages information regarding Oregon's mineral occurrences, prospects, and mines (*Niewendorp and Geitgey 2010*). It supersedes Gray's (*1993)* Mineral Information Layer for Oregon by County (MILOC). MILO-Release 2 contains over 21,201 site records. These sites are linked to available commodity information, such as metals (elements, metallic, and oxides), industrial minerals (non-metallic minerals and materials including gemstones), mineral fuel (coal and oil shale), and construction aggregate (sand, gravel and stone).

Agencies that provided data for MILO-Release 2 include: Bureau of Land Management (BLM), U.S. Bureau of Mines (USBM), U.S. Forest Service (USFS), U.S. Geological Survey (*USGS 2005*), Oregon Department of Energy, Oregon Department of Forestry, Oregon Department of Land Conservation and Development, Oregon Department of State Lands, Oregon Department of Transportation-Highway Division, and Oregon Department of Water Resources. However, much of MILO's data set is compiled from the Oregon Department of Geology and Mineral Industries' unpublished and published mineral resource reports (*Brooks and Ramp 1968, DOGAMI 1969, 1951, 1943, 1942, 1941, 1940, 1939*), mine files, and maps. The accuracy of these varies according to the original source(s). Likewise the accuracy of the other sources varies or is entirely unknown.

2.1.2 The Geoanalytical Information Layer for Oregon – Release 2

The Geoanalytical Information Layer for Oregon (GILO-Release 2) is an unpublished statewide GIS layer that stores and manages Oregon's geochemical data. It supersedes GILO-Release 1 (*Ferns and McConnell 2005*). GILO-Release 2 is divided into two data sets: the GILOROCK and GILSED. The former holds rock geochemistry for whole rock major oxides and major, minor, and trace elements, while the latter contains stream-sediment geochemistry for major, minor, and trace elements. Combined the two data sets contain geochemical data for over 39,300 sites.

Geochemical information for Oregon was obtained online from the North American Volcanic and Intrusive Rock Database (NAVDAT), which is now a major component of the EarthChem Project (*EarthChem 2007*) and the U.S. Geological Survey (*USGS 2008, 2004*). The Oregon Department of Geology and Mineral Industries' geochemical data were compiled directly from its unpublished and published mineral resources information and existing databases, the accuracy of which varies according to the original source(s). Similar data were also compiled from a limited number of unpublished theses and dissertations. Their accuracy also varies or is entirely unknown.

2.1.3 Geothermal Information Layer for Oregon – Release 2

The Geothermal Information Layer for Oregon-Release 2 (GTILO-Release 2) is an unpublished statewide GIS layer that stores and manages Oregon's geothermal resource information. GTILO-Release 2 supersedes GTILO-Release 1 (*DOGAMI 2008*) and contains the following data sets:

- Hot and Warm Springs - 690 points related to springs that are produced by the emergence of geothermally heated groundwater.

- Low Temperature Wells - 4203 points representing various types of wells (domestic, irrigation, and others) within which there is geothermally heated groundwater.

- Geothermal Wells - 124 points represent geothermal wells, either drilled or proposed. This data set was developed to illustrate those areas tested for geothermal potential.

- Geothermal Prospect Wells - 1019 points representing geothermal prospect wells. This data set was developed to illustrate those areas prospected for geothermal resources.

The following data sources are recognized for their contribution to the GTILO-Release 2 GIS layer:

- Geo-Heat Center's Western States Geothermal Databases CD.

- Geothermal Areas Database of the U.S.

- Geothermal information from the U.S. Geological Survey.

- The Great Basin Center for Geothermal Research, University of Nevada, Reno.

- The University of Idaho, Department of Geological Sciences, Moscow, Idaho.

- The U.S. Geological Survey's Geographic Names Information System and National Hydrography data set.

- Unpublished geothermal records of the Oregon Department of Geology and Mineral Industries – Mine Land Reclamation and Regulation program.

2.1.4 Soda Spring Database

The Soda Spring database is an unpublished statewide GIS layer that contains points representing springs that emit soda water having a content of dissolved carbon dioxide, (CO_2). The layer contains 35 points representing soda springs from the Willamette Valley to the Snake River. All the springs represent a leakage of natural carbon dioxide; some springs emit free gas (*Wagner 1959*).

2.1.5 Oregon Geologic Data Compilation

In 2003, DOGAMI undertook a 6-year project to compile the surface geology of the entire state. It is now complete and brings together the best-available geologic mapping from state and federal agency sources, student thesis work, and consultants *(Ma et al. 2009)*. This statewide coverage is called the Oregon Geologic Data Compilation (OGDC-5) which is derived from 345 maps and includes 106,690 map polygons represent various geologic units.

Rather than infer or lose detail by redrawing contacts, the original polygons/units for each of the best available source geologic maps were put into a single layer. This process creates a spliced or "appended" map that contains all of the best geologic unit polygons. However, the "appended" map also clearly conveys obvious differences between areas of detailed versus reconnaissance mapping. It also produces a seamed coverage with "map faults", or seams, between areas of differing original geologic interpretations and/or source scale (ranging from 1:6,000-scale to 1:500:000-scale).

Edge matching among the units of the original source maps is addressed by the addition of merge unit labels. This separate geologic merge unit designation still carries along, unchanged, the original map linework and unit descriptions, along with "map faults" but allows the "appended" geologic unit polygons to be conveyed with a "logical seamlessness" throughout the state. The final digital product is a patchwork of many geologic maps instead of a single coverage.

3.0   NOHM ASSESSMENT

3.1   TERMINOLOGY

The problem of "hazard" and "risk" terminology has bedeviled discussions related to natural hazards. Even the definition of "natural hazards" widely varies. Because there have been different usages, it is important to distinguish between these terms as they are used in this report.

- **Hazard:** An inherent property of certain elements, minerals, and materials of a varied geologic nature that could pose environmental and health concerns. In context of this study, it would be related to ODOT's geologic investigations and environmental assessment of projects, and potential pollution liability.

- **Hazard Assessment:** A reasonable indication of the threat posed by the hazard for the area. In this study, it is a process of estimating, for defined areas, the permissiveness/favorability of the occurrence of a particular NOHM.

- **Hazard Characterization:** The qualitative and, wherever possible, quantitative description of the nature of the hazard associated with the aforementioned agents or situation, such as mechanisms of action involved, biological extrapolation, dose-response and dose-effect relationships, and their respective attendant uncertainties.

- **Hazard Mapping:** The process of establishing geographically where the NOHMs are likely to impact ODOT operations, including material sources, staging areas, and disposal and stockpile sites.

- **Risk:** The probability of adverse effects caused under specified circumstances, in this case, by the aforementioned agents for situations related to ODOT's geologic investigations and environmental assessment of projects, and potential pollution liability. This project makes no attempt at risk characterization or assessment, which is the process intended to calculate or estimate the risk for a given target system following exposure to the agents or situation. It is left to ODOT to implement risk management decision-making and actions (i.e., risk evaluation, emission and exposure control, and risk monitoring) for safety from the hazard.

- **Exposure Scenario:** Set of conditions or assumptions about sources, exposure pathways, and how an exposure may take place.

3.2   HAZARD IDENTIFICATION

Identifying the NOHMs of concern is the first stage of the hazard assessment. DOGAMI compiled a preliminary list of 42 materials. The TAC reviewed this list and the 16 NOHMs they picked and included in the project are listed below (Table 3.1).

Table 3.1: NOHMs included in the project divided into two TAC specified classes

CLASS A[*]	CLASS B[*]
Arsenic and its compounds	Cobalt and its compounds
Asbestiform asbestos	Chromium III and its compounds
Beryllium and its compounds	Copper and its compounds
Cadmium and its compounds	Lithium and its compounds
Chromium VI and its compounds	Selenium and its compounds
Erionite	Tin
Nickel and its compounds (including Ni laterites)	
Radionuclides	
Talc with asbestiform component	
Lead and its compounds	
Mineral fuels (including bitumen)	
Antimony and its compounds	
Mercury and compounds	

*The two NOHM classes are not intended as a formal classification. Since many elements (e.g., arsenic, selenium, mercury) occur in multitude of molecular forms that continually and, in some cases, repeatedly interconvert, it is inappropriate and inaccurate to attempt to use terms other than "arsenic, selenium, mercury" to designate their occurrence. When specific molecular forms are discussed, they will be named, otherwise it should be understood that the comprehensive presence of these numerous chemical forms are all-inclusively designated by the use of the element name

3.3   CARINOGENIC RISK

The above mentioned NOHMs are grouped into a modified carcinogenic risk categories using IARC's (International Agency for Research on Cancer) classification (*IARC 2011*):

- Group 1: carcinogenic to humans.

- Group 2A: probably carcinogenic to humans.

- Group 2B: possibly carcinogenic to humans.

- Group 3: not classifiable as to carcinogenicity in humans.

- Group 4: probably not carcinogenic to humans, includes certain other health outcomes.

Table 3.2 is a tabulation of the NOHM's carcinogenic risk. A carcinogen is defined as a material or agent considered capable of causing cancer or may increase the incidence of malignant neoplasms. Exposure to some NOHMs are not necessarily linked to a cancer hazard but have certain other undesirable health effects, such as toxicity (i.e., Group 4). For example, a particular NOHM could be simply an irritant in certain circumstances or have far worse effects, such as: mutagenic, reproductive (teratogenic), tumorgenic, acute toxicity, and other multiple dose toxicity.

Table 3.2: NOHM Carcinogenic risk

NATURALLY OCCURRING HAZARDOUS MINERAL	
GROUP 1 Carcinogens (is carcinogenic to humans)	**Effects**
Arsenic (inorganic) and its compounds (e.g., sulfides containing arsenical poisons as natural impurities)	Carcinogenic (lung, skin, tumor); also neurotoxic, teratogenic, suspected as reprotoxic (may cause harm to unborn child), also toxic to gastrointestinal tract or liver; toxic for the environment
Asbestiform asbestos	Carcinogenic (lung) by inhalation, also toxic to gastrointestinal tract
Beryllium and its compounds	Carcinogenic – lung, suspected as reprotoxic
Cadmium and its compounds	Carcinogenic – prostate; neurotoxic; reprotoxic
Chromium VI (Cr^{+6}) and compounds	Carcinogenic (lung); also toxic to gastrointestinal tract or liver; allergenic, persistent and toxic for the environment
Erionite (zeolite)	Carcinogenic – lung
Nickel and compounds	Nickel metal is carcinogenic (nose, lung); also neurotoxic, and suspected as reprotoxic; allergenic and skin sensitizer if prolonged dermal contact; toxic to gastrointestinal tract or liver
Radionuclides or NORM (Naturally Occurring Radioactive Materials)	Carcinogenic (lung), also neurotoxic (uranium), mutagenic
Talc (containing asbestiform fibers)	Carcinogenic
GROUP 2A Carcinogens (probably carcinogenic to humans)	**Effects**
Lead and its compounds (excluding aerially deposited lead)	Neurotoxic, teratogenic, probably carcinogenic, and reprotoxic; toxic to gastrointestinal tract or liver; bioaccumulative & toxic for the environment
GROUP 2B Carcinogens (possibly carcinogenic to humans)	**Effects**
Cobalt and its compounds	Toxic to gastrointestinal tract or liver; suspected as reprotoxic and teratogenic in chickens
GROUP 3 (is not classified as to its carcinogenicity to humans)	**Effects**
Antimony and its compounds	Neurotoxic, long term exposure may participate in the development of gastrointestinal and lung problems and heart disease; suspected as reprotoxic
Mercury and its compounds	Neurotoxic, teratogenic, suspected as reprotoxic; toxic to gastrointestinal tract or liver; bioaccumulative toxic for the environment
Chromium (III) and its compounds	Respiratory toxicant, the potential for Cr^{+3} to oxidize forming Cr^{+6} can be the function of the concentration of high valence manganese (Mn) oxides
MODIFIED GROUP 4 (probably not carcinogenic to humans, includes certain other health outcomes)	**Effects**
Mineral fuels – Coal, oil shale, uranium	Respiratory toxicant; suspected as reprotoxic; bitumen fumes may be considered a Group 2B Carcinogen (*IARC 2011*)
Copper and its compounds	A respiratory, ocular, and gastrointestinal irritant (may be toxic to gastrointestinal tract or liver); suspected as reprotoxic at high levels
Lithium and its compounds	Little is known concerning the long-term effects of lithium excess on health or disease of domestic animals or man; may be toxic to gastrointestinal tract or liver
Selenium and its Compounds	Neurotoxin, hazardous to toxic in case of ingestion, or inhalation; suspected as reprotoxic; slightly hazardous in case of skin contact (irritant)
Tin	Respiratory toxicant, high levels of tin can have a neurotoxic effect on humans; suspected as reprotoxic

The following sources provided health information on NOHM toxicity:

- ToxProfiles 2007, U.S. Department of Health and Human Services – Agency for Toxic Substances and Disease Registry (*ATSDR 2007*).

- Material Safety Data Sheet for certain minerals.

- The United States National Laboratory of Medicine's (National Institutes for Health) list of toxicants in their Haz-Map database (*Brown 2011*).

- The Scorecard, The Pollution Information Site (*Scorecard 2005*).

3.4 GEOLOGIC SETTING AND EXPOSURE SCENARIO

This section contains a discussion of the selected NOHMs' geologic setting and their likely exposure scenario or pathway. Depending on the NOHM, a narrative on its regulatory guidelines may also be included. This narrative may not reflect the most recent situation. For example, occupational exposure limits are continuously reviewed and modified. For most NOHMs, it is difficult to find state laws or regulations that address screening levels, or if a corresponding elemental guideline exists whether or not it applies to the NOHM.

Most significant in the context of this section is an understanding of the geologic processes or mineralizing events associated with the NOHMs. This introduction will help set the stage for each NOHMs' geologic setting.

The NOHMs were formed through a variety of geologic processes or mineralizing events, as listed and summarized in Table 3.3:

- Weathering, a process important in the formation of nickel laterites and erionite (physical and chemical decomposition of rocks at the earth's surface).

- Sedimentation, important in the formation of non-mineral fuels, e.g., coal and oil shale.

- Hydrothermal processes of alteration and/or mineralization, important in the formation of lode deposits of gold, silver, copper, lead, zinc, mercury, and uranium. The hydrothermal systems that form these deposits are commonly associated with hot-spring or volcanic/igneous activity and marked by areas of alteration (*White 1981*).

As illustrated in Figure 3.1, the majority of the known precious, metallic, and nonmetallic mineralization in Oregon occur in older, pre-Tertiary rocks that are exposed in the northeastern and southwestern corners of the state (*Ramp and Peterson 1979; Ramp 1973; Ramp 1972; Hotz 1971; Libbey 1967; Youngberg 1947; Shenon 1933a; 1933b; Diller and Kay 1924; Diller 1914; Swartley 1914; Winchell 1914; Stafford, 1904*). These older rocks also contain ultramafic rocks, which are rocks that host chromite deposits and nickel-bearing laterites.

Table 3.3: Geologic processes and mineralizing events

MINERALIZATION IN OREGON[*]	
Geologic processes and mineralizing events	**Type of deposits**
Modern-day erosion, sedimentation, and volcanic activity	Gold placer and evaporite deposits
Volcanic and hot-spring activity in Western Cascades and eastern Oregon as coastline shifts from central to western Oregon	1) Low-temperature (epithermal), gold, mercury, and uranium deposits in southeast and central Oregon. 2) Gold, silver, copper, lead, and zinc deposits in Western Cascades and central and southeastern Oregon. 3) Nickel and cobalt laterites in southwestern Oregon. 4) Iron and aluminum laterites and clay deposits in northeastern Oregon. 5) Bentonite, zeolite, diatomite, and fluorite deposits in eastern Oregon. 6) Natural gas and coal deposits in various parts of the state.
Emplacement of large granitoid intrusives following accretion of exotic oceanic and island-arc crustal fragments	1) Major gold and silver veins in northeastern and southwestern Oregon. 2) Copper, molybdenum, tungsten, and antimony deposits.
Formation of oceanic and island-arc crust	1) Copper, gold, silver, zinc, and cobalt volcanogenic deposits. 2) Chromite deposits in southwestern and northeastern Oregon.

[*](*Ferns and Huber 1984*)
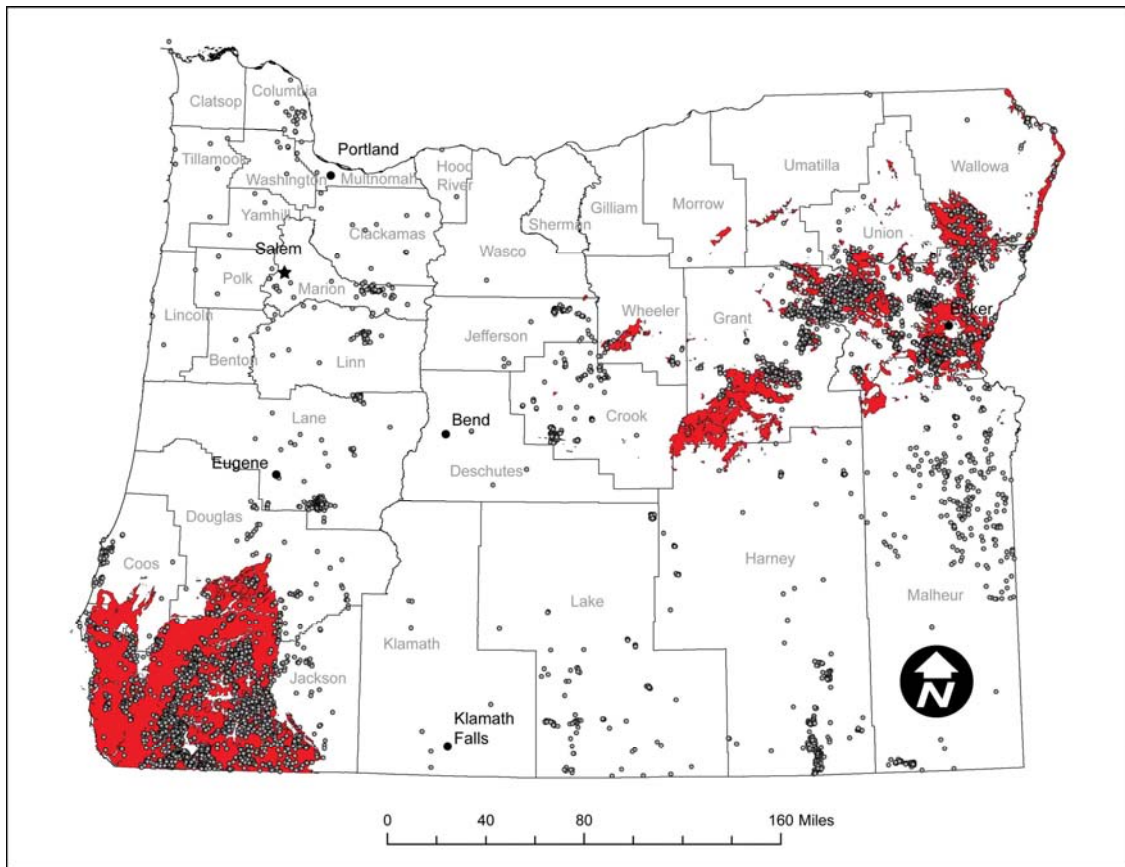
Figure 3.1: Metallic and nonmetallic mines, prospects, and occurrences (dark gray dots) shown in relation to older, pre-Tertiary rocks (red)

The importance of mineralization that occurred in Oregon's younger (Tertiary) rocks should not be minimized. This mineralization is epithermal (hot springs) mercury, uranium, and gold and base metal deposits in the Western Cascades (*Taber 1949; Callaghan and Buddington 1938*) and central (*Peck 1964; Libbey and Corcoran 1962*) and southeastern parts of the state.

When reading the NOHMs' geologic setting and exposure scenario, remember that minerals are rarely "pure" and commonly occur associated with a wide range of other minerals and trace elements. Generally, trace element and metal concentrations in areas characterized by mineral deposits are four or more orders of magnitude greater than average crustal abundance levels (*McKelvey 1960*). Lastly, it is fair to say that probably most, if not all, NOHM exposure pathways will be through ingestion and inhalation. Typically, the key management decisions at a NOHM site are how to interrupt or eliminate the ingestion and inhalation exposure pathways. Health-protective guidelines for some NOHMs may be as simple as controlling nuisance dust through material handling protocols. As always, health-protective guidelines and risk management issues should be evaluated beforehand, as appropriate.

3.4.1 Asbestiform Asbestos

The U.S. Department of Health and Human Services, Report on Carcinogens, Eleventh Edition (*NTP 2011*), states that "asbestos and all commercial forms of asbestos are known to be human carcinogens based on sufficient evidence of carcinogenicity in humans." Asbestos is the generic name given to a group of six fibrous silicate minerals found in natural deposits or as contaminants in other natural materials (Table 3.4). For this report, these minerals will be called NOA, the acronym for Naturally Occurring Asbestos. Note that because talc in Oregon generally contains asbestiform tremolite as a constituent (*Ferns and Ramp 1988*), it is also included in the NOA group.

Table 3.4: Regulated asbestiform asbestos minerals

Serpentine Group	Amphibole Group[*]
chrysotile asbestos (CAS No. 12001-29-5)	crocidolite asbestos (CAS No. 12001-28-4)
	amosite asbestos (CAS No. 12172-73-5[*])
	anthophyllite asbestos (CAS No. 77536-67-5[*])
	tremolite asbestos (CAS No. 77536-68-6[*])
	actinolite asbestos (CAS No. 77536-68-4[*])

[*]Asterisk following a Chemical Abstract Service (CAS) Registry Number indicates that the registration is for a substance which CAS does not treat in its regular CA index processing as a unique chemical entity; (asbestos, CAS No. 1332-21-4[*])

3.4.1.1 Geologic Setting

NOAs are present in at least eight of Oregon's 36 counties (*Ma et al. 2009, Van Gosen 2007, 2010*). There are 23 documented asbestos-bearing sites scattered throughout the pre-Tertiary terranes of the Blue Mountains and Klamath Mountains (Figure 3.2 and 3.3).
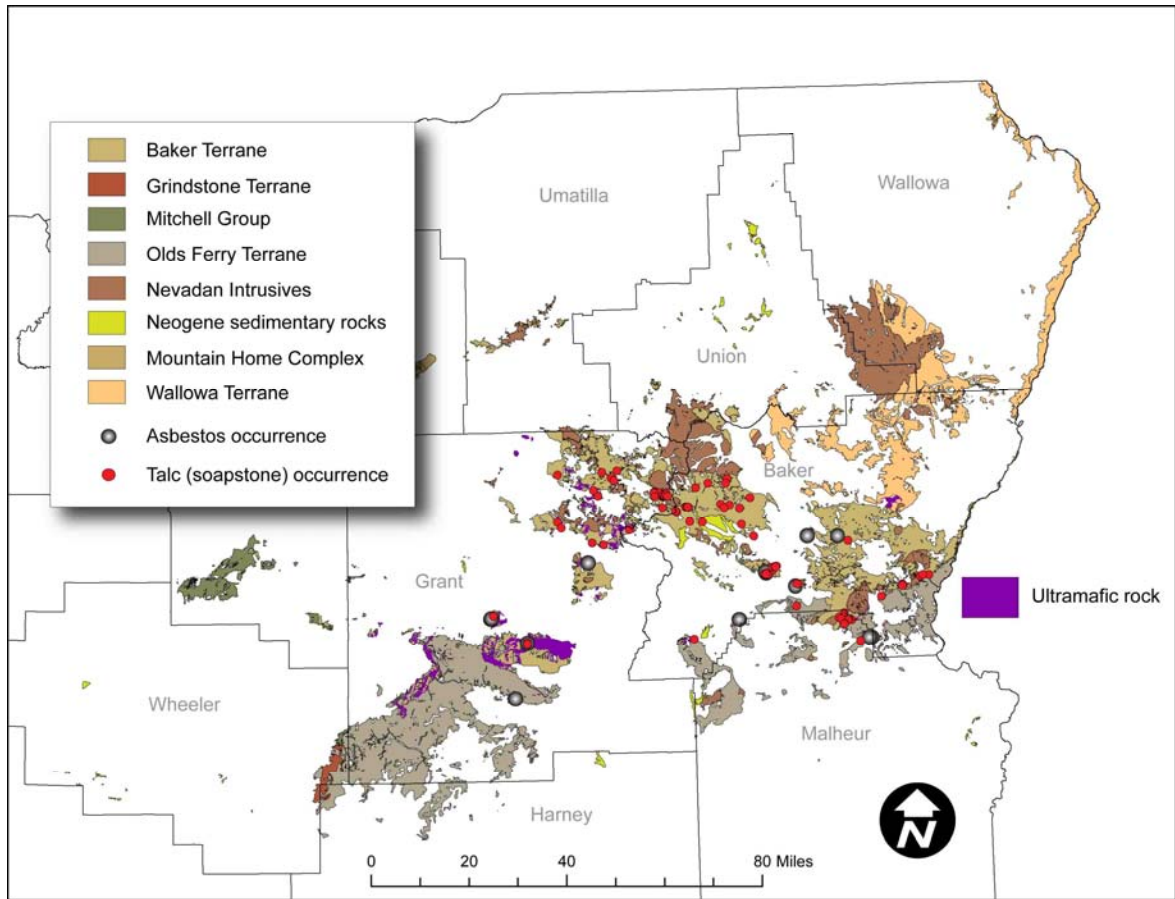
Figure 3.2: Map of the pre-Tertiary terranes of the Blue Mountains,
northeastern Oregon showing NOA locations

Of these deposits, Baker County has six deposits; followed by Grant County with four deposits while Malheur County has two deposits. In southwestern Oregon, Jackson County has seven deposits; followed by Josephine and Curry counties with two deposits each (Figure 3.3). A small amount of asbestos was shipped from Liberty Asbestos in Jackson County and the L.E.J. occurrence in Josephine County and 525 short tons of chyrsolite was milled at the Coast Asbestos Co. pilot plant near Mt. Vernon in Grant County (*Virta 2002; Bright and Ramp 1965; Wagner 1963*).
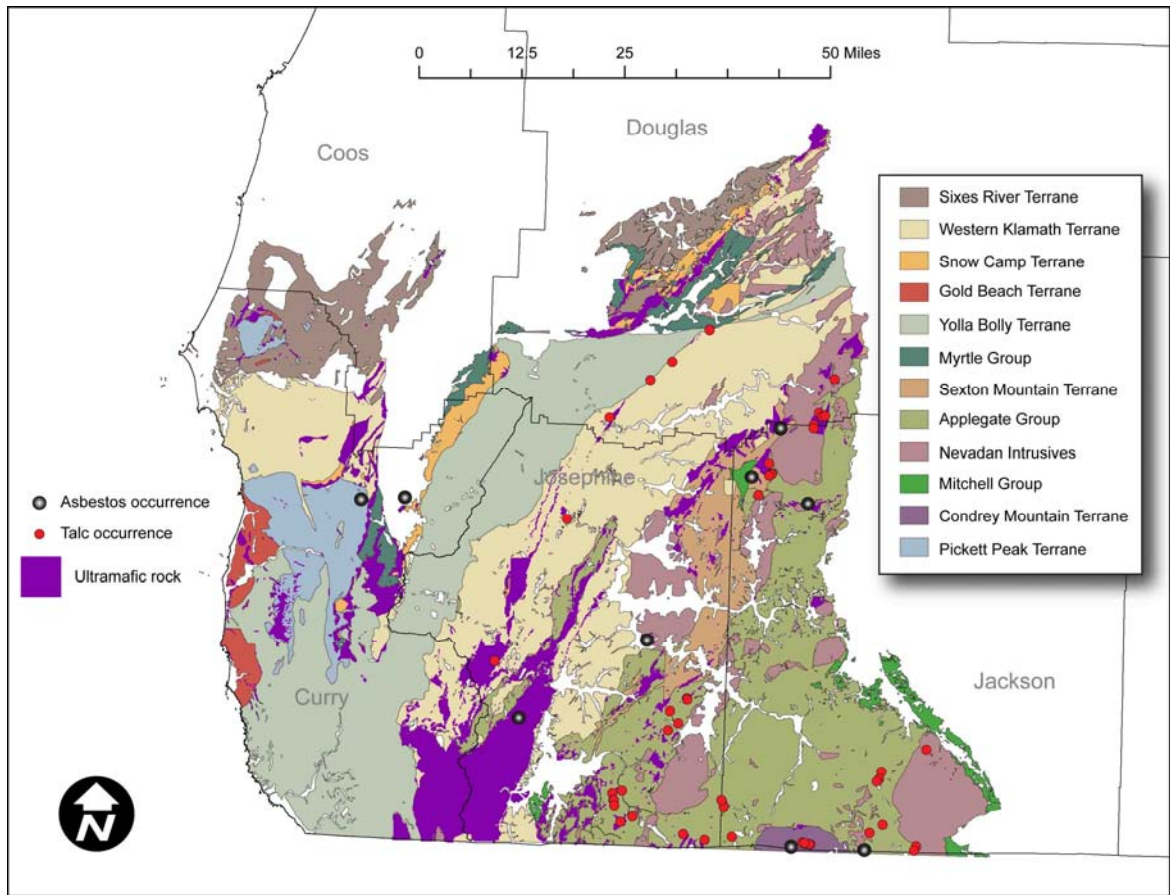
Figure 3.3: Map of the pre-Tertiary terranes of the Klamath Mountains, southwestern Oregon showing NOA locations

NOA is associated with ultramafic rocks which tend to be composed of ophiolitic complexes of gabbroic and dioritic rocks, and of pyroxenite, peridotite (harzburgite and enstatite) and dunite, serpentinized to various degrees with associated granite, rodingitic, and talc-carbonate rocks. The metamorphism of limestone/dolomite, mafic and ultramafic rocks, and alkali igneous rocks leads to serpentinization more than during metamorphism of other common rocks such as granite and sedimentary rocks. General deformation in the form of faulting, folding, or shearing evidently plays a major role in the localizing of the asbestos deposits.

Most of Oregon's asbestos is in the form of chyrsolite, tremolite fiber, and anthophyllite. The majority of chyrsolite-bearing deposits tend to occur in serpentinized peridotite rather than dunite host material. Asbestiform tremolite has an association with some schists in Oregon and it is also commonly associated with metamorphosed limestone. Other NOA minerals such as crocidolite have an association with blueschist and glaucophane, both rock types are found in the southwestern part of the state. The importance of nearby soils and alluvium derived from the source rocks containing NOA should not be overlooked. Depending on the concentrations of the source, the distance from the source, and other factors, the concentrations of NOAs found in this

unconsolidated material may easily exceed one percent in some cases. A case in point is the nickel-bearing laterites near Riddle, Oregon.

There are more than 100 separate talc occurrences in 18 talc areas in altered serpentinite (*Ferns and Ramp 1988*). Not surprisingly the talc occurrences are also found in the same eight Oregon counties mentioned earlier (see Figures 3.2 and 3.3).

3.4.1.2   Exposure Scenario

Clinkenbeard et al. (*2002*) state, "asbestos fibers in a geological setting are not inherently hazardous to humans if they are left undisturbed." However, Goldberg and Luce (*2005*) cite others who argue that environmental exposure to geological sources of asbestos may not be negligible and possibly be able to induce pleural mesothelioma. Complicating the matter is the relationship between the concentration of NOAs in a source material and the concentration of fibers in air that result when that source is disturbed. This relationship is very complex and dependent on a wide range of variables. To date, no method has been found that reliably predicts the NOA concentration in air given the NOA concentration of the source material.

With that said, there probably is no known safe level of NOA exposure. Even so the harmful effects of NOA depends on the asbestos mineral itself (not all asbestiform minerals pose the same degree of health risk) and exposure circumstance (how much), the duration (how long), and how you come in contact with it. It is also influenced by age, sex, diet, gender, lifestyle, and state of health. Asbestos-related disease, such as lung cancer, asbestosis, and mesothelioma, may not occur for decades after breathing asbestos fibers. Cigarette smoking significantly increases the risk of lung cancer from asbestos exposure. In an occupational exposure scenario, asbestos fibers may cause adverse health effects when mixed dust suspended in the air is inhaled. Particulate ingestion is possible and dermal adsorption is minimal.

Possible consequences of asbestos exposure are detailed in ToxProfiles (*ATSDR 2007*). General guidance on health and safety issues and practices for geologic field investigations in relation to asbestos are described in Yobbi et al. (*1996*), Lane and Fay (*1997*), and American Geological Institute (*1992*). Additional safety requirements can be found in U.S. Geological Survey Handbook 445-2-H (*USGS 2000*).

3.4.1.3   Regulatory Information

The regulation and management of indoor asbestos is straightforward; it is not the same for NOA exposure. State and local regulations exist for the transport of asbestos, demolition and renovation asbestos activities, and asbestos containing waste-disposal operations. However, state and local regulations do not address the monitoring of NOA disturbances or associated asbestos-bearing rocks and soil when it is disturbed, nor do they mention every variety of asbestiform amphibole. Federal regulations are lacking in the same way.

There are no regulations or airborne toxic control measures in the state right now that restrict the use of ultramafic rocks or serpentine rocks for surfacing applications, nor are grading and excavation activities in areas of serpentine or ultramafic rocks regulated or otherwise restricted. Where construction, grading, quarrying, and surface mining operations (cut and fill activities) use or disturb ultramafic rocks or serpentine rocks, the federal Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA) regulate workplace practices and set maximum asbestos exposure levels for these workers. MSHA has a requirement that miners cannot be exposed to more than two fibers per cubic centimeter of air for an 8-hour work shift. OSHA has a time-weighted permissible exposure limit and an excursion limit standard. The time-weighted average (averaged over an 8-hour period) permissible exposure limit is set at 0.1 fibers per cubic centimeter (f/cc). An excursion limit, averaged over a 30-minute period, is set at 1.0 f/cc. Both of these standards are called permissible exposure limits or PEL's. Table 3.5 presents a summary of Federal asbestos regulations.

Table 3.5: Asbestos Regulations

ABBREVIATION	NAME	DEFINITION
NESHAP	National Emissions Standards for Hazardous Air Pollutant	Asbestos was among the first hazardous air pollutants (HAP) regulated under Section 112 of the Clean Air Act (CAA), the asbestos National Emissions Standards for Hazardous Air Pollutant (NESHAP) in the Code of Federal Regulations (CFR) of 40 CFR Part 61. The USEPA has delegated NESHAP oversight authority to the Oregon Department of Environmental Quality (DEQ); Lane Regional Air Pollution Authority (LRAPA) also has regional air pollution authority. The state's asbestos regulation is Oregon Administrative Rule (OAR), Chapter 340, Division 248, Rule 0010 through 290 which generally follows NESHAP requirements.
TSCA	Toxic Substance Control Act	The USEPA used TSCA in 1989 to ban the use of asbestos in manufactured commercial products. Most of this ban was vacated by the United States 5th Circuit Court of Appeals in 1991 and the rule was remanded to the USEPA. The USEPA has not yet re-issued this rule.
OSHA	Occupational Safety and Health Administration (U.S. Department of Labor)	In NOA areas where ODOT personnel are working, they should be aware of the requirements for worker health and safety related to potential exposure to asbestos (*OSHA 1992, OSHA Labor 29 CFR § 17.1900-1910*).
MSHA	Mine Safety and Health Administration	Mine operators must ensure that asbestos-containing ore or rock is identified and measures are in place to protect mining personnel from overexposure to asbestos-containing dust.
NPDES	National Pollutant Discharge Elimination System	The National Pollutant Discharge Elimination System recognizes asbestos as a hazardous substance and quarries and surface mines are covered under the industrial section of the NPDES regulations.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	CERCLA section 104(a)(3) appears to be limited insofar as its authority to respond to certain releases of asbestos where it is a naturally occurring substance in its unaltered form. However, the USEPA (*1993*) still has the ability, if deemed necessary, to respond to the release or potential release of asbestos into the environment.

As for exposure to the abovementioned asbestos minerals that are non-asbestiform, i.e., particulates, and talc itself, some in the regulatory and health community believe that certain particulates should be regulated. However, no Federal or State regulatory agency treats elongated non-asbestiform mineral particulates as asbestos.

3.4.2 Talc with Asbestiform Component

3.4.2.1 Geologic Setting

Talc is a mineral but as a term "talc" has distinctly different connotations, an industrial usage and mineralogical connection. Pure talc is called steatite and bodies of more or less pure talc are referred to as talc schist. Soapstone is a rock name, not a mineral name. It is impure talc in lump form that is typically carved, machined, or used in decorative applications. Usage of the term talc in this report will refer to all forms.

Based on the tectonic history of the Tertiary terranes in southwestern Oregon and in northeast Oregon it is not surprising that they have numerous talc occurrences (see Figures 3.2 and 3.3). The state has more than 100 talc deposits in 18 talc areas (*Ferns and Ramp 1988*). These talc deposits are one of two types: 1) deposits associated with sedimentary rocks and 2) deposits associated with ultramafic igneous rocks. Talc is derived from specific parent rocks during metamorphic or metasomatic processes in response to regional high-grade metamorphic alteration. The sedimentary parent rock is generally a carbonate precursor, siliceous dolomite being the most common, but also limestone and magnesite. The best examples of a sedimentary type talc deposit in Oregon are the large talc-carbonate masses near Sumpter in Grant County. Talc deposits can also have their origin associated with altered serpentinite and related ultramafic rocks such as dunite, peridotite, and pyroxenite. Other siliceous rocks besides the above may be the precursor of talc, such as: argillite, phyllite, quartzite, and schist. A few talc occurrences are even reported to have a hydrothermal origin spatially connected with gold and silver lode and/or placer deposits.

Ferns and Ramp (*1988*) recognized that asbestos fibers are widely distributed in many of Oregon's talc deposits. Depending on the type of talc deposit, asbestiform amphiboles (e.g., tremolite) and metals such as arsenic and lead can be present; quartz, serpentine, chromium, and pyrite are not that uncommon. Crystalline silica can be a problem in the sedimentary type.

3.4.2.2 Exposure Scenario

Work that disturbs talc and creates dust conditions increases the risk of talc inhalation. The talc mineral itself—even talc free of asbestiform minerals—is being considered by the United States Department of Health and Human Services' National Toxicology Program for possible listing in its Report on Carcinogens. The United States National Laboratory of Medicine (National Institutes for Health) lists talc as a respiratory toxicant in its Haz-Map database (*Brown 2011*). Presently, talc powder is considered a nuisance dust at a threshold limit value (TLV) for an 8-hr exposure of 2 mg/m^3. Tremolite fiber is

the most common fibril in talc deposits and this fibril form is recognized as being a carcinogen.

3.4.3 Nickel and Its Compounds

3.4.3.1 *Geologic Setting*

Nickel (Ni) ores are of two general types: magmatic sulfide ores, which are mined underground, and lateritic hydrous nickel silicates or garnierites, which are surface mined. Apart from a small deposit of copper-nickel sulfides at the Shamrock mine in Jackson County (*Hundhausen 1952*), Oregon's known resources of nickel are almost entirely of the lateritic type (Figure 3.4). The lateritic hydrous nickel silicate ores are formed by the weathering of rocks rich in iron and magnesium in humid tropical areas. Fossil nickeliferous laterite deposits are found in Oregon (*Ramp 1978, Mason 1949, Pecora et al. 1949, Libbey et al. 1947, Pecora and Hobbs 1942, Dole et al. 1948*), where humid, tropical climates prevailed in the past. Laterite deposits of nickel in Oregon can contain nickel ore grading up to approximately 1.5 percent nickel, some of which contain a significant cobalt content (0.05 percent). Twenty nickel laterite deposits overlying ultramafic rocks are known in Curry and Josephine counties. At one time, the only production of nickel ore in the United States was from the Nickel Mountain mine; production ceased in 1986 (Figure 3.4).
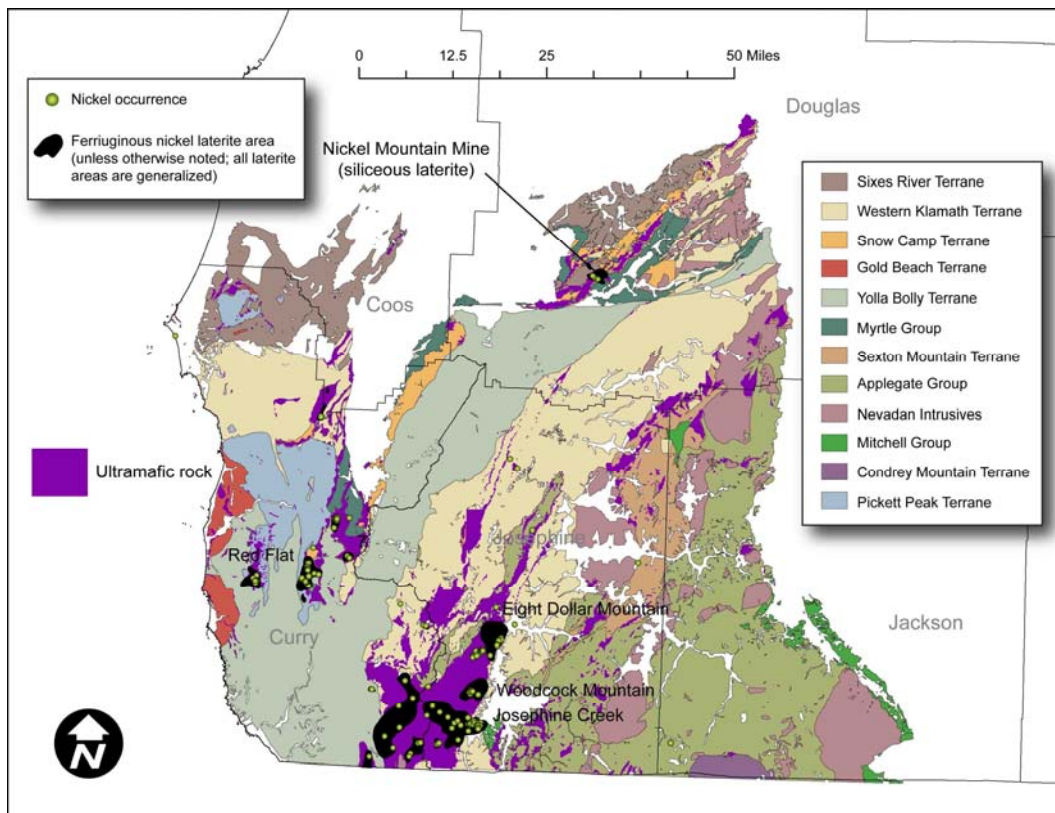
Figure 3.4: Nickel laterite deposit shown in relation to the pre-Tertiary rocks in southwestern Oregon. Laterite areas are black and correspond to ultramafic rocks (exaggerated for display purposes); nickel occurrences are green dots; principal laterite deposits are named

These deposits are a silicate Ni-type, dominated by hydrated Mg-Ni silicates (e.g., garnierite), generally occurring deep in the saprolite. Other metals associated with these deposits—some with economic value—are: chromium and ferruginous bauxite. The principal deposit, at Nickel Mountain near Riddle, Douglas County, is of the nickel silicate type (Figure 3.4). Shallow enrichment (<50 m, <150 ft) of nickel is developed over unaltered and altered serpentinized ultramafic lithologies, e.g., peridotite, dunite, and, to a lesser degree pyroxenite in various stages of weathering. Under acidic conditions, nickel is dissolved from olivine and deposited irregularly below the surface, either combined with iron hydroxide or as hydrous nickel silicates. It seems that nickel enrichment never develops over talc-carbonate lithologies. Generally speaking, higher percentages of nickel correspond to higher chromium content. Serpentine minerals can be a major constituent of nickel laterites with the probability of asbestiform asbestos being present.

3.4.3.2   *Exposure Scenario*

The western U.S. mean value for background soil concentration of nickel was reported as 15 ppm (*Shacklette and Beorngen 1984*). There is no known biochemical function for nickel in humans. The U.S. Department of Health and Human Services (DHSS), National Toxicology Program (*NTP 2011*) has determined that metallic nickel may reasonably be anticipated to be a carcinogen and that nickel compounds are known to be human carcinogens. The most common harmful health effect of nickel in humans is an allergic reaction, contact dermatitis, called Nickel itch. Once exposure ends, recovery occurs in about a week. Aside from the aforementioned problem, nickel toxicity appears quite low. Work that disturbs nickeliferous laterites and creates dust conditions increases the risk of nickel inhalation and ingestion.

3.4.4 Cobalt and Its Compounds

3.4.4.1   *Geologic Setting*

Cobalt (Co) is a hard, gray, magnetic metal closely related chemically to iron and nickel. The earth's crust averages 22 ppm cobalt (*Vhay 1969*). Ultramafic rocks average between 150 and 240 ppm cobalt; mafic rocks about 50 ppm; progressively lower in intermediate and felsic rocks; and granites are generally below 1 ppm. Worldwide, the vast majority of cobalt resources occur in nickel-bearing laterite deposits. The western U.S. mean value for background soil concentrations of cobalt was reported as 7.1 ppm (*Shacklette and Boerngen 1984*).

In Oregon, cobaltiferous deposits are associated with four geologic types: 1) segregated sulfides in ultramafic sills; 2) hydrothermal copper deposits in serpentine or at the contact; 3) nickeliferous laterites; and 4) hydrothermal veins with gold and copper, near quartz diorite intrusion (*Vhay 1969*). Below, in Table 3.6, is a list of Oregon's notable cobaltiferous deposits (*Ferns and Huber 1984*). Figures 3.5 and 3.6 that follow show the location of these deposits in the northeastern and southwestern part of the state, respectively.

Table 3.6: Cobaltiferous deposits

MINE	GEOLOGIC TYPES
1. Shamrock Mine	segregated sulfides in an ultramafic sills
2. Queen of Bronze	hydrothermal copper deposits in serpentine or at the contact
3. Lyttle Mine	hydrothermal copper deposits in serpentine or at the contact
4. Lilly Mine	hydrothermal copper deposits in serpentine or at the contact
5. Waldo Copper Mine	hydrothermal copper deposits in serpentine or at the contact
6. Cowboy Mine	hydrothermal copper deposits in serpentine or at the contact
7. Nickel Mountain (Hanna Nickel Mine)	nickeliferous laterites
8. Standard Mine	hydrothermal veins with gold, copper, and cobalt, near quartz diorite intrusion. The Standard mine was an important shipper of cobalt around the turn of the century
9. Copperpolis Property	hydrothermal veins with gold, copper, and cobalt, near quartz diorite intrusion
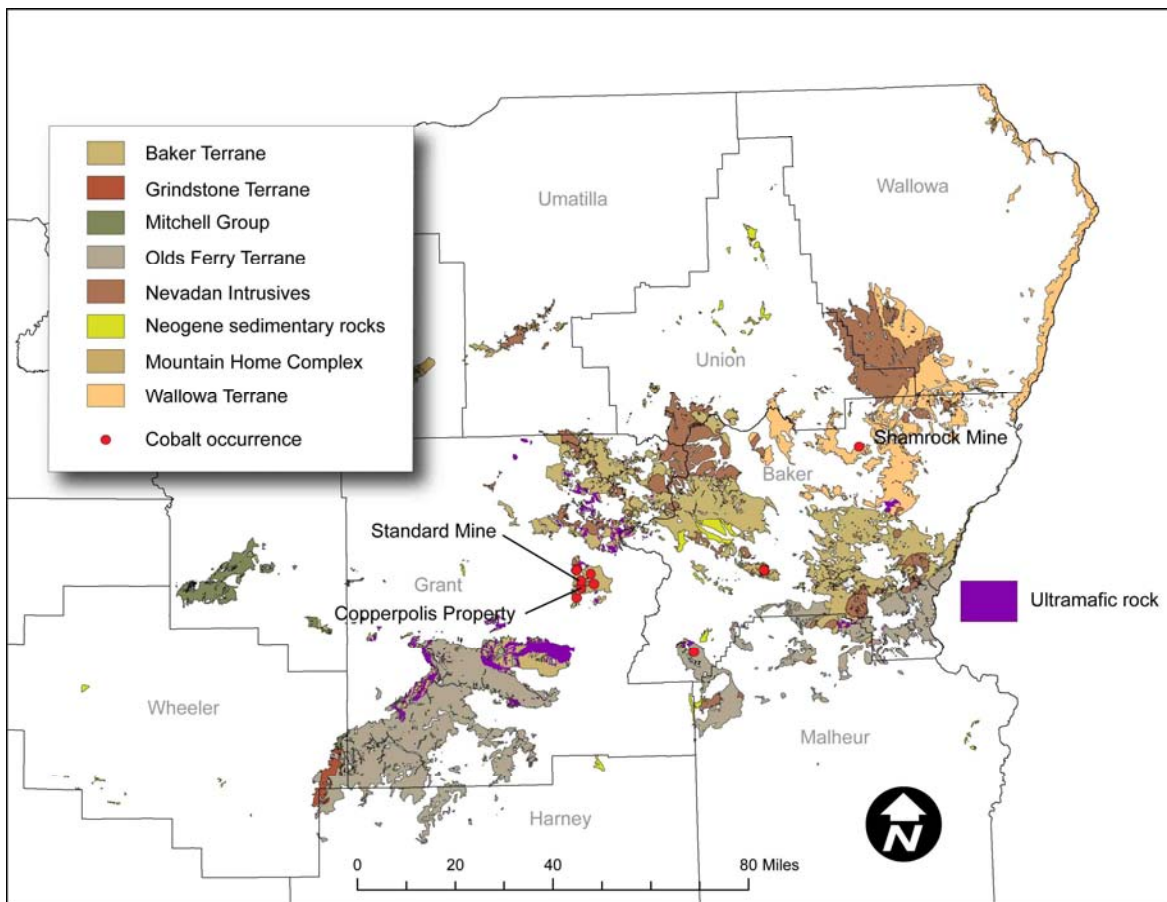
Figure 3.5: Cobalt-bearing deposits in northeastern Oregon
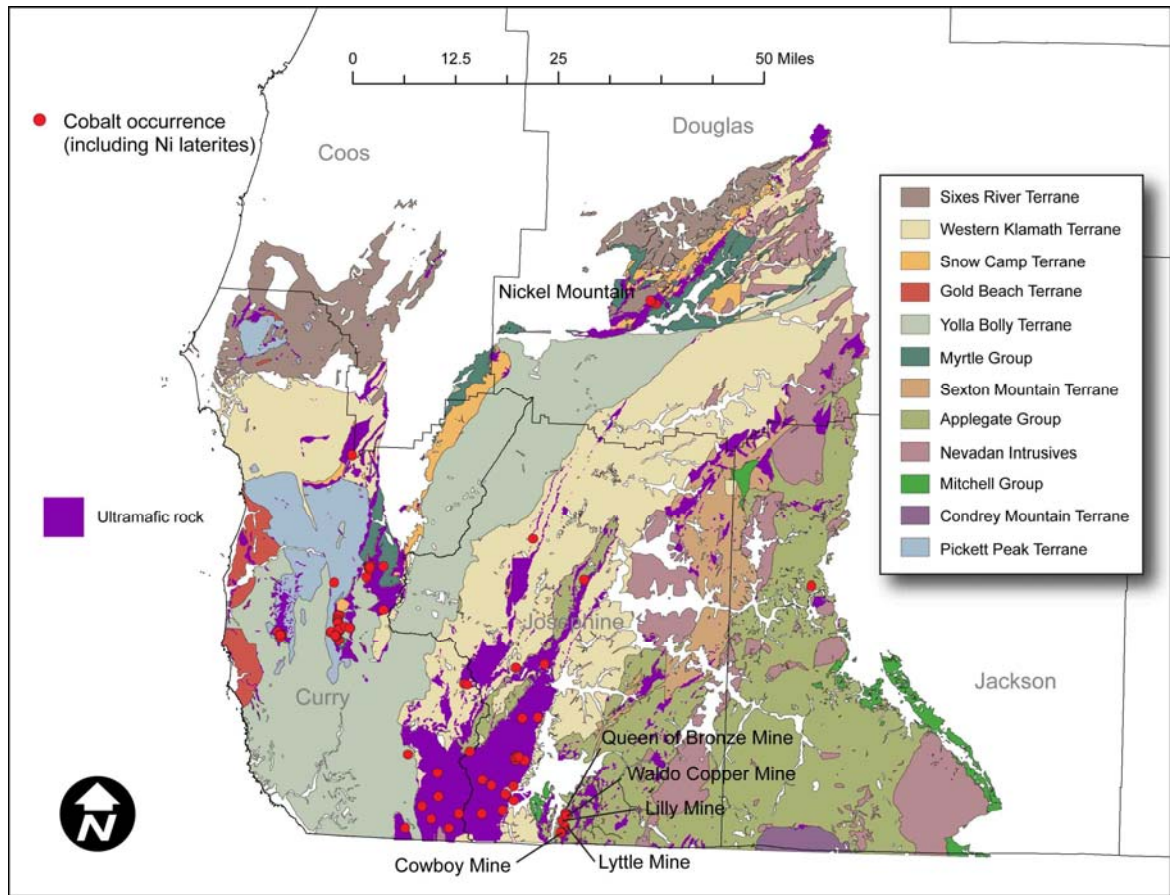
Figure 3.6: Cobalt-bearing deposits in southwestern Oregon

3.4.4.2   *Exposure Scenario*

Work that disturbs cobalt mineralization and creates dust conditions increases the risk of cobalt inhalation and ingestion. The IARC classifies cobalt sulfate and other soluble cobalt (II) salts as possibly carcinogenic to humans. As an industrial source, the carcinogenicity of cobalt metals with and without tungsten carbide has been classified as probably carcinogenic to humans (Group 2A) and possibly carcinogenic to humans (Group 2B), respectively (see Table 2.2). Cobalt is also classified as a neurotoxin. However, human carcinogenicity through environmental exposure of cobalt-bearing minerals found in the types of deposits mentioned above has not been evaluated specifically.

3.4.5 Chromium VI and Its Compounds

3.4.5.1   *Geological Setting*

In the earth's crust, chromium (Cr) is a rock-forming element found in a wide variety of oxide and silicate minerals. Under normal conditions, chromium is a metal. Chromite is the most important chromium-bearing mineral, which is the only ore of chromium. In Oregon, chromite occurs as either lode deposits or secondary deposits (*Hundausen 1947;*

Griggs 1945; Twenhofel 1943; Allen 1941; Hornor 1918). Lode chromite ore deposits are podiform deposits, whereas secondary chromite ore deposits comprise laterite and placer deposits.

Small podiform chromite deposits and occurrences are widespread in ultramafic rocks of the Klamath Mountains of southwest Oregon (Figure 3.7). The podiform deposits are usually separate, discrete, and appear as pods, lenses, and other irregular shapes, e.g., kidneys. Ramp (*1961*) described more than 250 occurrences in southwestern Oregon.
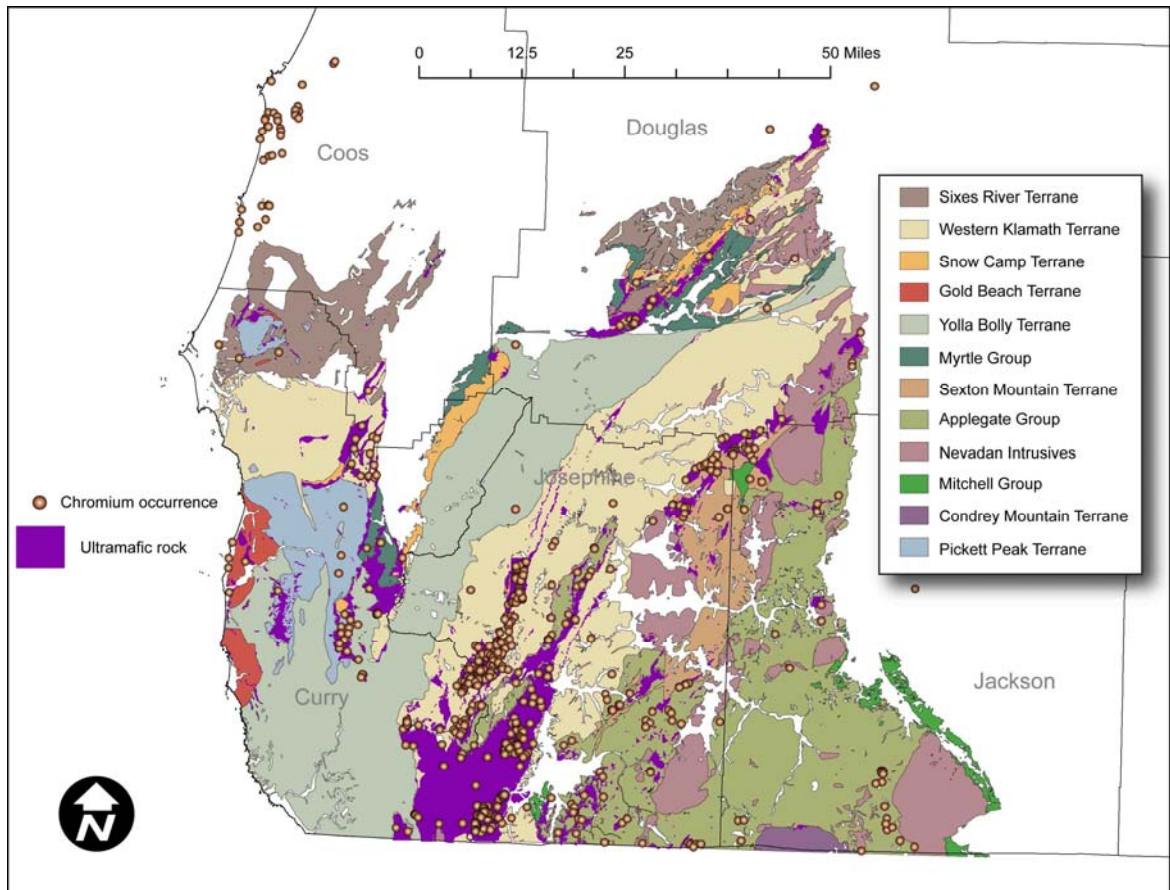
Figure 3.7: Chromium occurrences (podiform and chromiferous sand) in southwestern Oregon

The principal mines are situated in the central Illinois River area in Josephine County. At least 200 chromite mines and prospects are in northeastern Oregon (*Thayer and Ramp 1969, Ramp 1961*), most of which are located in Grant County (Figure 3.8). The Grant County chromite lode deposits are concentrated in two areas: the Canyon Mountains ultramafic complex, south and southeast of John Day, and in the Fields Creek-Deer Creek belt 20 miles to the east (*Hundhausen et al. 1956, Moore 1937*). The deposits in the Canyon Mountains ultramafic complex are localized along a 4 mile wide, 13 mile long zone of ultramafic rocks that crop out along the north slope of the Strawberry Mountains.

Concentrations of chromiferous sands (called black sands) are found along Oregon's beaches. Most of these deposits are on the lower-most Pleistocene marine terraces (<400

ft. above sea level) between Cape Arago and the town of Port Orford and in the South Slough region. Chromite was recovered as a secondary ore from the ferruginous nickel laterite at Riddle (Nickel Mountain), Oregon.
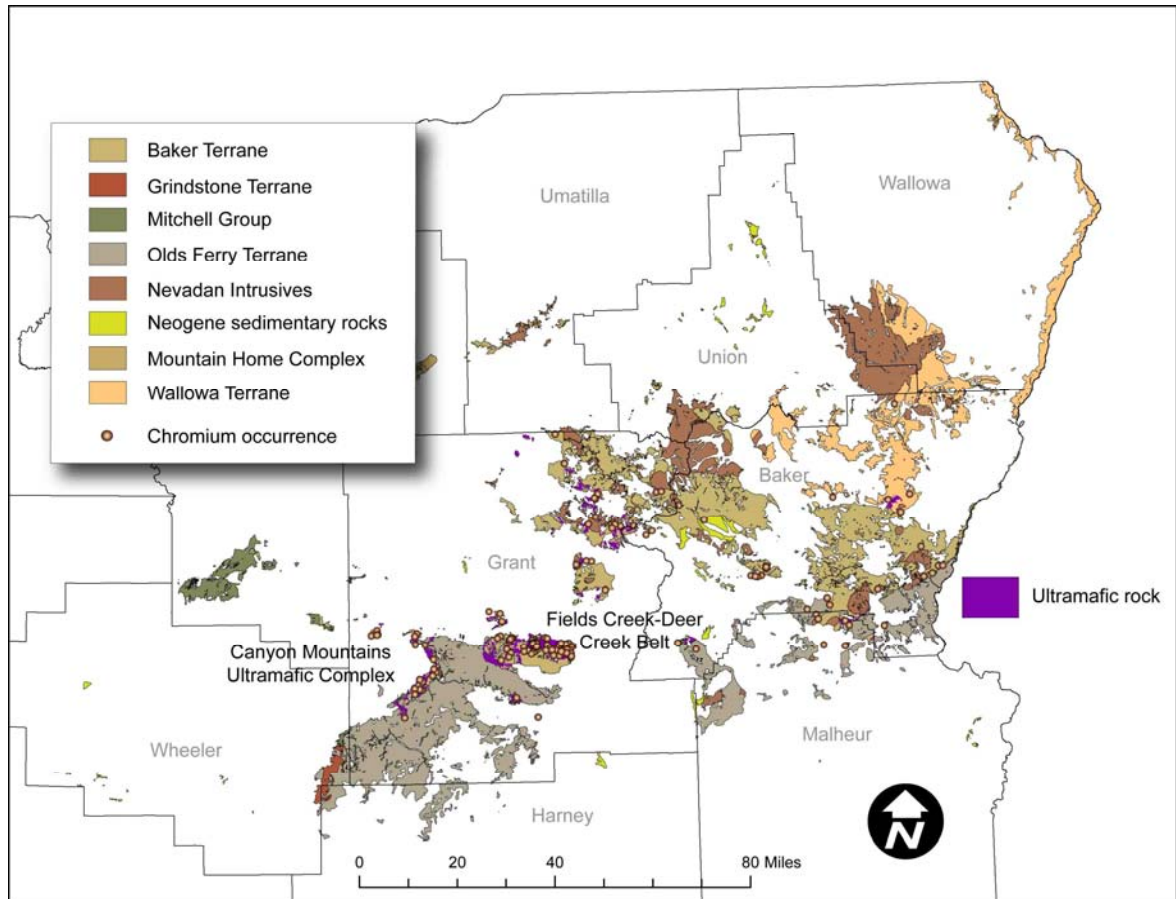
Figure 3.8: Chromium occurrences (podiform deposits) in northeastern Oregon

3.4.5.2   *Exposure Scenario*

The western U.S. mean value for background soil concentration of chromium was reported as 41 ppm (*Shacklette and Beorngen 1984*). According to IARC, chromium VI is a Group I human carcinogen (lung); toxic to gastrointestinal tract or liver; allergenic; and persistent and toxic for the environment. It is a "weakly" absorbing anion and consequently is chemically mobile. The potential for Cr^{+3} to oxidize forming Cr^{+6} is a function of the concentration of high valence manganese (Mn) oxides, the oxidation-reduction environment (elevated pH and Eh and increased dissolved O_2(aq), and microbial oxidation (*Oze 2003*). Manganese (Mn) can be leached from olivine, pyroxene and their metamorphic products. It then precipitates as Mn oxides. In this way Mn is available but commonly limited to certain horizons, depth, and macroscopic habit. The affects of wild fires on serpentines and ultramafic rocks may also elevate the potential for oxidation of Cr. Recent research suggest that chromites may contain outer zones which are chemically less stable than the inner zone, and under favorable conditions of lateritic weathering, the outer zones may be more susceptible to chemical breakdown whereby

25

chromium is released. The geochemical distribution of chromium in laterites is very much dependent on the degree of lateritization. Work that disturbs chromite-bearing lateritic deposits and ultramafic rocks and creates dust conditions increases the risk of chromium inhalation and ingestion.

3.4.6 Chromium III and Its Compounds

3.4.6.1   Geologic Setting

Chromium is a trace element in most natural environments where it occurs as Cr^{+3}, a non-hazardous species (*Oze 2003*). It is immobile. However, as mentioned above, Cr^{+3} can be oxidized to Cr^{+6}.

3.4.7 Erionite

Erionite is a fibrous zeolite mineral. A zeolite is a class of hydrated aluminosilicates with alkali and alkaline earth cations similar to the feldspars. There are over 50 naturally occurring zeolite species. Each species has a distinctive three-dimensional network of silicon or aluminum tetrahedra, some of which give rise to characteristics that are of practical use. The most unusual physical properties of zeolites are the ability to continuously give off water on heating with relative ease of rehydration. It is their internal structure's ability—a chemical property—to selectively adsorb molecules according to their size and/or shape that has led to a variety of commercial applications, e.g., ion-exchange, molecular sieves, and catalytic processes. As an example, erionite was once used as a noble metal-impregnated catalyst in a hydrocarbon-cracking process. Erionite was a promising additive for increasing soil fertility and has been studied as a means to control odors in livestock production. In eastern Oregon near the Hamlet of Rome, reports make reference to erionite-rich blocks (i.e., dimension stone) being used locally as house building materials.

3.4.7.1   Geologic Setting

Erionite, first described by A.S. Eakle in 1898, was found in cavities associated with an opal prospect along Swayze Creek near Durkee, Baker County, Oregon. Erionite is the Greek word for wool, alluding to its "woolly" crystalline form (habit). Its "woolly" habit is the result of ribbons and bunches that ravel and fray into aggregate bundles (Figure 3.9). When weather frees fibrous masses from its source they look like clots and mats of felt-like plates (*Gude and Sheppard 1981*).

In Oregon, zeolites are found mostly in volcanic and sedimentary-type deposits. Also, zeolite species, including erionite, have been found in active geothermal areas and their fossil equivalents, and as a metamorphic mineral of the zeolite facies. It is in volcanic rocks that a wide variety of zeolites, as many as 23, have been identified including erionite. It is in this setting that natural zeolites can occur as attractive crystals lining vugs, cavities, and vesicles. The literature reports many such occurrences in the Cascade Range, Coastal Range, and Newberry Crater (*Bargar and Oscarson 1997; Bargar 1994; Bargar and Keith 1993; Keith and Staples 1985; Clark 1964*). Zeolite quantities in basalt, for example, can sometimes reach 5 to 10 percent by rock volume.

Figure 3.9: Erionite's "woolly" crystalline habit, specimen collected from type locality at Swayze Creek near Durkee, Baker County, Oregon.Scale at bottom of image is an inch with a rule at one cm. Downloaded from http://www.mindat.org/photo-304278.html

Sedimentary-type zeolite deposits form by diagenetic alteration of volcanic ash deposited within "closed" and/or "open" hydrologic systems (*Mumpton 1977; Mumpton 1973; Sheppard 1994; Sheppard and Mumpton 1981; Sand and Mumpton 1978; Surdam and Sheppard 1978*). The occurrences of sedimentary-type zeolite deposits in Oregon are listed in Table 3.7. Figure 3.10 shows the general distribution of volcanic ash and related tuffaceous sediments in relation to the known sedimentary-type zeolite deposits. This Figure also shows notable volcanic zeolite occurrences.
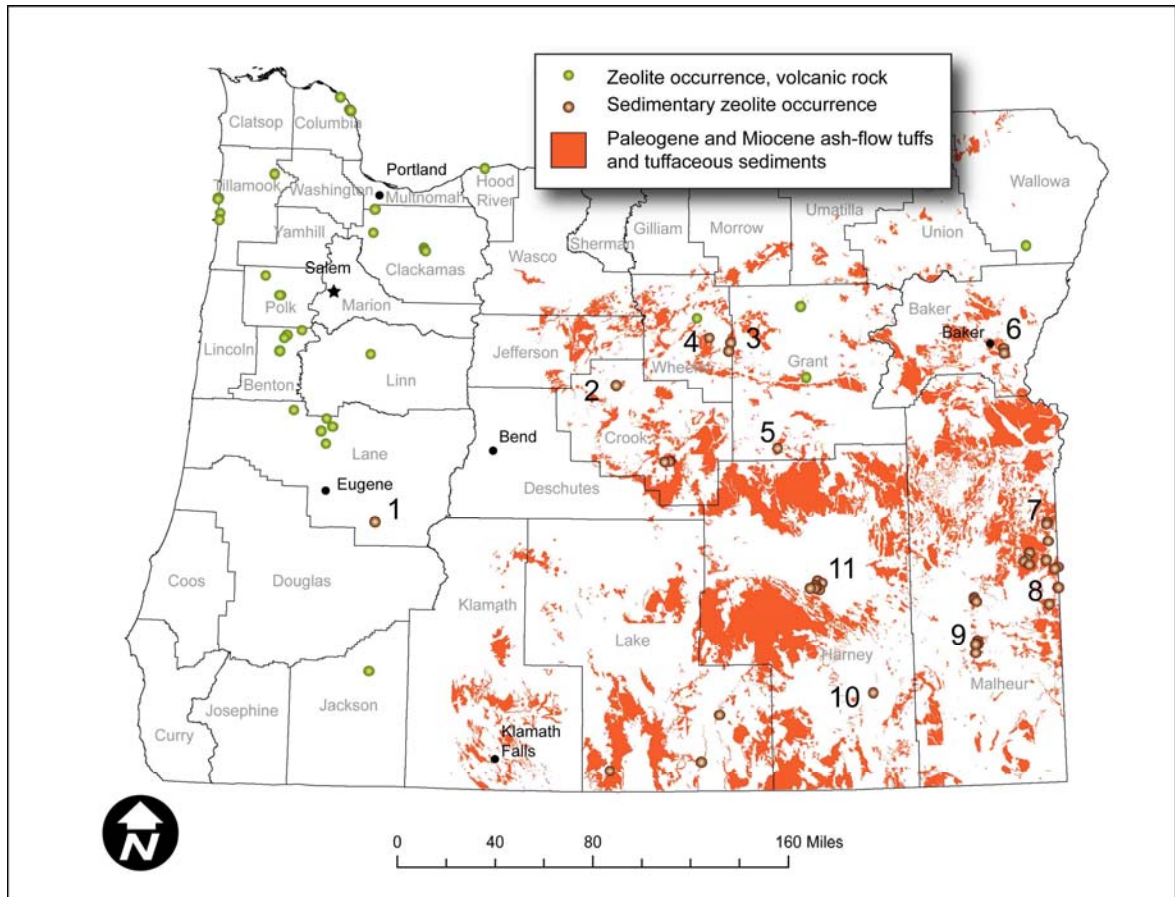
Figure 3.10: Map of Oregon showing the locations of sedimentary zeolite deposits (brown dots); zeolite deposits associated with volcanic, primarily basaltic rocks (green dots); and the general distribution of Paleogene and Miocene volcanic ash and related tuffaceous sediments (orange). Zeolite potential in the orange areas and by inference erionite potential is unknown. Refer to Table 3.7 for number index.

Six zeolite species, e.g., analcime, chabazite, clinoptilolite, erionite, mordenite, and phillipsite are grouped into this so called "authigenic" sedimentary-type. As a rule of thumb, clinoptilolite is generally the most prominent zeolite species. In central and eastern Oregon, four sedimentary-type zeolite deposits contain ore-zones: Durkee Zeolite Deposit, Rome Erionite Deposit, Harney Lake Deposit, and the Sheaville Zeolite Deposit. The locations of these deposits are shown in Figure 3.11 (*Brown 1962; Fisher 1963; Fisher 1962; Hay and Sheppard 1981; Lund 1966; Gude and Sheppard 1993; Gude and Sheppard 1986; Gude and Sheppard 1981; Gude and Sheppard 1978; Sheppard 1976; Sheppard 1991; Sheppard 1996; Sheppard and Gude 1993 Sheppard and Gude 1983; Sheppard and Sheppard 1993; Wagner 1966; Mason 1951*). Currently, Teague Mineral Products, Adrain, Oregon, is actively mining clinoptilolite from the Oregon portion of its Sheaville Zeolite Deposit. Note that the Durkee, Harney Basin, and Rome deposits contain significant erionite. Erionite's presence in the materials precludes these deposits from future commercial and consumer applications.

It is in the sedimentary zeolite deposits that visual recognition of zeolite species is especially difficult, if not altogether impossible (*Sheppard and Simandl 1999*). By nature

zeolites in these deposits are microscopic. Consequently, X-ray diffraction analysis is commonly employed to determine which zeolite species might be present. However, with a little experience one can discern reasonably well whether or not the precursor rock has been zeolitized.

Table 3.7: Sedimentary-type deposits in Oregon

INDEX NUMBER AND LOCATION, SEE FIGURE 3.10	ZEOLITES	OCCURRENCE[*]
1. Sec. 36, T. 23 S., R 2 E., near Bearbones Mountain, Lane County.	Clinoptilolite, mordenite	Tuff and lapilli tuff in the Little Butte Volcanic Series of Oligocene and Miocene age.
2. Sec. 30, T. 13 S., R 18 E., vicinity of Stein's Pillar, Crook County.	Clinoptilolite, mordenite	Welded tuff in the John Day Formation of Oligocene and Miocene age.
3. Sec. 35, 36, T. 10 S., R 21 E., vicinity of Deep Creek, Wheeler County.	Clinoptilolite	Tuff in the lower part of the John Day Formation of Oligocene and Miocene age.
4. Sec. 31, T. 10 S., R 21 E., vicinity of Painted Hills, Wheeler County.	Clinoptilolite	Tuff and claystone in the lower part of the John Day Formation of Oligocene and Miocene age.
5. Sec. 18, T. 17 S., R 29 E., along Lewis Creek, Grant County.	Heulandite, laumontite	Tuffaceous rocks in the lower part of the Trowbridge Formation.
6. Sec. 36, T. 11 S., R 43 E., near Durkee, Baker County.	Chabazite, erionite	Welded tuff of Tertiary age.
7. Sec. 28, T. 24 S., R 46 E., along Sucker Creek, Malheur County.	Clinoptilolite	Tuff and tuffaceous sandstone in the Sucker Creek Formation of Miocene age.
8. Sec. 1, T. 28 S., R 46 E., near Sheaville, Malheur County.	Clinoptilolite	Tuff probably equivalent to part of the Sucker Creek Formation of Miocene age.
9. Sec. 6, T. 32 S., R 41 E., near Rome, Malheur County.	Mordenite, erionite,clinoptilo-lite, phillipsite, chabazite	Tuff and tuffaceous sandstone in an unnamed lacustrine formation of Pliocene age.
10. W½. T. 34 S., R 34 E., east face of Steens Mountain, Harney County.	Clinoptilolite	Tuff in the Pike Creek Formation of Oligocene(?) and Miocene age.
11. Sec. 13, T. 27 S., R 30 E., near Harney Lake, Harney County.	Clinoptilolite, erionite, phillipsite	Tuff and tuffaceous sedimentary rocks in the Danforth Formation of Pliocene age.
12. West face of Hart Mountain, Lane County	Clinoptilolite, mordenite, phillipsite	Tuff and tuffaceous sedimentary rocks of late Oligocene or early Miocene age.

[*]after Sheppard and Walker (*1969*)

Common among zeolitized sedimentary rocks is their color. Although some zeolitic beds are pastel shades of yellow-brown, orange-red, or green, most are generally white or pale gray (*Sheppard and Gude 1993*). Another trait shared by most zeolitic beds is that they are relatively hard and dull or earthy, and can be resistant and a ledge former. In the case of a well-zeolitized tuff in which 90 percent or greater of the rock is a zeolite of one kind or another, certain gross physical properties of the rock may also aid in field identification.

In a DOGAMI confidential memo dated September 14, 1966, Norman Wagner gave an "...off-beat, but useable criteria for field recognition of one type [zeolite] against the other...". Wagner's field observations are provided in their entirety below:

- "Erionite—When hit a good blow with the point of a pointed sample pick, the pick will embed and tend to stay stuck to the extent that some prying is necessary to free it. This is a distinctive characteristic not found in the instance of the other zeolitized tuffs.

- Clinoptilolite—Practically always exhibits conspicuous conchoidal fractures.

- Mordenite—Almost never exhibits conchoidal fractures.

- Phillipsite—Very frequently, but not always, shows an oolitic-like texture, at least in places if not everywhere. Never conchoidal."

Understand that tuffs with lesser zeolite content become correspondingly less distinctive. Plus add the frustration that zeolite-bearing rocks often resemble a variety of tuffaceous sediments, bentonite, diatomite, freshwater limestone, and fine-grained mudstones. In other words, identifying the zeolite-bearing beds from those that are barren in a section where all of the rocks appear similar can be just as challenging as trying to identify the sedimentary zeolite type itself.

The geologic characteristics of Oregon's sedimentary zeolite deposits are tabulated in Table 3.8. Note that these characteristics from Sheppard and Simandl (*1999*) and provided here nearly verbatim.
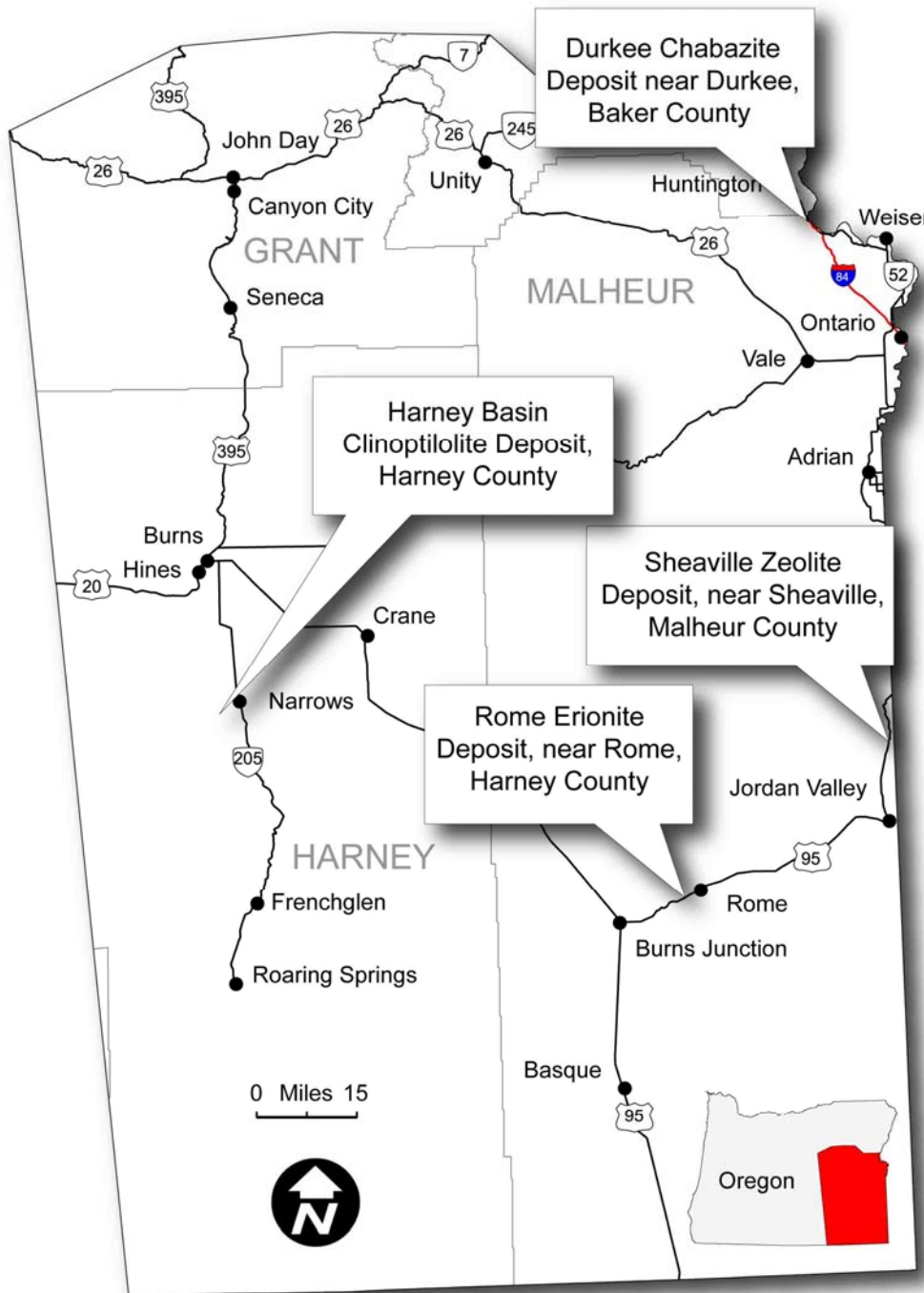
Figure 3.11: Sedimentary zeolites deposits with economic potential in eastern Oregon.
The Pliocene Durkee zeolite deposit is about 3 miles east of the Hamlet of Durkee, Baker County. The deposit is an irregular, nearly sinusoidal, 7 mi² area of chabazite and subordinate amounts of erionite. To the south in Malheur County, the Sheaville zeolite deposits straddle the Oregon-Idaho border and composed of clinoptilolite- and chabazite-bearing silicic tuffs. The zeolite deposits just west of Rome, Malheur County, have replaced the Miocene Rome beds over an elongated north-south 220 mi2 area. Some of these beds consist entirely of erionite; but other beds are mordenite- or phillipsite-bearing. A high-grade clinoptilolite deposit called the Harney Basin deposit is just west of the Narrows (Harney County); both phillipsite and erionite occur locally with clinoptolite

Table 3.8: Sedimentary zeolite deposit's characteristic features

CHARACTERISTICS	DESCRIPTION
CAPSULE DESCRIPTION	Microcrystalline zeolites (clinoptilolite, chabazite, mordenite, phillipsite) hosted by relatively thick, generally non-marine, tephra sequences. The ore zones are 10s to 100s of meters thick and commonly exhibit a more or less vertical zonation of zeolites and associated silicate minerals within the host sequence. The zeolites crystallized in the post-depositional environment over periods ranging from thousands to millions of years.
TECTONIC SETTINGS	Active or unmetamorphosed, continental, arc-related or other insular volcanic complexes.
DEPOSITIONAL ENVIRONMENT/- GEOLOGICAL SETTING	Non-marine and shallow marine basins in volcanic terrains. Depositional basins may be fault bound. Many deposits form in fluviatile and lacustrine volcanic sequences, but some are hosted by shallow marine or subaerial tuffaceous deposits. Typical regional depositional environments contain thick sequences of vitric tuffs affected by diagenesis or very low grade metamorphism.
AGE OF MINERALIZATION	Zeolite deposits in Oregon are Paleogene to Mesozoic.
HOST/ASSOCIATED ROCK TYPES	The zeolite-bearing rocks are hosted by volcanic ash and tuff beds with minor intercalated flows. Silicic tuffs commonly were deposited as non-welded ash flows. Other rock types include fluviatile mudstone, sandstone, conglomerate and diatomite.
DEPOSIT FORM	Stratabound, stratiform, or lens-shaped, mineral zonation may cross-cut the bedding. Thickness of the zeolitic tuffs in major deposits may range from 100s to 1000s of meters. Areal extent is commonly 100s to 1000s of square kilometers. Minor deposits and minable portions of above described zeolitic tuffs may be less than 30 meters in thickness.
TEXTURE/- STRUCTURE	Finely crystalline, commonly bedded, similar to bedded diatomite or bentonite. The common local attribute is vertical zonation of authigenic silicate minerals. In silicic tuff sequences, the alkali-rich siliceous zeolites (clinoptilolite and mordenite) in the upper part of the deposit are commonly replaced at depth by analcime, potassium feldspar and/or albite. A similar sequence occurs in deposits formed through burial diagenesis.
ORE MINERALOGY (Principal and *subordinate*)	Clinoptilolite, chabazite, mordenite, phillipsite, and erionite.
GANGUE MINERALOGY (Principal and *subordinate*)	Authigenic smectite, mixed layer illite-smectite, opal - (cristobalite/tridymite), quartz, plagioclase, microcline, sanidine, biotite, muscovite, calcite; pyrogenic crystal fragments, volcanic rock fragments, unreacted vitric material.
ALTERATION MINERALOGY	Zeolitization is the ore forming process (see ore mineralogy). Early zeolite minerals are further modified during burial diagenesis. In silicic tuff sequences, the alkali-rich siliceous zeolites (clinoptilolite and mordenite) in the upper part of the deposit are commonly replaced at depth by analcime, potassium feldspar and/or albite. In some cases the zonation may be enhanced or overprinted by hydrothermal alteration related to intrusive activity.
WEATHERING	Zeolitic tuffs commonly resist weathering and erosion and may be ledge formers.
ORE CONTROLS	Grain size and permeability of host tuff; flow of meteoric water downward in an open hydrologic system; hydrolysis and solution of vitric material by the subsurface water in the upper part of the system raised the pH, activity of SiO_2 and content of dissolved solids to values where zeolites crystallized. These result in a vertical or near-vertical zonation of zeolites and other authigenic minerals. Composition of the vitric material and the characteristics of the solutions may have dictated which zeolite species precipitated. For example, clinoptilolite and mordenite are common in silicic tuffs, but chabazite and phillipsite are common in mafic or trachytic tuffs. In many

CHARACTERISTICS	DESCRIPTION
	cases the composition of the glassy protolith is believed to determine the mineralogy of the deposit. Trachyte to phonolite glassy protoliths with low Si/Al ratios (£ 3.0) may favor the formation of phillipsite and chabazite, while a more felsic protolith may favor formation of clinoptilolite. Chabazite forms within the systems characterized by low Na/K ratio, whereas phillipsite dominates where the protolith has a high Na/K ratio. Conversion of zeolite to an assemblage of alkali feldspar-quartz can occur at a later stage if the stability field of zeolites is exceeded.
ASSOCIATED DEPOSIT TYPES	Deposits that may occur in the same geographic area include pumice, bentonite, diatomaceous earth, and volcanic-hosted precious opal.
GENETIC MODELS	It is nearly universally accepted that zeolite formation is linked to syn- and post-depositional reaction of volcanic glass with relatively alkaline solutions. The zonation of the open-system type of zeolite deposit is in many cases similar to the upper zones of burial diagenesis (burial metamorphism) that affected thick sequences of silicic, vitric tuffs. Zeolitization temperatures are believed to be less than 100° C, but higher temperatures are estimated for some of the deposits. In many cases, there is controversy as to whether the fluids are "low temperature hydrothermal solutions", "diagenetic fluids" or "heated meteoritic waters". The genetic process probably varies from one deposit to another. There may be some overlap between different fluid types in the same deposit and also in the terminology used by individual authors.
EXPLORATION GUIDES	Very low grade or unmetamorphosed volcaniclastic sequences typically containing large proportions of ignimbrites. Vertical zonation of zeolites and associated authigenic silicate minerals in thick (100s to 1000s of meters) tuffaceous sequences. This vertical zonation commonly is (from top to bottom) unaltered vitric material - smectite to clinoptilolite to mordenite to opal-(cristobalite-tridymite) to analcime to potassium feldspar to quartz and then to albite and quartz. This zonation may cut across bedding.

3.4.7.2   Exposure Scenario

IARC considers erionite (CAS No. 12510-42-8 & 66733-21-9) a Group 1 Carcinogen, a known cause of mesothelioma in animals and man. It was found to be responsible for an alarming mortality rate in two Turkish villages (*Dogan et al. 2006a; Temel and Gundogdu 1996*). The occupational and non-occupational exposures to erionite fibers occurred during disturbance of zeolite beds and soil in the form of dust. There may be a latency period of 20 to 30 years before erionite-associated disease presents itself (*Kliment et al. 2009*).

There are published studies that took a cursory look at the fibrogenic properties of erionite from the Rome Erionite Deposit (*Lowers et al. 2010; Ballinrano et al. 2009; Dogan et al. 2006b; Fraire et al. 2007*). Fraire and his colleagues regarded the variability in risk associated with this erionite as follows: "...there appears to be no reported instances of mesotheliomas environmentally related to erionite in men or women living in this [Rome area] region."

Ilgren et al. (*2008*) is cited by USEPA (*2010*) as recognizing an erionite link to a mesothelioma disease cluster in Zacatecas, Mexico. Although no erionite disease clusters are identified in the United States, USEPA (*2010*) citing Rom et al. (*1983*), says that a road worker and resident in Utah in a zeolite-rich area developed parenchymal and

pleural fibrosis. Here erionite exposure is suspected. The North Dakota Department of Health (NDDoH) has initiated management actions after an USEPA study in 2006 assessed gravel deposits containing erionite (*Forsman 2006*). A subsequent health study was conducted by the USEPA, in collaboration with ASTDR and the University of Cincinnati, Department of Environmental Health (*NDDoH 2010*). The results of which showed evidence of a likely association in two individuals working in road maintenance and/or gravel pits with erionite exposure (*USEPA 2010*). Though the possibility exists, the NDDoH has yet to observe any adverse health-related impacts to these individuals. In response to all this, the North Dakota Department of Transportation adopted special provisions on aggregate testing (*NDDoH 2007*) within estimated areas of erionite occurrences (*Triplett et al. 2010*).

As for other zeolite species, a low-level of toxicity by swallowing may result, and prolonged inhalation of any zeolite dust may cause inflammation or interstitial fibrosis (lung damage).

3.4.7.3   *Regulatory Information*

OSHA and MSHA

The Federal Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA) regulate workplace practices and set dust exposure levels for workers. Their respective dust exposure levels would apply to ODOT's construction, grading, quarrying, and surface mining operations (cut and fill activities). However, regulations or airborne toxic control measures for the same activities that restrict the exposure to natural erionite itself do not exist. Lastly, there is mention that OSHA regulates erionite under the Hazard Communication Standard but this appears related to chemical hazards in laboratories.

TSCA and Other Requirements

Erionite fiber is listed on the Toxic Substance Control Act's (TSCA) inventory. A helpful overview of basic TSCA provisions is provided by Schierow (*2009*). Under TSCA, in 1991, the United States Environmental Protection Agency (USEPA) promulgated a Significant New Use Rule (SNUR), Section 5(e) of (40 CFR § 721.2800) for erionite fiber. According to the rule, "[a] person (or entity) who intends to manufacture, import, or process for commercial purposes the substance [i.e., erionite fibers]...and intends to distribute the substance in commerce must submit a significant new use notice." It appears that this reporting gives the USEPA a 90-day notification period in which it could evaluate the intended new use and, if necessary, to prohibit or restrict that activity if such use would pose an unreasonable risk to human health.

There are apparent inconsistencies in how TSCA's provisions might be applied to naturally occurring erionite. Statutory language makes plain that the requirement of SNUR reporting and recordkeeping is not intended for substances that are only considered as an impurity or contaminant (40 CFR § 721.45, Exemptions). It is

unclear whether the USEPA would have to be notified, if at all, about workers involved in production or use of erionite-bearing construction aggregate that is mined from quarries/borrow pits or disturbed by roadside construction (e.g., cut and fill activities). Arguably, the use or disturbance of material as stated above and containing "natural" erionite fibers—mainly occurring only as an impurity or contaminant—is neither "significant" nor "new", and hence, should be exempt from the SNUR requirements. From a purely definitional standpoint, extraction or disturbance of material where there is "natural" erionite fibers is an activity distinct from—and not one and the same as—"manufacture" or "process" of the chemical substance. Specifically, "significant new use" would typically mean a use of some importance that has not yet occurred, or that is sufficiently distinct form current uses, such that a new or different risk of injury to human health or the environment is created.

Erionite is not identified as a hazardous air pollutant (HAP) under Section 112 of the Clean Air Act (*USEPA 1990*). The Institute of Health and Safety (NIOSH) has been focused on expanding the definition of asbestos to include other fiber-types, but has yet not classified erionite as an "asbestos-type" under its the national current scientific definition.

3.4.8 Radionuclides

Naturally Occurring Radioactive Materials (NORM); Uranium (also see Mineral Fuels)

USEPA defines NORM as "Materials which may contain any of the primordial radionuclides or radioactive elements as they occur in nature, such as radium, uranium, thorium, potassium, and their radioactive decay products, that are undisturbed as a result of human activities." Long-lived radioactive elements occurring naturally in Oregon include: uranium, thorium, and potassium, and any of their radioactive decay progeny, such as radium and radon. When specific radioactive elements are discussed, they will be named, otherwise it should be understood that the comprehensive presence of these elements are all-inclusively designated as uranium. Exposure to the radon is not addressed in this report.

3.4.8.1   Geologic Setting

In the environment, uranium (U) is a natural radioactive element; it is found in almost everything. Uranium combines readily with oxygen to form a great number of primary and secondary minerals, e.g., oxide minerals and compounds. Uranium minerals (there are over 150 known uranium minerals) can occur in a variety of deposit types, as listed in Table 3.9. Uranium is also commonly found in active and fossil geothermal springs, but gold systems are notoriously low in U (*Nash 2010*).

Table 3.9: Uranium classified by deposit type and uranium transport/precipitation conditions (IAEA[*] classification)

URANIUM TRANSPORT/PRECIPICATION CONDITIONS	DEPOSIT TYPE
Surface Process/synsedimentary	Surficial deposits (calcretes)
	Quart-pebble conglomerate deposits
	Phosphorite deposits
	Lignite
	Black shales
Diagenetic	Sandstone deposits
Diagenetic – Hydrothermal(?)	Unconformity-related deposits
	Vein deposits
	Collapse breccia pipe deposits
Magmatic – Hydrothermal(?)	Volcanic deposits
	Metasomatite deposits
	Vein deposits

[*] IAEA – International Atomic Energy Agency

Uranium mines, prospects, and occurrences in Oregon are widely scattered throughout the state, as shown in Figure 3.12. Of the deposit types in Oregon, volcanic-type deposits of uranium represent the bulk of the uranium deposits.

Uranium was first discovered in Oregon in the 1930s (*Bowen 1969; Matthews 1955; Matthews 1956*). On December 20, 1958, Oregon experienced its first commercial mining of uranium ore at the White King mine and the adjacent Lucky Lass mine (Figure 3.12). These two mines are located approximately one mile apart in rural Lakeview County, Oregon. The tabular veins and disseminated uranium mineralization at the White King and Lucky Lass share the same host rocks: clayey tuffs, tuff breccias, agglomerates, and basalt and rhyolitic flows and dikes (*Vhay 1969; Peterson 1959*). Arsenic, molybdenum, and mercury minerals were found in the White King ore body but none of these minerals were reported at the Lucky Lass. Uranium mining at these mines lasted for over a decade. Contamination of both sites involves arsenic and radionuclides. Superfund cleanup of the mines has been completed but uranium concentrations in the surrounding area are still anomalous. In this Lakeview area, at least nine other uranium occurrences or anomalies occur.
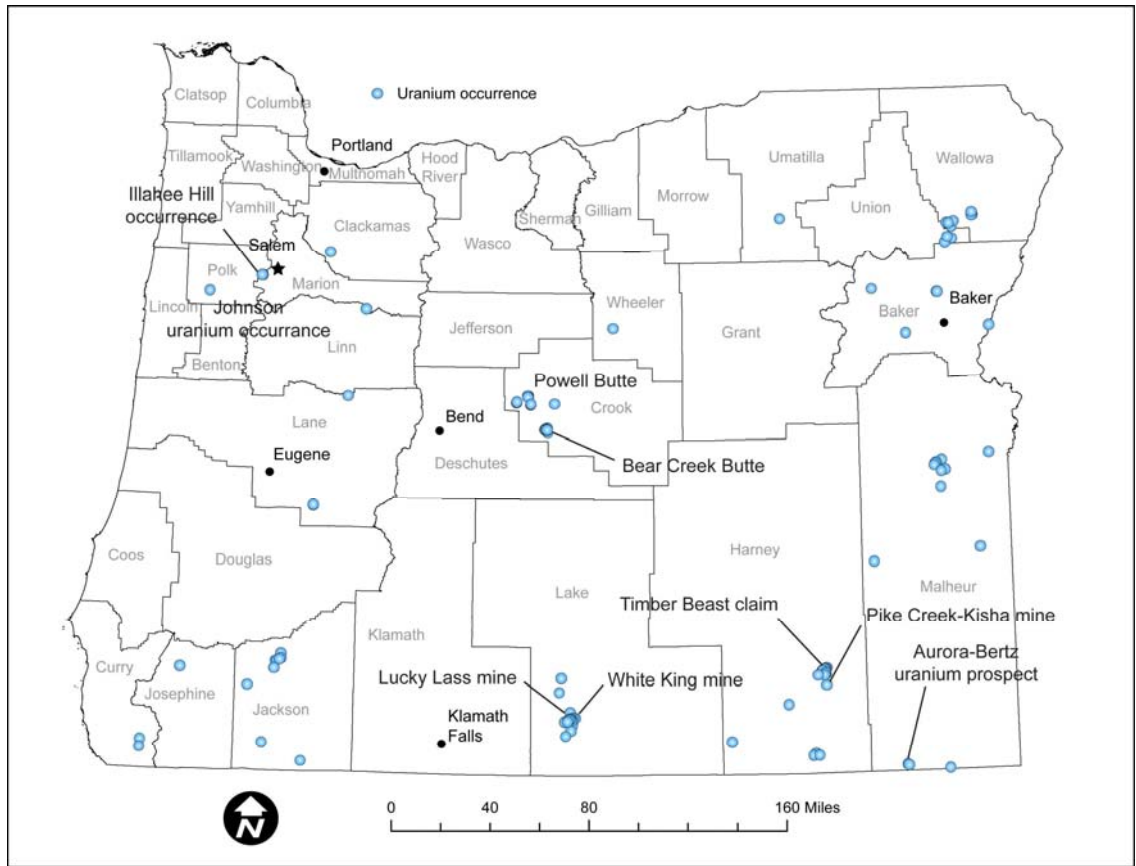
Figure 3.12: Uranium occurrences in Oregon; notable mines, prospects (claims),
and occurrences are labeled

A minor amount of uranium was mined in 1960 from a deposit at Bear Creek Butte in
Crook County (Figure 3.13). The uranium was present as autunite at the contact between
a rhyolite dike and tuffs of the Oligocene-Miocene John Day Formation (*Wilkening and
Cummings 1987*). Other occurrences of note statewide are listed in Table 3.10.

An area in the state where uraniferous rocks could still prove to be a viable commercial
mining and processing operation, given the right economic circumstances, is the north-
northwest portion of the McDermitt Caldera Complex located in Malheur County near
the border with Nevada (*Berry et al. 1982*). This uranium-bearing ore deposit is called
the Aurora and Bretz uranium prospect.

In most natural settings exposure to NORM is quite low. The western U.S. mean value
for background soil concentrations of uranium was reported as 3 ppm (*Shacklette and
Beorngen 1984*). Natural background for the U.S. averages of 300 mrem/yr (includes
radon). However, uranium mining, beneficiation, and milling can disperse contaminants
throughout the general vicinity. Uranium mining waste is 1) overburden (soil and rock
covering a deposit of uranium ore and spoil material left over or removed to gain access
to ore usually contains at least trace amounts of the ore plus radioactive decay products);
2) unreclaimed, subeconomic ores (ores that have too little uranium to be profitable,
called "protores"); 3) "barren" rock (rock containing no ore); and 4) drill cuttings.

NORM contaminated environments can also be associated with uraniferous mineralization that coexists with other metals, such as gold and silver deposits and particularly with active and fossil geothermal features.

Table 3.10: Other noteworthy uranium type deposits in Oregon

DEPOSIT NAMES*	LOCATION	DESCRIPTION-COMMENTS
Dooley Mountain	Baker	Autunite reported in silicified rhyolite tuff, limonite-stained
Johnson and Laird	Clackamas	Carnotite reported in friable tuffaceous sandstone
Powell Butte, Dosser	Crook	Radioactive anomaly in flow-banded rhyolite, in Clarno Formation (Eocene)
Game Guides Group	Crook	Autunite reported in tuffaceous sandstone
Squire	Curry	Autunite reported in fine-grained tuff
Timber Beast	Harney	Autunite reported in flow-banded dacite
Pike Creek (Kiska), Alex-Ladd	Harney	Autunite and uranophane in tuff and rhyolite breccia
Marshall	Harney	Uranium minerals in pumiceous sandstone
Lobo No. 3	Harney	Uranium minerals in porphyritic andesitic breccia
Mary D	Harney	Uranium minerals in chert and veinlets associated with pyrite
Maple	Jackson	Autunite in rhyolitic tuffs and flows
Dawn Marie Claim	Jackson	Uranium minerals in tuff
Shaknis Farm	Jackson	Uranium minerals in conglomeratic and arkosic sandstone, Umpqua Formation
Board Mountain Group, Canyon Creek Group	Jackson	Uranium minerals in sandstone
Bald Butte Claim	Lake	Uranium minerals in silicified tuff
Valley View (Rasmussen	Malheur	Uranium minerals in clayey sandstone
Speerstra Farm, Rhoten and Speerstra	Malheur	Tyuyamunite, autunite, zipperite, in marine tuffaceous sandstone, Eugene Formation
Johnson	Polk	Carnotite in sandstone
Tungs Ore Group	Union	Uranium minerals in tuffaceous sandstone, copper-pyrite minerals

* The mined uranium occurrences or anomalies in the Lakeview area and Bear Creek Butte deposit mentioned above are not listed in the Table; after Peterson (*1969*) and Schafer (*1956*).

3.4.8.2   *Exposure Scenario*

Uranium is soluble in oxidizing aqueous solutions, especially the U^{+6} valence state, and can be redistributed from primary source rocks into porous sedimentary rocks and structures (e.g., secondary epigenetic uranium mineral deposits) by groundwater. Uranium can have chemical (toxicity as a heavy metal) and radiological effects on the body. Technical Bulletin 2007 issued by the Oregon Department of Human Services' Environmental Toxicology Section (*ODHS 2007*) states, "people who have ingested large amounts of uranium have developed symptoms of kidney disease...and cancer is possible." NORM exposure pathways can be separated into external dose and internal dose. The former is gamma radiation penetrating tissue and reaching internal organs. The latter is by inhaling radioactive gas or particles suspended in the air, or by ingesting radioactive dust. The material may remain in the body for some time after the intake and

the energy the radiation deposits is called a (radiation) dose. In the U.S., doses are most commonly reported in millirem (mrem). A millirem is one thousandth of a rem (1000 mrem = 1 rem).

The statutory and regulatory requirements promulgated by the State of Oregon that govern disposal of radioactive material, including uranium mine overburden, appear relevant and appropriate for NORM sites. The Oregon Office of Energy (OOE) is charged with Oregon Revised Statute (ORS), Chapter 469, Division 375 (Required Findings for Radioactive Waste Disposal Facility); Oregon Administrative Rule (OAR), Chapter 345-050 (Rule 35 Pathway Exemption and Rule 60 Site Suitability). NORMs are exempt from the provisions of OAR 345-050-0006 if OOE finds that accumulation of material cannot result in exposures exceeding 500 millirem of external gamma radiation per year.

Oregon Environmental Cleanup Law, ORS Chapter 465, Division 315; OAR Chapter 340, Division 122 (Hazardous Substance Remedial Action Rule) establishes cleanup levels and selection of remedial actions that would not only apply to NORMs but also to the other NOHMs (e.g., arsenic and mercury). If a cleanup was undertaken, then the aim of the rule is to achieve: 1) acceptable risk levels, 2) generic soil numeric cleanup levels, 3) remedy-specific cleanup levels provided by ODEQ as part of an approved generic remedy, or 4) background levels in areas where the NOHM occurs naturally. Under existing regulations for workers classified as radiation workers by state or federal law, doses are required to be as low as reasonably achievable, not to exceed an annual dose of 5 rem/yr, as specified in OAR Chapter 345, Division 95 (Construction, Operation and Decommissioning Rules for Uranium Mills), Section 90 (Public Health Impacts) and Part 20 of 10 CFR. This limit would apply to workers who handle NORM only if they were classified as radiation workers by state regulations; otherwise, NORM workers are subject to dose limits that apply to the general public. The currently accepted public dose limit is 100mrem/yr from all sources, including NORM.

3.4.9 Arsenic and Its Compounds

3.4.9.1   *Geologic Setting*

Everyone is exposed to some level of arsenic (As), in the air you breathe, the water you drink, and the food you eat. The concentration of arsenic in the environment varies widely. For the western United States arsenic levels generally range from about <0.1 to 97 ppm, with an average level of 5.5 ppm (*Shacklette and Boerngen 1984*). An average basalt, for example, may contain 2 ppm arsenic (*Drever 1988*) and there is generally little difference between concentrations in the other different igneous rock types (*Garelick et al. 2008*). Arsenic can enter the air, water, and land from wind-blown dust and may get into the water from runoff and leaching. Arsenic cannot be destroyed in the environment; it can only change its form, or become attached to or separated from particles.

There are more than 200 minerals that contain arsenic either as a major or minor constituent. The common mineral forms that As takes are arsenopyrite, orpiment, and realgar. The greatest concentrations of these minerals occur in mineralized areas

associated with base- and precious-metal deposits. Hot springs are another source where realgar and orpiment are the two common As mineral forms (*Welch et al. 1988*). The water's high metal content can leave nearby soils enriched in arsenic.

It is probably safe to assume that arsenic is either a major or minor constituent in most, if not all of Oregon's mining/prospecting sites (see Figure 3.1). Of course, its form and concentration are different and usually varies from ore to ore and within each ore-type in a deposit. In some of the important gold and silver mines of Oregon's Blue Mountains, a large percentage of the gold is free; in others it is locked in sulfides (referred to as refractory ores) which are chiefly arsenopyrite and (arsenian) pyrite with lesser amounts of chalcopyrite, sphalerite, and galena (*Koch 1959; Libbey 1943; Pardee and Hewett 1941; Gilluly 1933a; Gilluly 1933b; Gilluly et al. 1933; Parks and Swartley 1916; Grant and Cady 1914; Lindgren 1901*). The arsenic concentration in arsenopyrite is 46 percent by mass. Mineralogically, chalcopyrite, sphalerite, and galena are also arsenic carriers and can contain several weight percentages (and may exceed 10 wt percent) of As in their structure. Furthermore, high arsenic concentrations are found in many oxide minerals where arsenic occurs as part of the mineral structure or as sorbed species. Notably nickel and cobalt minerals can have a high As content.

Arsenic is introduced into the environment when weathering of sulfides produce iron and sulfuric acid (acid mine drainage), which in turn releases arsenic and can also leach other major and trace elements from mine waste and surrounding rock. Arsenic first oxidizes to As (V) (arsenate) and readily co-precipitates with or sorbs onto iron bearing oxides, thus rendering it temporally immobile (*Hinkle and Polette 1999*). This arsenate form is by no means locked into a state of immobility. Then as water chemistry changes over time and becomes more reducing, or if the pH becomes more alkaline, As (V) is desorped and reduced to As (III) (arsenite). This arsenite form is far more toxic and mobile than arsenate and is, therefore, a contaminant of great concern (*Loredo et al. 2003*).

3.4.9.2   *Exposure Scenario*

Arsenic poisoning is manifested in different ways, some symptoms as benign as drowsiness to symptoms as serious as comas or death. Inorganic arsenic is extremely toxic and enters into the human body through ingestion, inhalation, or to a lesser degree by skin absorption. Arsenic is distributed in the lungs, skin, kidneys, and liver where it can cause many types of cancer, including skin cancer, scrotal cancer, liver cancer, cancer of the lymphatic system, and lung cancer. The main arsenic exposure pathway from a geological source and/or mining waste to people in the vicinity is inhalation of particulates containing arsenic.

3.4.9.3   *Regulatory Information*

Arsenic cleanup criteria for soils in Oregon is an interesting situation as the mean western U.S. concentration is 5.5 ppm (*Shacklette and Beorngen 1984*), while the Oregon Department of Environmental Quality's (DEQ) default background arsenic soil concentration for the state is 7 ppm (*DEQ 2002*). Teaf et al. (*2010*) indicated that such guidelines, "vary across about a 1000-fold range (0.039 to 40 kg/mg) in the U.S. alone."

Oregon's standards for remedial action vary based on soil As background levels and are tempered with what is achievable. In order to screen environmental arsenic concentrations against appropriate risk-based concentration, DEQ recommends using the following screening level resources:

- USEPA Region 9 Preliminary Remediation Goals (PRGs).

- DEQ's Risk-Based Concentrations for petroleum sites (RBCs).

- DEQ's Screening Level Values (SLVs) for potential ecological receptors.

- Oregon's Default Background Metals – to use if it is suspected that naturally occurring concentrations of metals exceed PRGs.

- Be aware that OSHA (*2008*) has standards related to arsenic.

DEQ is currently updating their risk calculations for arsenic based on 80 percent bioavailability of arsenic in soil but their present standards are as follows:

- Long-term exposure to arsenic in public drinking water above 10 parts per billion (ppb), which is the current maximum contaminant level (MCL), has been associated with skin, lung, and bladder cancer.

- Hyperpigmentation, or darkening of the skin, has been observed at daily doses of 0.01 ppm/ day—soil exposure.

- 20-30 ppm As^{+5} is a regulatory issue.

- Smaller the particle sizes yield higher the availability of As, e.g., soil with less than 250 μm sieve fraction sticks to skin. This is an absorption exposure route if the soil contains As^{+5}.

3.4.10 Antimony and Its Compounds

3.4.10.1 *Geologic Setting*

Antimony (Sb) is sometimes found natively, but more frequently it is found as the sulfide stibnite. It occurs in a variety of deposits: epithermal veins, pegmatites, and replacement and hot spring deposits. In Oregon, antimony is commonly a minor metal in gold veins (*Wagner 1944, Peterson 1969*). However, there are five mines in Oregon that have a record of antimony production, albeit small. These mines are shown in Figure 3.13 below, along with other mines, prospects, and occurrences which contain some antimony as a minor metal.
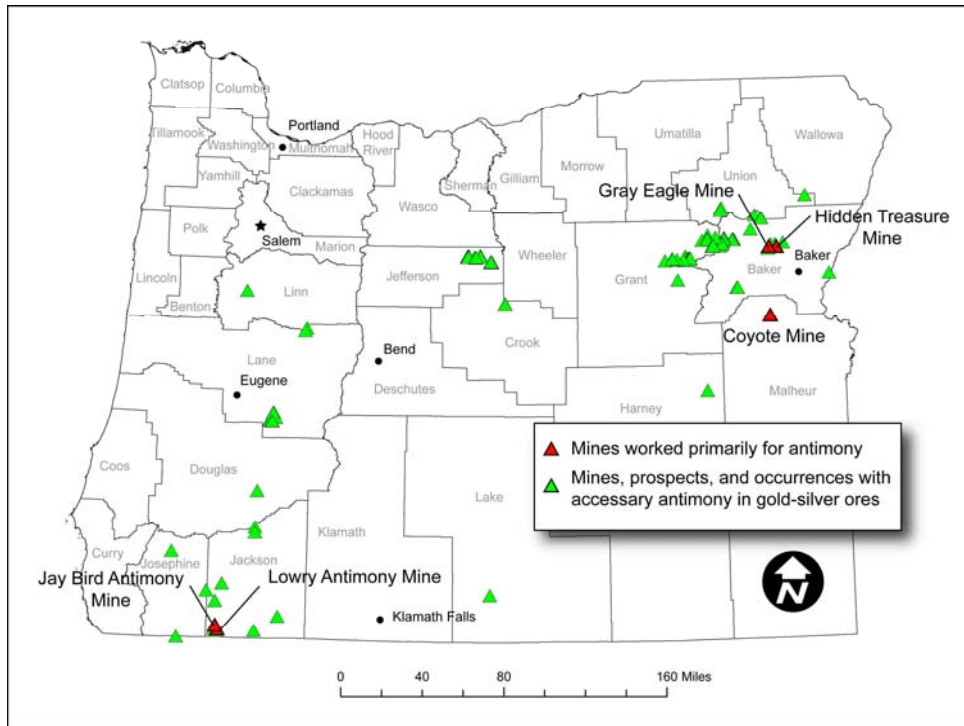
Figure 3.13: Antimony mines, prospects, and occurrences

The antimony deposits consist of stibnite associated with pyrite, arsenopyrite, cinnabar, scheelite (tungsten), or of antimony sulfosalts with varying amounts of copper, lead, and silver.

3.4.10.2   *Exposure Scenario*

Antimony resembles arsenic chemically and biologically. The western U.S. mean value for background soil concentrations of antimony was reported as 0.47 ppm (*Shacklette and Beorngen 1984*). Inhalation of antimony dust can be an upper respiratory tract irritant. Long term exposure may participate in the development of gastrointestinal and lung problems and heart disease.

3.4.11   **Mercury and Its Compounds**

3.4.11.1   *Geologic Setting*

Mercury (Hg), or "quicksilver," as it is popularly called, is a heavy silver gray metal that is liquid at ordinary temperatures. Cinnabar is a mercury sulfide, HgS. It occurs in red crystals and masses and is the principal ore of mercury. Metacinnabar is the high temperature, less stable form of cinnabar. Natural sources of mercury include volcanoes, active and fossil hot springs, and natural mercury deposits.

Quicksilver mines, prospects, and occurrences are present in at least 18 of Oregon's 36 counties (Figure 3.14). The greatest number and most productive quicksilver deposits lie

in the southwestern, north-central, and southeastern parts of the state (*Brooks 1963, Wilkening and Cummings 1987, Williams and Compton 1953, Schuette 1938, Wells and Waters 1934*). A common characteristic shared across the state is that mercury deposits are concentrated in areas underlain by Tertiary volcanic and sedimentary rocks and are most commonly associated with younger, low-temperature (epithermal) hydrothermal systems (*Ferns and Huber 1984*). Of note is the common association of quicksilver with many of Oregon's gold and base-metal deposits, where it occurs in small quantities or sufficiently concentrated to warrant exploration.
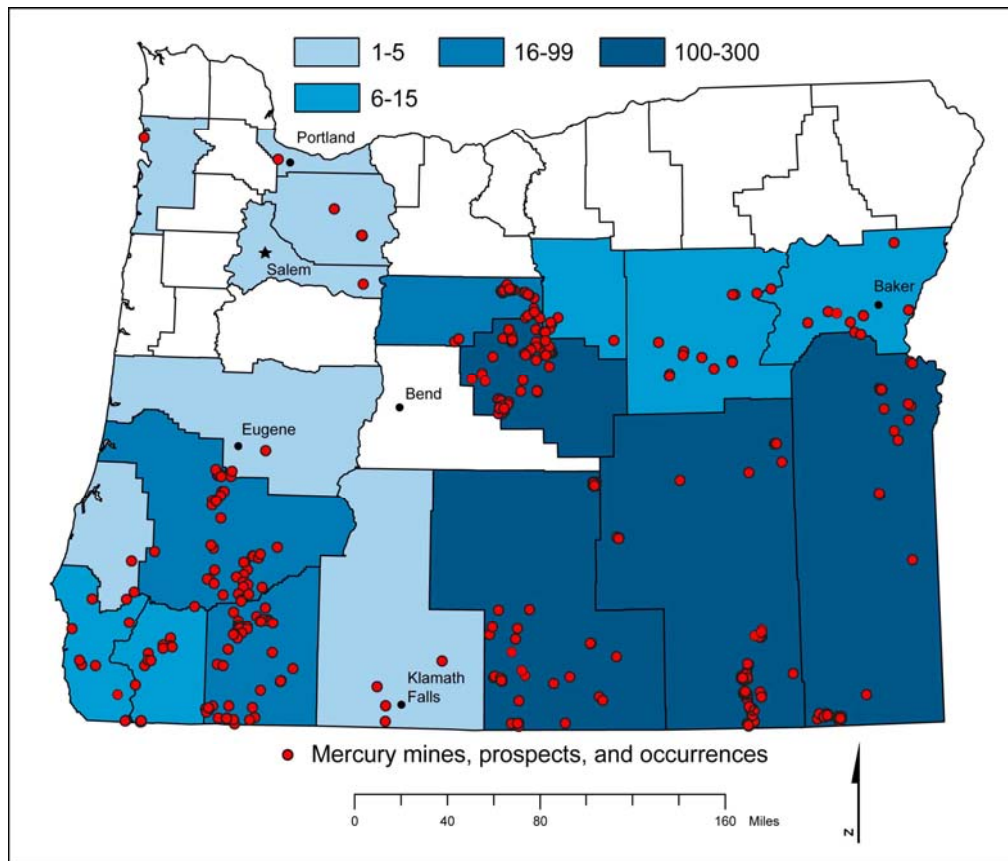
Figure 3.14: Mercury mines, prospects, and occurrences (red circles) in Oregon.
The mercury data has been generalized and aggregated to the county level. (mercury, n = 937)

Five mines accounted for over 90 percent of Oregon's mercury production (*Brooks 1963*): the Bonanza in Douglas County (*Brown and Waters 1951, Brown 1962*), Black Butte in Lane County (*Derkey 1973, Waters 1945*), Horse Heaven in Jefferson County (*Waters et al. 1951*), and Bretz and Opalite in Malheur County (*Ross 1941, Yates 1942*). However, there are 60 other deposits that produced mercury (one to 1,000 flasks) and at least that many more non-productive occurrences scattered throughout the state have had some exploratory work done on them. The richest mercury ores in Oregon contain up to 2.5 percent mercury by mass, and even deposits with the leanest concentrations are at least 0.1 percent mercury. Approximately l08,000 flasks of quicksilver were produced in Oregon, representing about 3% of the total U.S. output. (A steel flask holds 76 pounds net of quicksilver.) In October 1960, the last mercury mine in Oregon closed. It was the

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Bonanza mine and stands as Oregon's largest producer with an output just over 39,000 flasks.

Typically in a quicksilver deposit, pyrite and marcasite are almost always gangue minerals in the mineralized and altered host rock. Trace amounts of antimony, arsenic, copper minerals, and tungsten are usually present. As far as a typical host rock, Brooks (*1963*) points out that physical properties, e.g., permeability and porosity, are more important than the actual rock type. He also points out that the most important quicksilver deposits in Oregon have been found along fault and breccia zones in the following rocks: tuffaceous sandstones, volcanic flows and plugs, and tuffs of andesitic to rhyolitic composition of late Tertiary time (Eocene, Oligocene, and Miocene). It is the fissure system, i.e., faults and breccia zones, that provided space for deposition, but there also had to be an impermeable layer or plug associated with the system in order to cap the mineralization and act as a barrier to oxidation.

It takes several milling steps to extract mercury from its ore. The ore is first crushed and screened. Then it is placed into a furnace called a retort, which is essentially a mercury still. The ore is roasted in a current of air to a temperature in excess of 400° C, at which point the mercury vaporizes. The mercury vapors are captured in tubing, cooled, and condensed back to liquid mercury. A calcined waste, together with mine rock, is the by-product that's left behind. Cinnabar and metacinnabar constitute the highest proportion of Hg-containing species in the Hg mine rock waste, while metacinnabar is doubly concentrated in roasted or calcined waste (*Christopher et al. 2005; Kim et al. 2005*). Metacinnabar is more soluble than cinnabar making the calcined waste a greater concern (*Gray 2003*).

As mentioned previously, both gold and silver amalgamate readily with mercury, a property that has long been used in Oregon to extract gold and silver (*Lorain 1938*). Amalgamation of mercury and gold/silver is not an efficient process and the process itself can be inhibited by refractory sulfides. Consider that Hg losses to the tailings, and consequently to the environment, could be as high as 10 to 30 percent of the Hg applied.

3.4.11.2 *Exposure Scenario*

Mercury is a naturally occurring element found in air, water, and soil. The western U.S. mean value for background soil concentrations of mercury was reported as 16 ppm (*Shacklette and Beorngen 1984*), while the U.S. continental background concentration for mercury is 0.06-0.08 ppm. Mercury is distributed throughout the environment by both natural and anthropogenic processes.

All humans are exposed to some low levels of mercury. Most of this exposure is through air emissions and our diet. Occupational exposure of workers has been reported from (among others) mercury mines, mercury-based gold and silver mining, and refineries. Sometimes significant releases can occur due to mining wastes where mercury is present in tailings piles as impurities. Similar situations also occur in gold mining operations using cyanide-leaching techniques instead of gold amalgamation. Here, dissolved

cyanide reacts with traces of mercury in the tailings and acts as a carrier downstream (*Boyle and Smith 1994*).

The primary targets for toxicity of mercury and mercury compounds are the nervous system, the kidneys, and the cardiovascular system. Effects on brain function (Mad Hatter's disease) may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Exposure to high levels of metallic, inorganic, or organic mercury (methlymercury) can also permanently damage kidneys and developing fetuses. Short-term exposure to high levels of metallic mercury vapors may cause effects including lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation.

3.4.12 Copper and Its Compounds

3.4.12.1 Geologic Setting

The crustal abundance of copper (Cu) is about 63 ppm. The main mineral of commercial importance as a source of copper is chalcopyrite. The production of copper in Oregon has been small, primarily as chalcopyrite, and comes from vein and irregular replacement bodies along shear and fault zones (*Bowen 1969; Vhay 1960; Hundhausen 1952; Lowell 1942; Gilluly 1933a; Shenon 1933a*). Small amounts of chalcopyrite (along with pyrite, galena, and sphalerite) are also commonly present in gold and silver deposits, and the gold and silver minerals often are intimately associated with them.

In Oregon, the principal copper producing mines and significant occurrences with little or no production are shown in Figure 3.15. Two mines: the Iron Dyke, located on the Snake River near Homestead in Baker County, and Queen of Bronze, located in Josephine County were operated primarily as copper mines (*Bowen 1969; Hundhausen 1956*). These mines share similarities with volcanogenic (volcanic in origin) massive sulfide deposits, chiefly pyrite and chalcopyrite (*Ferns and Huber 1984*). The Cowboy Mine and Turner-Albright Mines in southern Josephine County and the Formosa mine (Silver Peak mine) in Douglas County are also believed to be volcanogenic.

Exploration in the Western Cascades and in the Blue Mountains of northeastern Oregon has identified several potentially large-tonnage, low-grade porphyry-type copper and molybdenum deposits. This type of deposit is generally associated with granitic porphyritic intrusions.

3.4.12.2 Exposure Scenario

The western U.S. mean value for background soil concentrations of copper is reported as 21 ppm (*Shacklette and Beorngen 1984*). Acid rock and acid mine drainage contributes to copper loading. Although trace amounts of copper are essential to life, copper in large amounts is quite toxic. Excessive zinc intake may inhibit copper absorption and lead to copper deficiency.

3.4.13   Lead and Its Compounds

3.4.13.1   Geologic Setting

Lead (Pb) is a base metal and galena is the most important lead mineral. Crustal abundance of lead is about 12 ppm. In Oregon, galena is a common constituent in copper, gold, and silver deposits. There were no mines in Oregon that operated primarily for the production of lead. However, the places where lead concentrate was produced are Lane County, which produced the greatest amount, followed by Grant, Josephine, Jefferson, and Marion counties also having some history of production (*Bowen 1969*).

3.4.13.2   Exposure Scenario

The western U.S. mean value for background soil concentrations of lead is reported as 17 ppm (*Shacklette and Beorngen 1984*). Neurologic problems, especially in children, are the principal concerns for chronic lead exposure. Lead is considered to be hazardous, a known carcinogen and mutagen. Lead in soils near roadways can be attributed to the historic use of lead in gasoline, referred to as aerially deposited lead (ADL), but presently not considered a health threat to the public.
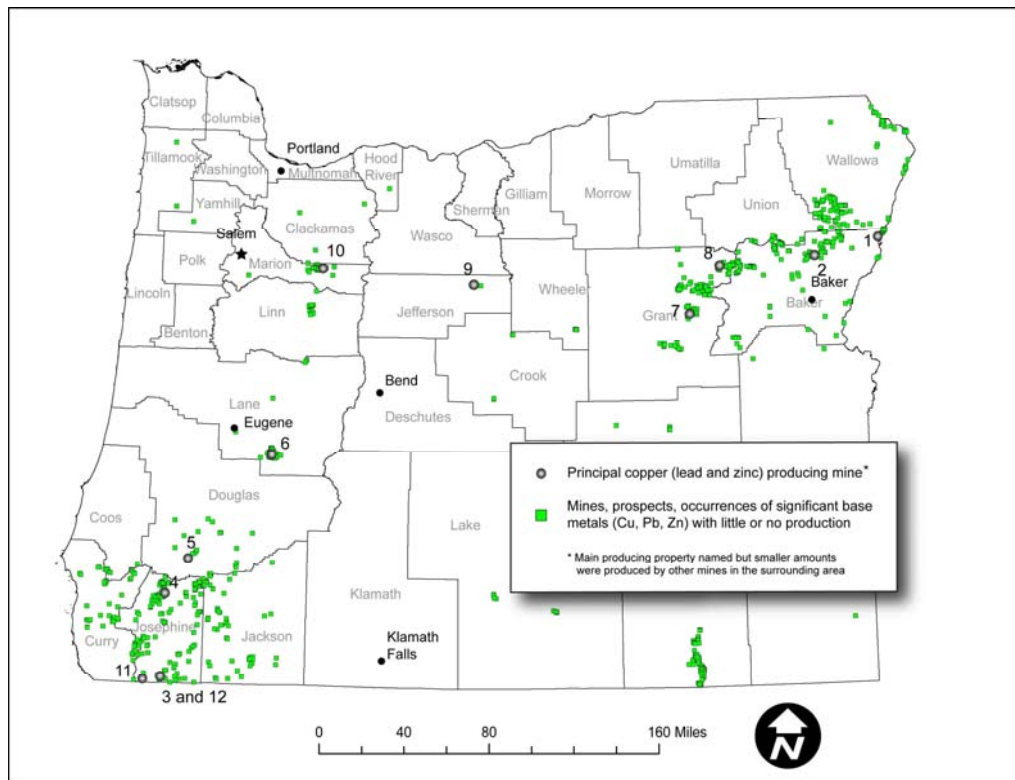
Figure 3.15: Principal copper, lead, and zinc producing mines and significant occurrences with little or no production in Oregon. Index number reference: 1. Iron Dyke mine (Cu), 2. Balm Creek mine (Cu), 3. Queen of Bronze mine (Cu, Pb), 4. Almeda mine (Cu, Pb), 5. Formosa mine (Silver Peak mine) (Cu), 6. Champion mine (Cu, Pb, Zn), 7. Standard mine (Cu), 8. Buffalo mine (Cu, Pb, Zn), 9. Oregon King mine (Cu, Pb),10. Amalgamated and Ruth mine (Cu, Pb, Zn), 11. Albright-Turner mine (Cu, Pb, Zn), and 12. Cowboy mine (Cu)

3.4.14 Cadmium and Its Compounds

3.4.14.1   *Geologic Setting*

Cadmium (Cd) is obtained from ore minerals and detected in many different types of ore deposits; chief among them is zinc. The zinc mineral, sphalerite, is an ancillary mineral in almost all of the state's copper deposits and many of the gold and uranium-mercury deposits. However, information is lacking as to whether any zinc ores in the state are cadmiferous, or if cadmium was a local milling/smelting by-product or contaminant.

3.4.14.2   *Exposure Scenario*

Cadmium is considered to be carcinogenic (prostate); it is neurotoxic and reprotoxic. Cadmium occurs predominately in the form of a free divalent cation. Increased water hardness reduces cadmium's toxicity. No mean western U.S. concentration value for cadmium was reported by Shacklette and Beorngen (*1984*).

3.4.15 Mineral Fuels (Including Bitumen)

3.4.15.1   *Coal and Oil Shale*

Coal has been mined in Oregon since pioneer times (*Newton and Mason 1973; Mason 1969; Wayland 1964; Mason and Erwin 1955; Duncan 1953;, Yancey and Geer 1950; T'oneges et al. 1948; Allen and Baldwin 1944; Curran 1944; Libbey 1938; Lesher 1914; Williams 1914; Diller and Pishel 1911; Diller 1899; Diller 1901*). Oregon's coal mining ended in the late 1950s. The bulk of coal production in Oregon came from the Coos Bay field, Coos County (Figure 3.16). The figure also shows other important coal fields in Oregon, including Eden Ridge, Rogue River, Vernonia, Wilhoit, Waldo Hills, Eckley, Squaw Basin, and Shasta Costa. All contain small tonnages of coal that either have been or could be developed. Other counties in which thin seams of low-grade coal are known to crop out are: Tillamook, Lincoln, Yamhill, Douglas, Grant, Morrow, Wheeler, Wasco, Wallowa, Baker, and Harney.

The presence of some soda springs in the western part of the state may be an indication of near-surface, coal seams that are off-gassing free CO_2. In the context of a discussion of NOHMs, it should be noted that carbon dioxide is a neurotoxin at concentrations significantly above normal atmospheric concentrations.

Oil shale is a fine-grained organic-rich, thin-bedded sedimentary rock that contains kerogen, the oil's source. Newton and Mason (*1973*) and Newton and Lawson (*1974*) both described a small deposit of oil shale in the Western Cascades of Oregon 10 miles northeast of Ashland. It is the only known "oil shale" deposit in the state, called the Shale City deposit (Figure 3.16). The deposit occurs in lacustrine beds interbedded with tuffaceous sandstone and fine-grained rhyolitic tuff. Total thickness of the deposit ranges from 10 to 15 feet and capable of yielding 35 to 37 gallons of oil per ton of shale. Sulfur encrustations on the shale can be collected at the site. Additionally, there are organic-

rich lacustrine beds in Payette and Succor Creek Formations in southeastern Oregon. Tests on these formations yielded about half a gallon of oil per ton.
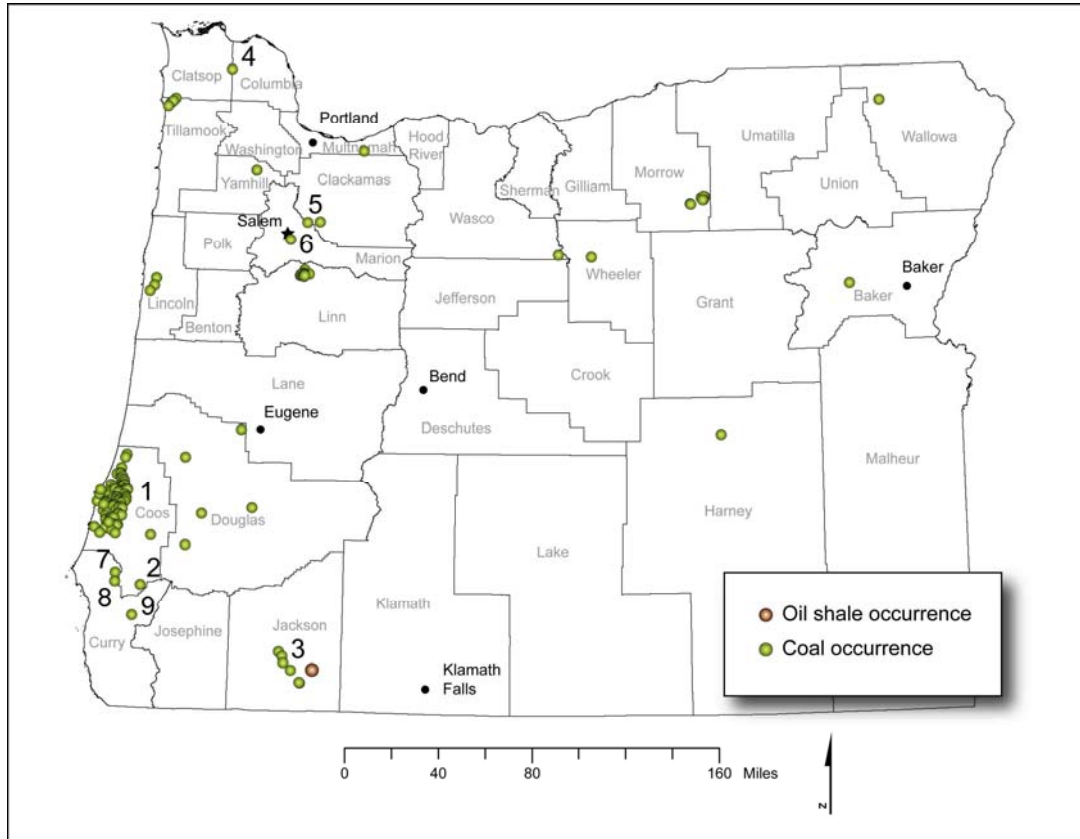
Figure 3.16: Coal occurrences in Oregon (green dots). Index number is reference to coal fields: 1. Coos Bay, 2. Eden Ridge, 3. Rogue River, 4. Vernonia, 5. Wilhoit, 6. Waldo Hills, 7. Eckley, 8. Squaw Basin, and 9. Shasta Costa. The location of the Shale City deposit is designated by the brown dot

3.4.15.2   *Exposure Scenario*

Dust from exposed seams of bituminous, lignite, and sub-bituminous coal is of concern. This dust can be introduced into the atmosphere by mining, fuel use, or simply by disturbing surface exposures. The latter scenario is the most relevant to ODOT. Coal dust is a complex heterogeneous mixture that can contain more than 50 different elements and oxides. The material content varies with the particle size and with the coal seam itself. It not only includes coal particles but also quartz, ash, clays (kaolinite, sericite/illitte, etc.), and sulfides. The major health hazard associated with coal is pneumoconiosis as a result of respirable dust.

Oil shale in the Shale City deposit is a concern because the shale gives off a bituminous odor on fresh fractures. Prolonged exposure to the bituminous fumes and vapors cause irritation of the eyes, nose, and respiratory tract in animals and humans. Also, an IARC working group determined that there is sufficient evidence to associate oxidized bitumen and bitumen fumes to certain cancers and possibly mutagenic and genotoxic/cytogenetic effects (*IARC 2011*).

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3.4.16 Lithium and Its Compounds

3.4.16.1   Geologic Setting

Lithium is the lightest metal and the least dense solid element. Lithium does not occur naturally in its metallic form, because of its reactivity. Lithium-bearing pegmatites once were the primary source for this element. Saline brines are today's main resource. The Lithium potential in Oregon is largely unknown. The minerals of commercial importance as a source of lithium are spodumene, petalite, and a rare magnesium-lithium clay (smectite) called hectorite.

Late Tertiary silicic ashflow tuffs and lavas, peralkaline in chemical character are favorable geologic environments for both Rare Earth Elements (REE) and lithium-related deposits. Peralkaline lavas, mostly rhyolites, differ from "normal" rhyolites in that they contain lesser amounts of alumina, higher amounts of potassium and sodium, and, quite often considerably higher amounts of lithium, thorium, uranium, zirconium, and REEs.

The only known lithium deposit in Oregon is associated with the McDermitt caldera that straddles the Oregon-Nevada border, southwestern Malheur County (Figure 3.17). Hectorite beds occur in moat-like lake sediments (i.e., closed basin) formed after the collapse of the McDermitt caldera's resurgent dome complex (*Glanzman et al. 1977*). The hectorite beds and lenses are associated with volcanic sediments, limestones, dolomites, zeolites, and locally sandy bentonites (*Odom 1992*). The high purity deposits appear to be associated with hydrothermally affected areas.
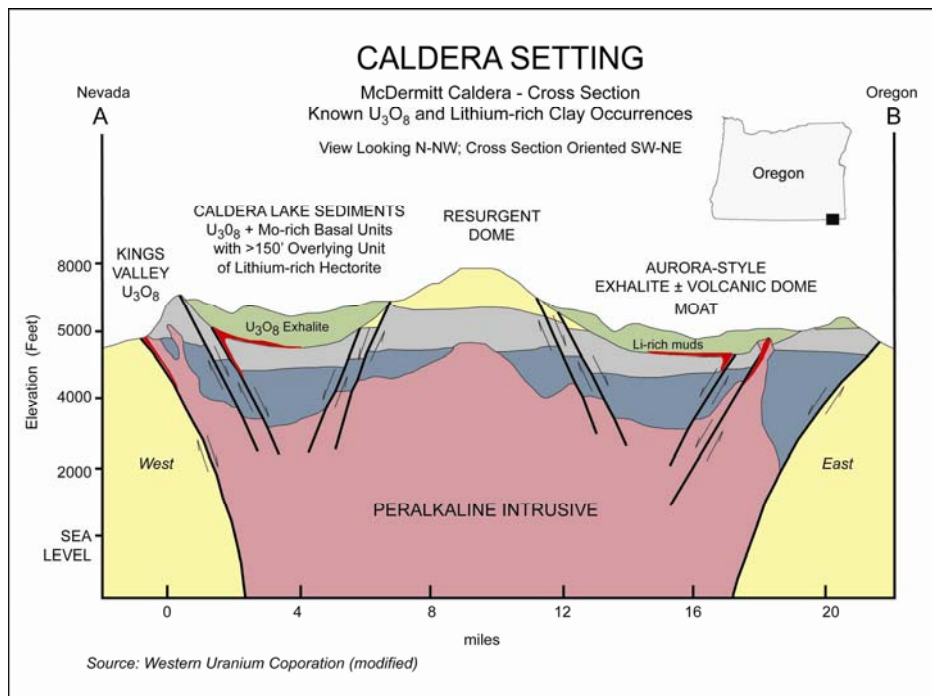
Figure 3.17: A cross-section through the McDermitt caldera complex, green represents the caldera lake sediments. No relationship is apparent between the lithium beds and uranium mineralization

Elsewhere in the state, there are other peralkaline rhyolite calderas as shown in Figure 3.18 (*McClaughry et al. 2009; Rytuba and McKee 1984*). Whether lithium could be concentrated in adjacent hydrologically closed basins, in which tuffs/tuffaceous sediments accumulated and altered, has as yet, not been regionally evaluated. The carbonated springs' association with higher rare-metal concentrations has not been evaluated either.

3.4.16.2   *Exposure Scenario*

Little is known concerning the long-term effects of lithium excess on health or disease of domestic animals or man. No cases of toxicity from naturally occurring lithium have been reported, but lithium itself is classified as a neurotoxicant. USEPA's regional screening level for lithium residential and industrial soil is 160 ppm and 2,000 ppm, respectively (*USEPA 2009b*).
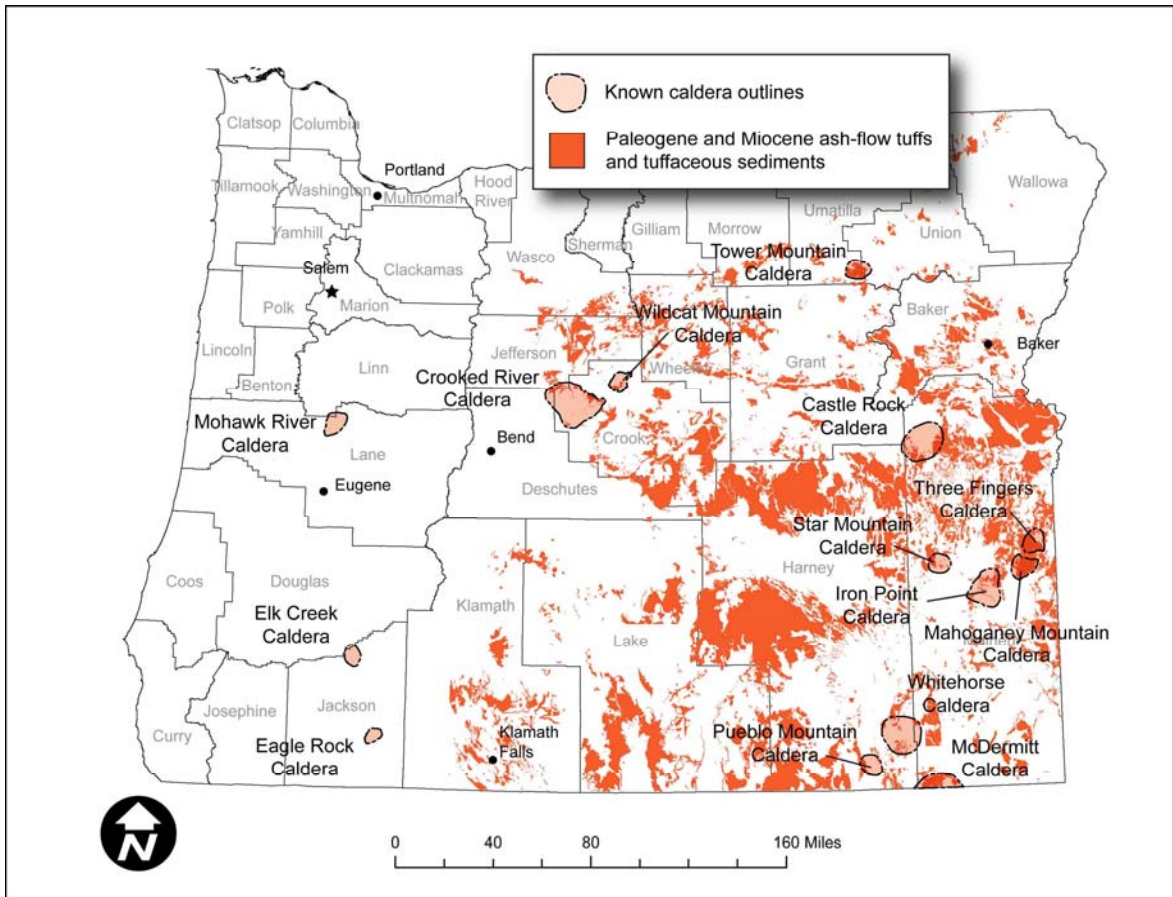
Figure 3.18: Caldera complexes of Oregon showing spatial relationship with Paleogene and Miocene tuffs and tuffaceous sediments. Younger and older rhyolites are not shown. Caldera margins are not well constrained, and most areas have not been evaluated for either lithium or rare earth elements

3.4.17 Beryllium and Its Compounds

3.4.17.1 Geologic Setting

Beryllium (Be) is rare as an element, and therefore minerals with Be as a principal compositional element appear only after extensive differentiation. Beryllium is present in some 106 minerals; two minerals are sought after for commercial recovery of beryllium: bertrandite and beryl. Granitic pegmatites are the world's principal source of beryllium, while minor sources are hydrothermal (gresien) quartz veins associated with shallow-level plutonic rocks and skarns, metamorphic tactite and emerald-bearing schists, and alkaline igneous rocks (e.g., nepheline syenites). Rarely are beryllium deposits in volcanic rocks.

Beryllium has been reported at six sites, all in southwestern Oregon. DOGAMI's investigation of these sites did not authenticate beryllium's presence.

3.4.17.2 Exposure Scenario

The general population has daily exposure to naturally occurring beryllium from ambient air and drinking water, as well as through dietary intake. The western U.S. mean value for background soil concentrations of beryllium was 0.68 ppm (*Shacklette and Boerngen 1984*). In excess and in the right form, beryllium compounds are quite toxic, particularly those industrial products if not handled with reasonable precautions. Chronic exposure to beryllium and its compounds may produce berylliosis, a frequently fatal pulmonary granulomatosis. Its water-soluble salts (sulfates and fluorides) have acute effects, causing dermatitis, conjunctivitis, and through inhalation, irritation of the respiratory tract.

3.4.18 Selenium and Its Compounds

3.4.18.1 Geologic Setting

Selenium (Se) is a naturally occurring mineral element that is distributed widely in most soil and rocks. Highly seleniferous soils can be directly related to certain parent materials from which the soil was first derived, e.g., tuffs or marine siltstone and shales. Anthropogenic sources of selenium are concentrated in waste left from certain mining, agricultural, petrochemical, and industrial manufacturing operations. The western U.S. mean value for background soil concentrations of selenium was reported as 0.2 ppm (*Shacklette and Boerngen 1984*). Higher levels of selenium (> 0.2 ppm) are present in 13 out of Oregon's 36 counties. In contrast, soils that are deficient in selenium (<0.1 ppm) are found in Crook, Deschutes, and Jefferson counties. A dietary deficiency of Selenium causes a troublesome myopathy, called "white muscle disease." (*Hathaway et al. 2004*)

Selenium substitutes for sulfur in minerals and higher concentrations of selenium are generally found in copper and copper-lead-zinc deposits. Exposure of selenium hosting sulfide minerals to air and water causes oxidation (i.e., acid rock drainage) and results in release to the environment. Agricultural practices also play a major role. In either case,

weathering and oxidation produces the more soluble selenite or selenate (analogous to sulfate) forms, and once in the aquatic environment, this selenium type can attain levels through bioaccumulation in the food chain that are toxic to fish and wildlife (*Lemly 2004*).

Selenium can be associated with uranium-bearing synsedimentary and diagenetic deposits. Certain species of plants occur only in soils of high selenium content (Table 3.11), and hence these plants can be useful guides to uranium prospecting. The plants give off volatile selenium compounds and consequently have a very offensive garlicky odor (*Oehne and Keyler 2008*).

Table 3.11: Tabulation of plants that accumulate soluble selenium

SELENIUM INDICATOR PLANTS[*]			
Common Name	**Genus**	**Common Name**	**Genus**
Milk and legume vetch	Astragalus sp.	Aster	Aster sp.
Woody aster	Xylorrhiza sp.	Saltbushes	Atriplex sp.
Golden weed	Oonopsis, sp.	Gumweeds	Grindelia sp.
Prince's plume	Stanleya, sp.	Snakeweed	Gutierrezia sp.
Tansy aster	Machaeranthea sp.	Beard tongue	Penstemon sp.

[*] not a complete list of selenium indicator plants, see Oehne and Keyler (*2008*)

Selenium is often associated with organic-rich deposits including coal and black shale. By analogy, marine shale and siltstone units and certain tuff units might be areas expected to contain selenium in higher concentrations. The only reported seleniferous area in Oregon is located 4 to 8 miles northwest of Rome, Malheur County (*Steere 1954; Lakin and Beyers 1948*). This general area is also where the Rome Erionite Deposit occurs.

3.4.18.2   Exposure Scenario

Selenium has the distinction of being a nutrient and toxicant, a narrow range separates beneficial concentrations of selenium and concentrations causing toxic effects (*FNB 2000*). Selenosis occurs if selenium is ingested in excess. Symptoms of selenosis include gastrointestinal upsets, hair loss, white blotchy nails, garlic breath odor, fatigue, irritability, and mild nerve damage (*Koller and Exon 1986*). Selenium is slightly hazardous in case of skin contact (irritant). In light of potential toxicity risks, the Institute of Medicine at the National Academy of Sciences set a tolerable upper limit (UL) for selenium of 400 micrograms per day for men and women 19 years and older (*NAS 2000*). For water quality standards, the USEPA designated selenium as a priority pollutant. USEPA's regional screening level for selenium in residential and industrial soil is 390 ppm and 5,100 ppm, respectively (*USEPA 2009b*).

3.4.19   Tin

3.4.19.1   Geologic Setting

Tin (Sn) is a relatively scarce element with a crustal abundance of 1.7 ppm. The only mineral of commercial importance as a source of tin is cassiterite. Worldwide, most sources of cassiterite today are found as secondary deposits. Cassiterite in these alluvial or placer deposits is called "stream tin", while a nodular variety is called "wood tin". Primary deposits are associated with granite intrusive rocks or within pegmatites or aplites associated with the granite. They occur also in rocks surrounding the margins of the intrusive rocks as veins, disseminations, skarns or carbonate replacements generated by tin bearing fluids derived from the granite magmas.

Domestic reserves of tin are small, of which Oregon has none. In southwestern and northeastern Oregon, there have been reports, from time to time, of cassiterite occurrences. The Irwin mine in Jackson County is one such occurrence. The only authenticated occurrence of cassiterite (stream tin) is on Pine Creek, northwest of Baker, Oregon. The source of this stream tin is unknown.

3.4.19.2   Exposure Scenario

Tin is toxic when ingested and may cause nausea, vomiting, and diarrhea; slightly hazardous in case of skin contact (irritant).

4.0 NOHM SAMPLING AND DETECTION

This section discusses the detection of NOHMs using appropriate sampling methods and laboratory testing.

4.1 SAMPLING SITES

Ten sites were examined in this study for the likelihood of a positive NOHM detection and sites that might have a negative or unknown expectation. The sites included five quarries, where hard rock aggregate is extracted; two gravel pits, unconsolidated accumulation of rounded rock fragments; and three road cuts, steep slopes parallel to, and above the highway. These sites are tabulated in Table 4.1.

Table 4.1: A list of the selected sites, ODOT inventory number, and site types used for this study

SITE[*]	ODOT NO.	TYPE	COUNTY	LOCATION
Painted Hill, W. Branch Bridge Creek; Brooks Quarry	OR-35-014-4	quarry	Wheeler	On Hwy 26 at MP 41 adjacent to West Branch Bridge Creek
Sheaville Quarry	OR-23-064-5	quarry	Malheur	On US 95 or Hwy 456 turn at MP 8.9 approximately 1.5 miles-up hill to quarry
Chancellor Quarry	OR-17-020-3	quarry	Josephine	Exit I-5 near MP 61.45; 1.7 north on Highland Road from Interchange
I-84/MP 356		road cut	Wallowa	One mile west of Exit 356 on I-84
Gravel (unnamed)	OR-13-077-5	gravel	Harney	From Hwy 440/ Refuge Road, to Harney Rock & Paving Co. pit
Sears Creek Quarry	OR-07-016	quarry	Crook	MP 40.1, Hwy 26
Gravel (unnamed)	OR-23-076-5	gravel	Malheur	MP 61.47, Hwy 95
I-5/MP 80		road cut	Josephine	I-5 southbound lane at MP 80
I-5/MP 69		road cut	Josephine	I-5 northbound lane at MP 69
Fulton Canyon Quarry	OR-28-002-4	quarry	Sherman	2.53 miles west of Biggs on the Biggs-Rufus Highway

[*]Site selection is based on Russell Frost, Statewide Aggregate Coordinator recommendations. The results of this limited NOHM sampling are not a guarantee that a NOHM does or does not exist at the examined sites; the results are indicative only of the presence of the NOHM in the areas sampled in the time the limited NOHM sampling was performed

4.2 SITE DESCRIPTION

The geology of each sampling site is briefly summarized below. Figures 4.1 through 4.4 are location maps for these sites.
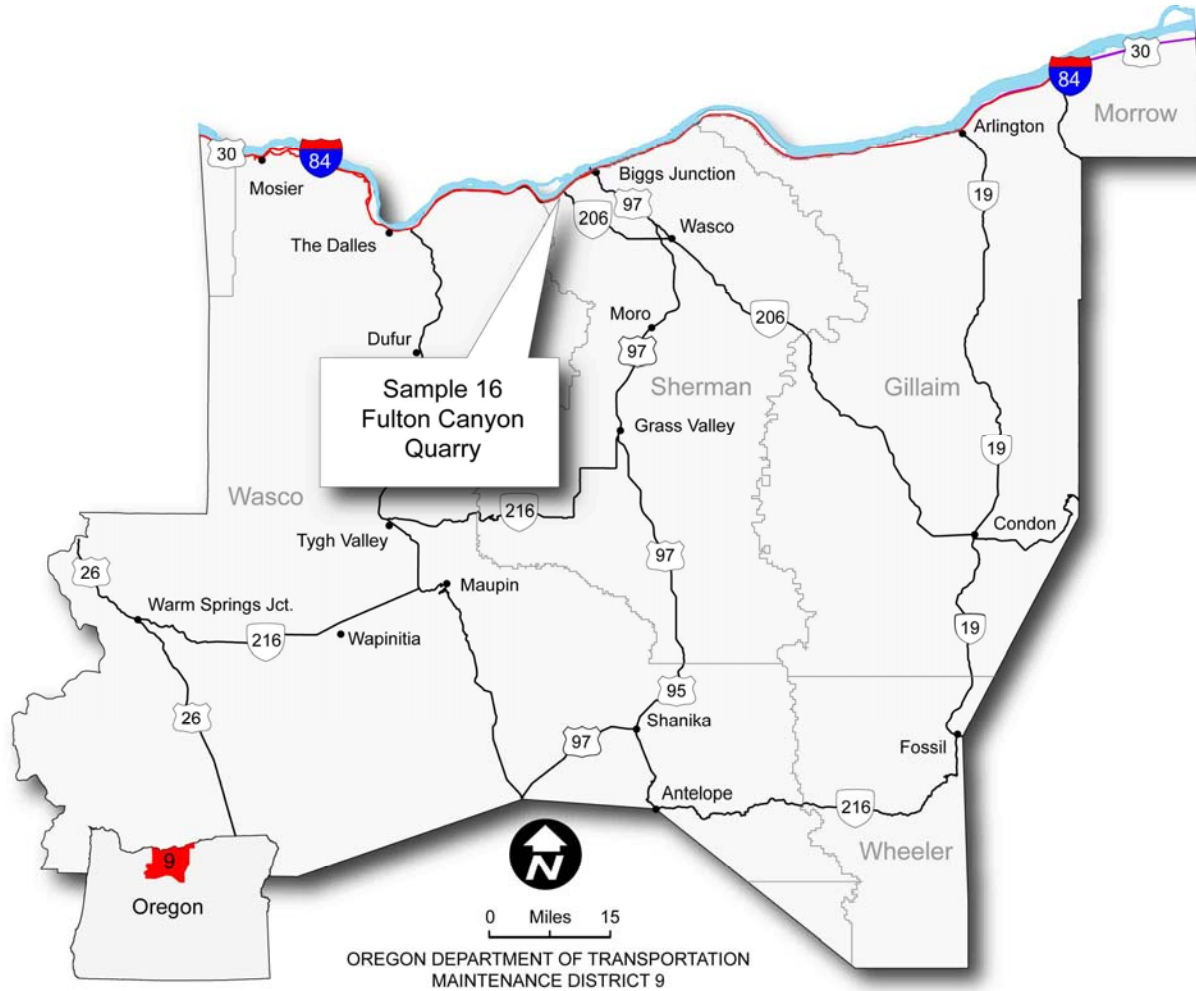
Figure 4.1: Location of the sampling site in ODOT Maintenance District 9
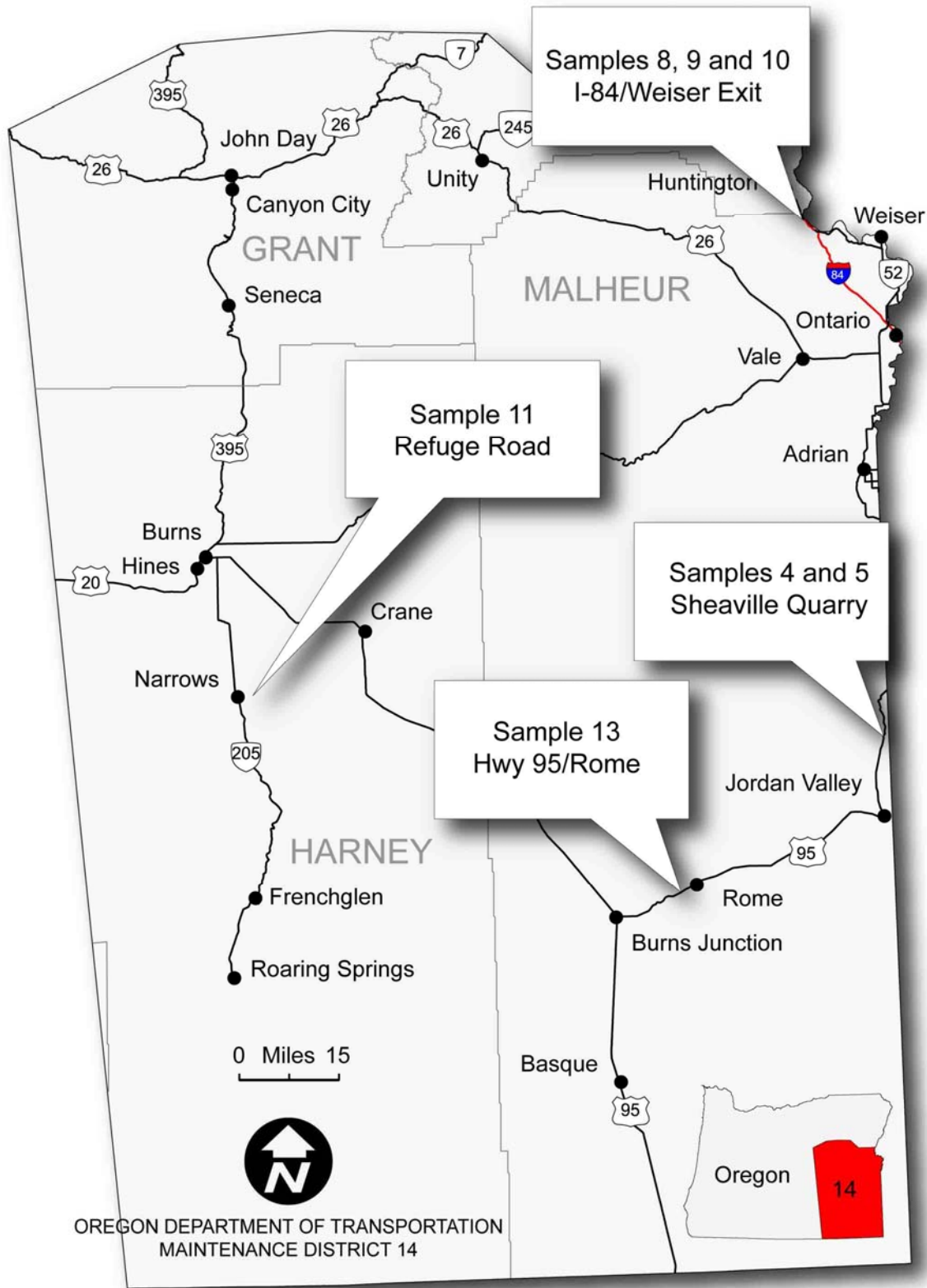
Figure 4.2: Location of the sampling sites in ODOT's Maintenance District 14
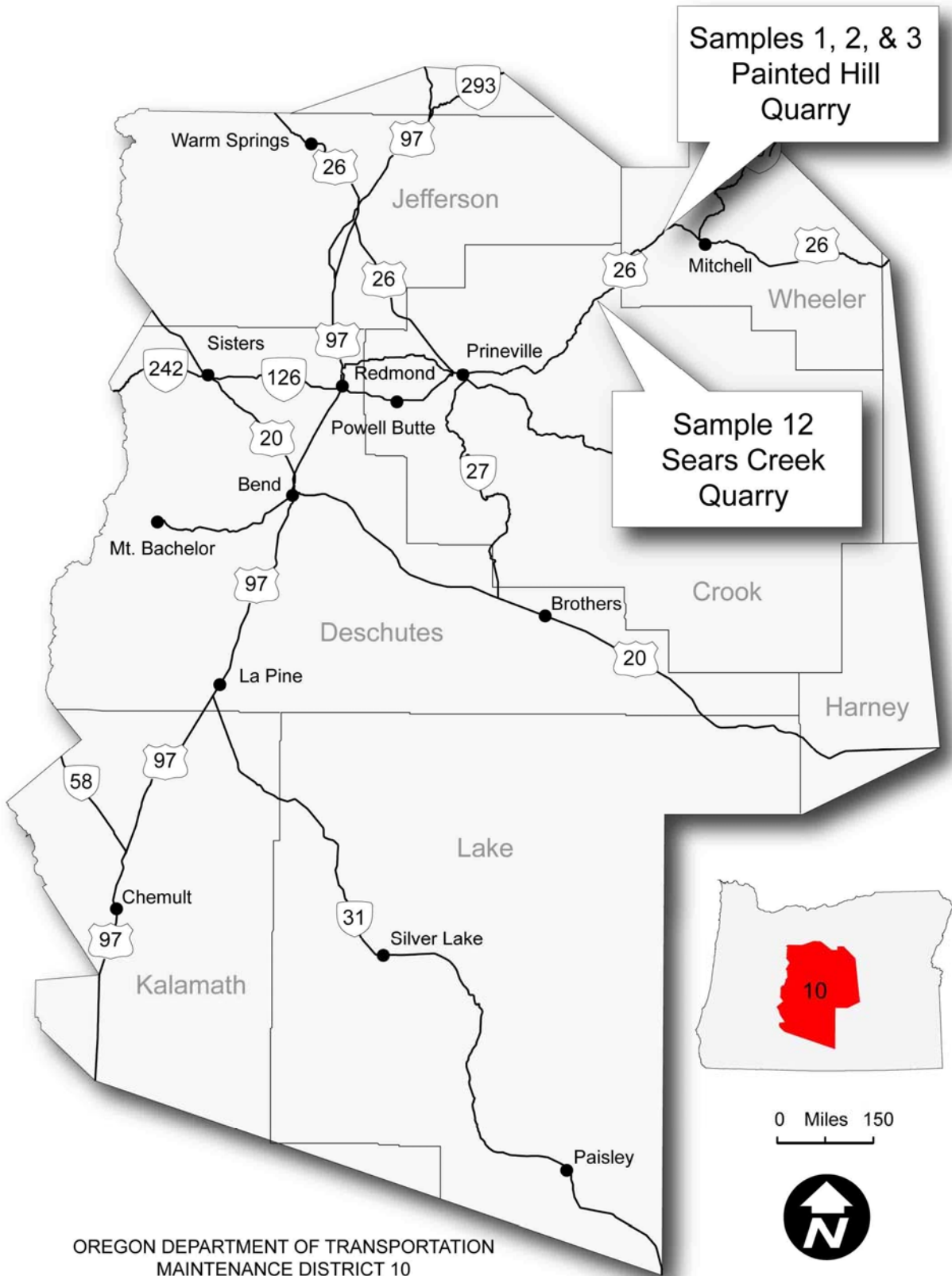
Figure 4.3: Location of the sampling sites in ODOT's Maintenance District 10
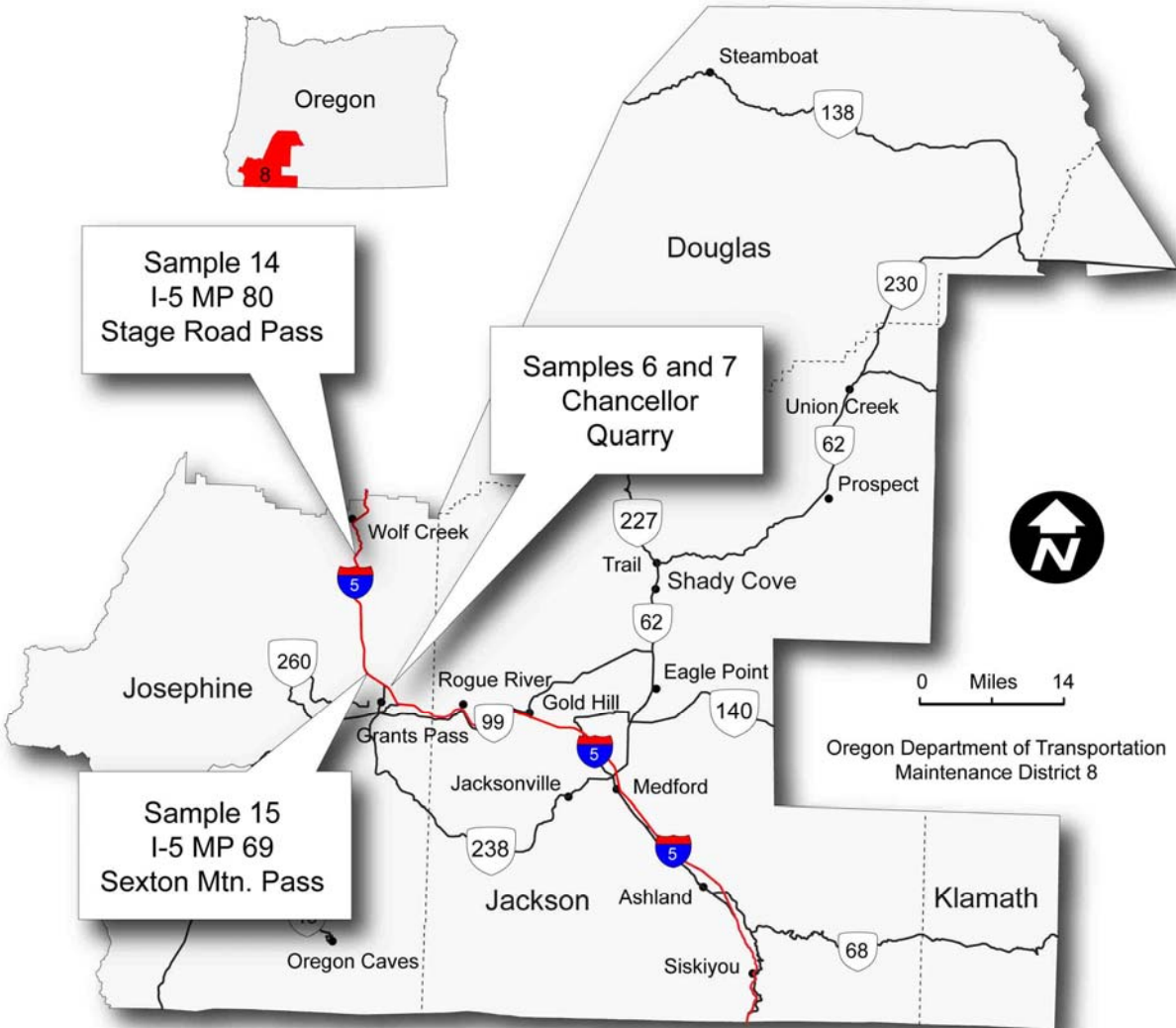
Figure 4.4: Location of the sampling sites in ODOT's Maintenance District 8

4.2.1 Fulton Canyon Quarry (28-022-4)

As shown in Figure 4.1, the Fulton Canyon Quarry (28-022-4) is located in Sherman County about 2.53 miles west of Biggs (Section 24, Township 2N, Range 15E). From Biggs, take the Biggs-Rufus Highway (Highway 30) west. Just beyond the Celilo-Wasco Highway/Fulton Canyon Road (Highway 206) intersection is the quarry's entrance. A locked gate prevents driving into an expansive load-out/stockpile area and then up a ramp onto the quarry's floor (Figure 4.5).

The quarry property covers about ±60.07 acres including ample room to work and process (load-out/stockpile) rock. As can be seen in Figure 4.5, rock has been mined from multiple bench levels in a ridge along the western side of Fulton Canyon. ODOT lists the quarry as active, but at the time of the site visit no operations were underway. When in use, operations at the quarry utilize conventional mining practices common in the industry.

Figure 4.5: Fulton Canyon Quarry, the load-out/stockpile area (foreground); looking south

The quarried rock is the Wampum Basalt of the Frenchman Springs Member in Columbia River Basalt Group (*Swanson et al. 1981*). The basalt is fine-grained, locally vesicular, and aphyric. The jointing type is an entablature-colonnade jointing pattern in which the rock "breaks" into hackly elongated pieces. Locally, flow tops can have abundant vesicles ranging from pinhole size to ½ inch in diameter. These vesicles are often filled with secondary minerals (Figure 4.6) and locally the openings along joints are filled with similar appearing secondary mineralization (Figure 4.7).

Jasper was found on a muck pile but not at its source. The jasper occurrence does not necessarily suggest a problem at the Fulton Canyon quarry, but it does put forward the possibility that certain horizons in the basalt have facilitated local hydrothermal systems. A localized system could have silicified either sediments or a weathered horizon/fossil soil between individual lava flows. Even more intriguing is the detection of trace amounts of gold in the jasper-bearing horizon over at the private quarry on east side of Fulton Canyon (*Mark Ferns 2010 Personal Communication*).

Figure 4.6: View of vesicular basalt with whitish zeolites lining vesicles (gas bubbles)

Figure 4.7: Photograph of secondary mineral(s) filling a joint

4.2.2 I-84/Weiser Exit 206 (Mile Post 356)

The location for the I-84/Weiser Exit 356 site is shown in Figure 4.2. This site is a 50 ft. high freeway road cut with steep slopes parallel to, and above the south side of I-84, about 1 mile

west of the exit to Highway 201 (Figure 4.8). The road cut section examined lies between Mile Posts 355 and 356. As a point of reference, the red pickup truck on the shoulder of the Interstate is parked next to Mile Post 355 (Figure 4.8).

Swanson et al. (*1981*) mapped the rocks along this stretch of I-84 as a mixture of Neogene volcanic rocks, which in this road cut are almost entirely basalt. Weathering altered/mineralized basaltic rock can be seen quite well in the road cut by the rock's variegated yellow, red, and orange color. There is a general increase in secondary minerals towards the western end of the road cut, perhaps an indication of more intensely altered rock.

Figure 4.8: I-84 road cut, Mile Post 355 is next to the pickup truck on the shoulder of the road; The vent structure is exposed near the cut's end (looking west)

Epithermal gold "bonanza" style mineralization known as the Kerby Prospect is the reason for sampling the I-84/Weiser Exit 206 site. This roadcut provides an opportunity to examine a "fossil" hot spring system for its hydrothermal alteration minerals. Alteration minerals that may form at depth in epithermal hot springs systems (and by inference, fossil systems like this one) include kaolinite, alunite, adularia, montmorillonite, illite, sericite, chlorite, pyrite, calcite, zeolites, and sodic plagioclase, as well as ore minerals such as Ag, Au, Hg, Mn, W, Sb, Pb, Zn, Cu, As, Sn, and Fe (*White 1955*).

Convincing evidence supporting the idea of a fossil hot spring system is seen near the western end of the road cut (Figure 4.9). A hot spring vent is recognizable by an area of shattered and silicified rock. In the vent, rocks appear to have tumbled, as evidenced by rounded rocks, an indication that boiling, a strong flow of hot water, or both occurred. Also, the vent area is veined with quartz or chalcedony. A whitish siliceous material blankets the top of the road cut; it may be silica sinter around the hot spring vent.

Figure 4.9: Close-up of the vent structure and the shattered, silicified rock related to a fossil hot spring system. Bladed crystals appearing to be stilbite have precipitated on walls of chambers and cemented the shattered fragments together

4.2.3 Sheaville Quarry (23-064-5)

As shown in Figure 4.2, the Sheaville Quarry is located in Malheur County (N½S½, Section 13, Township 28S, Range 46E). From U.S. Highway 456 or Highway 95 (Mile Post 8.9) turn onto County road to Silver City and continue 1.7 miles to the quarry. Site occupies 90-acres on the westerly flank of Purser Ridge (Figure 4.10). ODOT lists this quarry in its inventory as active, but no operations were underway at the time of the site visit. When in use, operations at the quarry use conventional mining practices common in the industry.

Figure 4.10: Sheaville Quarry, panoramic view of the quarry (looking east)

The quarry rock is a Miocene fine-grained basalt, part of the calc-alkaline lavas in this part of Purser Ridge. Mining has exposed an entablature with a curved columnar-blocky jointing pattern. There is a ½ to 2 inch thick weathering rind on the outside of most hexagonal columns; this may decrease with increased quarry depth. Vesicles are rare and secondary minerals are conspicuously absent.

ODOT's site documentation for the Sheaville Quarry mentioned that there were "occasional hydrothermal dikes of siliceous rock-chert." Chert float is exposed on the main haul road that leads into the quarry (Figure 4.11) and another cherty zone directly below the quarry's upper load-out area. The possibility of hydrothermal alteration is the reason the site was examined.

Figure 4.11: Photograph of white and black colored siliceous "cherty" rock material

4.2.4 Gravel Pit – U.S. Highway 95 (23-076-5)

The location of this gravel pit is in Malheur County (Figure 4.2). It can be reached by traveling east approximately 4.5 miles from Burns Junction on U.S. Highway 95 (Highway 456) to Mile Post 61.47. Here the road starts its ½-mile eastward descent into the 100 ft. deep canyon carved by Crooked Creek. Two adjoining parcels of about 37.54 acres comprise the site; the pit is about 300 ft. south off the road. The Bureau of Land Management administers the eastern 20 acres (W½SW¼SW¼, Section 12, Township 32S, Range 40E) and ODOT's land is the western 17.54 acres (E½SE¼SE¼, Section 11, Township 32S, Range 40E). ODOT lists the gravel source as active, but at the time of the site visit no operations were underway. When the site is in use the operations at the pit employ conventional mining practices common in the industry.

The gravel at the site is related to the flat-lying alluvial and lacustrine strata of the Rome Beds, which is mapped by Walker (*1966*) as Quaternary sedimentary rocks and interbedded lava flows. The strata is easily traceable from butte to butte and across the intervening canyon. Vitric volcaniclastic tuff material was deposited in the lacustrine system, which was highly alkaline and saline. The tuffs were altered to erionite- and/or bentonite-bearing beds (*Sheppard and Gude 1983; Gude and Sheppard 1986, 1993*). Stratigraphically below the gravel site is one of these bentonitic tuff layers.

The site was sampled for the possibility that the gravel bed received erionite-bearing sediments, eroded and transported from adjacent zeolite beds, because to the east on the other side of the canyon is the Rome Erionite Deposit. This deposit extends over an elongated north-south 220 mi^2 area.

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4.2.5 Gravel Pit – Refuge Road (13-077-05)

As shown in Figure 4.2, the Refuge Road site is located approximately ½ mile east of Highway 440/Refuge Road (NW¼, Section 1, Township 27S, Range 6W)—called the Narrows. The photograph of the site (Figure 4.12) was taken from the adjoining Harney Rock & Paving Company gravel pit, a private source. This ODOT site is listed as active. Across the road from the ODOT site is another private gravel pit that appears abandoned. The gravel here is part of the Harney Basin lakebed alluvium.

The Refuge Road site was sampled for the possibility that the lakebed alluvium received erionite-bearing sediment eroded and transported from adjacent zeolite beds, because to the west is the Harney Basin Clinoptilolite Deposit.

Figure 4.12: Refuge Road pit (looking west)

4.2.6 Sears Creek Quarry (07-016-4)

As shown in Figure 4.3, the Sears Creek Quarry is located in Crook County (NE¼, Section 36, Township 13S, Range 18E). Along Highway 26 at Mile Post 40.1 the quarry is on the highway's north side. The entrance gate for the road that leads up to the quarry floor and its load-out/stockpile area is unlocked (Figure 4.13). The ODOT-owned land here amounts to 3.76-acres and is adjacent to the quarry area which is USDA Forest Service owned land.

ODOT lists this quarry in its inventory as active, but at the time of the site visit no operations were underway. When in use the operations at the quarry use conventional mining practices common in the industry. As can be seen in Figure 4.13, the quarry's westerly-facing high wall has multiple bench levels.

Figure 4.13: Sears Creek Quarry (looking east), panoramic view that shows the quarry's westerly-facing high wall and multi-bench levels, well developed curved jointing and cool fracturing pattern is exposed

In Waters' (*1968*) geologic map, the quarry rock was mapped as andesite. The jointing style here is multiple curved columnar-blocky jointing patterns. These columns are cut by irregularly spaced horizontal to subhorizontal cooling fractures.

The sampling objective at the Sears Creek Quarry was to address the possibility of zeolites in joints and cooling fractures. It is common to find white to translucent, crystalline "veining" in these features (Figure 4.14). Occasionally rock voids and vesicles are filled with secondary minerals.

Figure 4.14: Photograph of veining in a horizontal cooling fracture.
The "vein" material is banded and contains sporadic cavities

4.2.7 Painted Hill Quarry (35-014-4)

The Painted Hill Quarry is located in Wheeler County (NE¼ NE¼, Section 25, Township 11S., Range 20E). The property covers ±20.12 acres between the south side of Highway 26 at Mile Post 59.7 and W. Branch Bridge Creek (Figure 4.3). At the mile post, turn south onto Gates Road; it leads a short distance down to the quarry's load-out/stockpiling area (Figure 4.15). ODOT lists the quarry as active, but at the time of the site visit no operations were underway. When the site is in use, the operations at the quarry employ conventional mining practices common in the industry.

Figure 4.15: Painted Hill Quarry (looking east), load-out/stockpile in foreground and quarried hill in the background

Owen (*1977*) mapped the rocks in the quarry as andesite (dikes, plugs, and sills) in the Clarno Formation. The jointing style here is a curved columnar-blocky jointing pattern that in plan displays well-formed polygonal columns averaging about 1 ft. in diameter. These columns are cut by irregularly spaced horizontal to subhorizontal cooling joints and fractures.

ODOT's site documentation for the Painted Hill Quarry indicated that minor hydrothermal alteration occurs on fractures and abundant secondary minerals. The secondary minerals are commonly white, solid crystalline, and fill widened fractures and joints (Figure 4.16). In the wider joints, some up to several inches wide, the vein material locally contains internal angular rock breccia fragments (resembling a stockwork texture) and variously sized crystal-lined cavities (Figure 4.17).

Figure 4.16: Photograph of minor hydrothermal alteration on a fracture

Figure 4.17: Photograph of a cavity containing secondary minerals.
The cavity contains framboidal pyrite precipitate on the walls, which is typical. In turn, the pyrite is covered by either white to colorless banded amorphous quartz and on which are showy colorless quartz crystals. It is also common to find in these cavities blocky calcite and/or gypsum

4.2.8 Chancellor Quarry (17-020-3)

The Chancellor Quarry is ±243.4 acre site located in the east-central part of Josephine County (Figure 4.4), close to Merlin (Section 13, Township 35S, Range 6W). Take I-5 Exit 61, the Merlin exit. Turn east on Merlin-Galice Road for approximately 100 ft. then turn north on Highland Road and continue 1.7 miles. The quarry's entrance is to the right and blocked by a locked gate. ODOT lists this quarry as active, but no operations were underway at the time of the site visit. When in use, the operations at the quarry use conventional mining practices common in the industry.

The quarry is situated in a peridotite ridge, which is on the southwest side of Walker Mountain. The Chancellor Quarry provided the opportunity to sample a site that has ultramafic rocks. There are two pits side-by-side separated by a narrow rock ledge; the south pit is the larger of the two (Figures 4.18 and 4.19). A flat load-out/stockpile area lies at floor level in front of the south pit, while another is near the bottom of the hill close to the gate.

Figure 4.18: Chancellor quarry, panoramic view of the south pit (looking east)

Figure 4.19: Chancellor quarry, panoramic view of the north pit (looking north)

The peridotite is primarily serpentinized olivine with minor amounts of pyroxene and chromite (*Yule et al. 2009*). The peridotite is brown, often appearing speckled, and has a granular texture (Figure 4.20). The Grants Pass batholith, a metamorphosed diorite to granodiorite, is exposed in a haul road along the southern-side of the present workings. Where the rocks have been completely serpentinized, they are light- to dark-green, fine-grained, blocky to highly fractured, and locally sheared (Figure 4.21). The shear zones contain narrow veins or stringers of calcite and other white secondary (unidentified) minerals.

Figure 4.20: Photograph of peridotite containing a vein-like mass of anthophyllite

Figure 4.21: Photograph of serpentine cut by a near vertical, foot wide shear zone

4.2.9 I-5/MP69 – Sexton Summit

The Sexton Summit site is shown in Figure 4.22 where ODOT is preparing to upgrade Interstate 5 (I-5), Mile Post 69. The project will involve the construction of northbound and southbound truck-climbing lanes requiring shoulder/rock slope work. The rock slope was inspected along the northbound lane from Mile Post 68 to the summit, called the Sexton Summit transect.

At the summit, the I-5 roadway passes through almost 100 feet of bedrock where the rock slope along both lanes has been terraced to retain rock fall and preventing spillage onto the roadway (Figure 4.22). The rocks along the Sexton Summit transect are part of the Sexton Mountain Ophiolite (*Smith et al. 1982*). Alternatively, Wiley (*2006*) described the rocks as a wide band of serpentinite-matrix (Greenback) mélange underlying the ophiolite. The lithologies observed along the Sexton Summit transect starting at Mile Post 68 changed from granodiorite saprolite and float (Grants Pass Batholith) to metasedimentary (argillite) and metavolcanic rocks (greenstone) at the summit. These rocks are metamorphosed to greenschist facies. According to Russell Frost (*2010 ODOT written communication*), ODOT's geotechnical drilling for the upgrade also encountered serpentine. This rock was not observed along the Sexton Summit transect.

Figure 4.22: View of the Sexton Summit from I-5's northbound lane.
In the highwall of the roadcut, the rocks are metavolcanic and metasedimentary rock.

There is a sulfide prospect about 1,000 ft. north of Mile Post 68 and just below the Interstate (*Ramp and Peterson 1979*). Here rock exposures along the roadway are locally altered and decomposed, iron oxide staining is conspicuous, and when struck gives off a sulfur odor. Pyrite when exposed to air and water reacts to produce sulfuric acid. The iron oxide staining is a tell-tale sign of possible acid rock drainage and may cause technical, environmental, and aesthetic problems through both the decomposition of the rock and its associated acidification.

4.2.10 I-5/MP 80 – Stage Pass Road Summit

The Stage Pass Road Summit site is shown in Figure 4.23 where ODOT also plans to upgrade I-5, Mile Post 79.7. The project will involve a northbound and southbound truck-climbing lane requiring shoulder/rock slope work. The rock slope at highway level was inspected along the southbound lane from Mile Post 80 to the summit, called the Stage Pass transect.

The I-5 roadway passes through at least 80 feet of bedrock where the rock slope along both lanes has been terraced to retain rock fall and prevent spillage onto the roadway. This bedrock is a hornblende-bearing metatuff assigned to the Rogue and Galice Formations (*Ramp and Peterson 1979, Smith et al. 1982*). The metatuff is fine grained, appears massive, and exhibits a gray-green hue. These rocks are metamorphosed to greenschist facies. Several fault or shear zones are well exposed in the roadcut, the larger zones range from 6 inches to 2 feet wide. Rocks adjacent to these structures appear somewhat phyllitic, while the rocks within the zones are locally shattered, even looking mylonized. Mineralized rock was absent in this Stage Pass transect, though quartz knots are scattered throughout the rock itself.

Figure 4.23: View of the Stage Road Pass Summit from I-5's northbound lane.
In the highwall of the roadcut, the rock is metatuff

4.3   SAMPLING METHOD

The sampling methods were designed with the emphasis on practicality. The time and funds invested need to be sustainably implementable. The variance from an ideal plan was recognized from the beginning (detect v. non-detect). Sampling intensity was kept at a minimum by targeting altered or mineralized rock, secondary minerals (e.g., zeolitic phases, specifically fibrous types), or an asbestos/rock association. These so called "spot tests" could represent a single piece of rock (or chunks) or a potential NOHM specimen itself, chiseled free from a rock exposure or quarry wall; or it was a scoop of rubble occurring below the suspected NOHM occurrence. As a general rule, multiple samples from a site were combined into one

representative laboratory sample, called a composite sample. This was done to quantitatively balance between the variability of samples and to balance data quality with the intended use and analytical costs.

Random or profile sampling of material was conducted at sand and gravel pits, generally within a predetermined area. These are numerous individual scoop samples (usually three per acre of area, 1000 tons, or mile of road) taken irregularly over the site. Then the samples are mixed into a single grab sample, from which a laboratory sample is retrieved. Minimum sample volume was 1 quart. Usually the top 12 inches of unconsolidated material was collected as surface disturbance was not a concern. Gravel samples, as well as most rubble scoop samples, were field sieved (a nominal size of less than 3/8 inch) to remove larger fragments. Similar sampling methods were used at road cuts, but the sampling strategy depended on the slope material and whether it was unconsolidated material or rock.

Sampling tools consisted of a small shovel, plastic scoop, rock hammer and chisel, and sieves. These tools were cleaned before each use. All laboratory samples were "sacked" in 1-quart-sized, resealable zipper, plastic bags. The sacking was indelibly labeled or tagged and usually doubled. A project field notebook was used to record site and sample information. To supplement field notes, digital photographs were taken at most sites to help document the NOHM sampling area; these also included images of some sites that were "stitched together" to produce a panoramic mosaic.

4.4   SAMPLE DESCRIPTION

NOHM samples can be categorized three ways:

- Geochemical: a determination of the abundance of multiple elements.

- Asbestos: a determination of the presence of asbestos minerals.

- Mineralogical: determination of zeolite minerals, erionite being the mineral of interest.

Fifteen samples were collected. Of these, 4 were geochemical samples only, 2 were asbestos samples only, and 10 were mineralogical samples (Table 4.2). The four geochemical samples were analyzed by ALS Laboratory Group (ALS), Inc. in Sparks, Nevada. LabCor, Inc. in Portland, Oregon conducted the mineralogical and asbestos testing. Their respective reports of laboratory analysis are provided as separate electronic files in appendices.

Table 4.2: Sample category, quantity, and locations

SAMPLE CATEGORY	QUANTITY	LOCATION
Geochemical	4	Painted Hill, Sheaville, and I-84/Weiser Exit 206
Asbestos	2	Chancellor
Mineralogical	10	Painted Hill, Sheaville, I-84/Weiser, Refuge Road, Sears Creek, Hwy 95/Rome, I-5/MP80, I-5/MP69, and Fulton Canyon

Table 4.3 below lists the detection protocol used by each laboratory, followed by Table 4.4 that summarizes the sampling methods.

Table 4.3: Detection protocol

LAB NO.	LAB	SAMPLE	DETECTION PROTOCOL	SAMPLE CATEGORY	SITE
102184-S01	Lab/Cor	1	PLM/XRD, TEM	Mineralogical	Painted Hill
102184-S02	Lab/Cor	2	PLM/XRD, TEM	Mineralogical	Painted Hill
	ALS	3	35-element ICP-AES	Geochem	Painted Hill
102184-S03	Lab/Cor	4	PLM/XRD	Mineralogical	Sheaville
	ALS	5	35-element ICP-AES	Geochem	Sheaville
102184-S04	Lab/Cor	6	CARB 435 by PLM	Asbestos	Chancellor
102184-S05	Lab/Cor	7	CARB 435 by PLM	Asbestos	Chancellor
102184-S06	Lab/Cor	8	PLM/XRD, TEM	Mineralogical	I-84/Weiser Exit 206
102184-S07	Lab/Cor	9	PLM/XRD, TEM	Mineralogical	I-84/Weiser Exit 206
	ALS	10	35-element ICP-AES	Geochem	I-84/Weiser Exit 206
102184-S08	Lab/Cor	11	PLM/XRD, TEM	Mineralogical	Refuge Road
102184-S09	Lab/Cor	12	PLM/XRD, TEM	Mineralogical	Sears Creek
102184-S10	Lab/Cor	13	PLM/XRD	Mineralogical	Hwy 95/Rome
102184-S11	Lab/Cor	14	PLM/XRD, TEM	Mineralogical	I-5/MP80
	ALS	15	35-element ICP-AES	Geochem	I-5/MP69
102184-S12	Lab/Cor	16	PLM/XRD	Mineralogical	Fulton Canyon

Table 4.4: Summary of the sampling methods

SAMPLE	SITE	SAMPLE DESCRIPTION
1	Painted Hill	A sample chiseled free from the cavity shown in Figure 4.16.
2	Painted Hill	A composited grab sample from stockpile areas containing a mixture of unconsolidated material, rock chunks, and white secondary minerals.
3	Painted Hill	A rock "chunk" obtained from the conspicuous halo of iron staining that irregularly outlines the fracture shown in Figure 4.15. Here framboidal pyrite (source of the iron staining) coats the fracture walls and through which secondary minerals are common. When struck the altered rock gives off a strong sulfur smell suggesting the presence of disseminated pyrite.
4	Sheaville	A composited grab sample was collected from stockpile rock which contained a mixture of unconsolidated material and crushed rock.
5	Sheaville	A sample of the "cherty" material shown in Figure 4.11.
6	Chancellor	Particular attention was paid to the serpentinite blocks in the north pit where one might assume that chyrsolite is present. The shear zone shown in Figure 4.20 was sampled and a scooped sample from the loose pile below the shear was added to the sample.
7	Chancellor	A vein-like, honey-colored crystalline mass in the south pit was sampled (Figure 4.20). This mass and others exhibited radiating crystals that resembled anthophyllite.
8	I-84/Weiser Exit 206	Between Mile Posts 355 and 356, a composite sample of loose rock material collected from the middle portion of the road cut at 100 to 200 feet intervals. Sampling the material at the bottom of the road cut was avoided because this material did not appear to be in-place.
9 & 10	I-84/Weiser Exit 206	A rock sample obtained from the west end of the roadcut. This sample was crushed and split into two laboratory samples--one for mineralogical examination (erionite) and another for hydrothermal alteration elements (geochem).
11	Refuge Road	A composite sample of unconsolidated material was collected from the excavation floor, sides, and road bank.
12	Sears Creek	A composite sample of vein material (Figure 4.14) was collected from multiple horizontal cooling fractures.
13	Hwy 95/Rome	The alluvium at this site was sampled at three locations: the disturbance floor and the adjacent road cut exposures both sides of the highway, and combined together (i.e., composite sample).
14	I-5/MP80	Rock samples along the southbound lane starting at Mile Post 80 up to the Stage Road Pass summit were randomly collected and combined into a single representative sample.
15	I-5/MP69	A rock sample was collected from a high wall cut just beyond the northbound lane's northerly curve up to the summit.
16	Fulton Canyon	A sample was collected from the secondary mineralization filling the joint shown in Figure 4.7.

4.5   SAMPLE GEOCHEMISTRY

A wide variety of methods exist for extracting and analyzing multi-elements in geologic materials. Table 4.5 below lists the principal analytical methods that are commercially available.

Table 4.5: Multi-element analysis methods

Method*	Description
ICP-MS	Inductive Coupled Plasma Mass Spectrometry is the coupling of inductively coupled plasma with a mass spectrometer that separates and detects ions (mass-to-charge ratio).
ICP-AES	Inductive Coupled Plasma Atomic Emission Spectrometry is detection of element concentration by examining the intensity and wavelength of light emitted from the sample when gaseous sample is ionized and maintained in a plasma state.
INAA	Inductive Neutron Activation Analysis is a qualitative and quantitative analysis of elements in samples in which target nuclei are bombarded with neutron beams to start nuclear reactions which emit characteristic gamma ray radiation.
AAS (Flame or Electro-thermal Atomizers)	Atomic Absorption Spectroscopy is a technique used to identify chemicals based on the measurement of the spectra produced by atoms and molecules with absorption of electromagnetic radiation.
XRF	X-ray Fluorescence is a widely used technique for elemental analysis that uses the emission of characteristic fluorescence from a material that has been excited by bombarding with high-energy X-rays or gamma rays.

*No critical evaluation or recommendation of any method is meant or implied

While each of the five instrumental techniques above could be used to adequately characterize the project's geochemical samples, the final choice of which technique, or techniques, was based on the relative importance of these factors: cost, sensitivity, speed, precision, and utility of the technique. There is no advantage in using an expensive high precision analysis when the objective was a "first pass" screening. With the exception of lithium, selenium, and tin, the 35-element ICP-AES analysis with trace Hg by Cold Vapor/AAS using an aqua regia leach included the elements of most concern (Table 4.6). Note that other analytical packages are commercially available that can give a wider possible elemental range (Table 4.7).

Table 4.6: List of the 35-elements and their detection limits

ANALYTES[†] AND RANGES (PARTS PER MILLION – PPM, UNLESS OTHERWISE NOTED)									
Ag	0.2-100	Co	1-10,000	Mn	5-100,000	Sr	1-10,000
Al	0.01%-50%	Cr	1-10,000	Mo	1-10,000	Th	20-10,000
As	2-10,000	Cu	1-10,000	Na	0.01%-10%	Ti	0.01%-10%
B	10-10,000	Fe	0.01%-50%	Ni	1-10,000	Tl	10-10,000
Ba	10-10,000	Ga	10-10,000	P	10-10,000	U	10-10,000
Be	0.5-1,000	Hg[*]	0.01-10,000	Pb	2-10,000	V	1-10,000
Bi	2-10,000	K	0.01%-10%	S	0.01%-10%	W	10-10,000
Ca	0.01%-25%	La	10-10,000	Sb	5-10,000	Zn	2-10,000
Cd	0.5-1,000	Mg	0.01%-50%	Sc	1-10,000		

[†] Data reported from aqua regia leach should be considered as representing only the leachable portion of the particular analyte. [*] Hg by Cold Vapor/AAS (Atomic Absorption Spectrometry) was added to the analytical package to report Hg at a lower detection limit that otherwise would have been 1 ppm

Table 4.7: ALS Group multi-element analytical packages with price per sample information

ELEMENT COVERAGE	SAMPLE SIZE (g)	DIGESTION METHOD	PERCISION	DETECTION PROTOCOL	PRICE PER SAMPLE
51 (Super Trace)*	0.5	aqua regia	ultra-trace level	ICP-MS & ICP-AES	24.55
51	1.0	aqua regia	trace level	ICP-MS & ICP-AES	21.30
48	1.0	4-acid[†]	trace level	ICP-MS & ICP-AES	25.50
35	1.0	aqua regia	trace level	ICP-AES	10.25
33	1.0	4-acid[†]	trace level	ICP-AES	13.60

*Suitable for soil and sediment survey; small sample size and lowest detection limits
[†]This procedure quantitatively dissolves nearly all elements for the majority of geologic materials

4.6   ERIONITE DETERMINATION

The detection of erionite is fairly well documented through previous zeolite investigations (*Eylands et al. 2009*). The instrument most often employed for erionite detection is currently X-ray (powder) Diffraction (XRD). XRD is regularly complemented by Scanning Electron Microscopy (SEM) and/or Transmission Electron Microscopy (TEM). Both can be equipped with an Energy-Dispersive Spectrometry (EDS) to quantify elemental compositions. Seldom is stereomicroscopy and Polarized-Light Microscopy with Dispersion Staining (PLM/DS) used alone to confirm erionite's presence, but as a screening step, it can be a useful technique.

Table 4.8 below is a compilation of available (published) analytical methods for detection of natural erionite. It gives the reader some background information which can be supplemented by consulting relevant literature and authoritative works on each technique.

Table 4.8: Erionite analysis methods

Method[*]	Information Provided	Advantage and Disadvantages
PCM, OM, PLM/DS	The tenet of this procedure is to determine optically the presence or absence of fibers and particulate morphology. Estimation of the percent of fibers (usually as area or particle percent) by visual or point count methods is possible. Erionite has refractive indices in the range of 1.458-1.48, birefringence of about 0.0191, with a uniaxial positive sign of elongation and parallel extinction; fibers, rods, very distinct needles and prismatic-shaped crystals. Erionite fibers, with a maximum length of approximately 50 μm, are generally shorter than asbestos fibers.	Polarized light microscopy can be used as a first means of identification—a screening step only. Optical screening is more suitable for zeolites filling amygdales and cavities in basalts than sedimentary zeolites. For sedimentary zeolites, optical investigation alone is not conclusive and may not even serve to screen the sample for fibers. However, erionite is not the only zeolite mineral with a fibrous habit. Natrolite, mesolite, scolecite, thomsonite, and mordenite have similar appearing fibrous crystal habits (*Wright et al. 1983, Sand and Mumpton 1978*).
SEM/EDS	SEM is used for inspecting topographies of specimens at very high magnifications. To produce the SEM image, the electron beam is swept across the area being inspected, producing many signals that are then amplified, analyzed, and translated into 3D images of the topography being inspected. Mineral identification is possible when the SEM is equipped with an EDS (*Lowers and Meeker 2007*). When the zeolite morphology is not distinctive for example,	SEM can provide complimentary data for large particles, including bundles and clumps of fibers, surface morphologies, and quality assurance for uniform particle distribution on filters. The SEM method may be able to identify erionite in concentrations far too low to be detected by the standard XRD. Conversely, erionite can be masked in clay lump-like particles and not visually imaged but identified by XRD.

Method[*]	Information Provided	Advantage and Disadvantages
	SEM/EDS can be used to discriminate fibrous erionite from other zeolite fibers (e.g., mordenite) by quantitatively determining the Si:Al ratio.	
TEM/EDS	High magnification imaging of particle morphology, semi-quantitative chemical analysis by EDS, and crystal structure information by Selective Area Electron Diffraction (SAED) can all be used to aid in positively identifying mineral grains and fibers. TEM/EDS can be zeolite fibers (e.g., mordenite) by quantitatively determining the Si:Al ratio.	TEM can be used for the analysis of erionite in soils and bulk samples in general. TEM does not provide three-dimensional information as this type of imagery is lost due to the projection into a two-dimensional image. Particle length and width, i.e., fibrosity indices (F), characteristics are obtained from TEM data and the TEM technique can discriminate intergrowth fault planes and stacking faults of mineral intergrowths, e.g., erionite-offretite intergrowths. Sample preparation is very important because the quality of sample preparation contributes greatly to whether the micrograph will be good or not.
XRD	XRD is the industry standard for the determination of mineral or crystalline content in any given sample (*USEPA 2009a*). The XRD method may be used to estimate relative mineral abundance in the sample. While XRD can determine the presence of erionite, it cannot confirm the type of erionite, e.g., Na-rich and Ca-rich erionite. Hexagonal cell parameters are a=13.19-13.34 Å and c=15.04-15.17 Å (*Smith 1963, Staples and Gard 1959*). The erionite 100 reflection at approximately 7.67° 2θ is commonly used as a structural match and indication of the presence of erionite. The peak is also used to determine the relative abundance of erionite in relation to other samples by determining the net area of this peak.	The XRD method has a triple advantage: it is simple, only a few milligrams of sample are required, and the sample need not be a single crystal. XRD techniques can detect erionite in trace amounts, usually limited to between 100-500 ppm erionite in tuffaceous rocks (Chipera and Bish 1989, Dogan et al. 2006b, E*berly 1964, Eyland et al. 2009, Gualtieri et al. 1998, Passaglia et al. 1998*). A major disadvantage of the XRD with respect to erionite is that it must be present in relatively high amounts compared to what can often be seen by SEM methods. Also, the detection by XRD of trace amounts of erionite in zeolitic-bearing samples can be hindered by its coexistence with authigenic clay (smectite) and other zeolite minerals, such as clinoptilolite and offretite (*Wise 1976*). Additionally, the presence of smectite can interfere with the identification of erionite by XRD giving false positive result. So careful XRD analysis is important.
XRF	XRF is a multi element analysis technique with sensitivities in the range of 10^{-8} g. Sample sizes of a few mg to one gram can be analyzed. Liquid samples also can be analyzed.	Characteristic X-rays are fingerprints of elements.

PLM/DS – Polarized Light Microscopy with Dispersion Staining, PCM – Phase Contrast Optical Microscopy, OM – Optical Microscopy, XRF– X-ray fluorescence spectroscopy, XRD – X-ray Powder Diffraction, TEM – Transmission Electron Microscopy, SEM/EDS – Scanning Electron Microscopy equipped with Energy Dispersive Spectroscopy
[*] No critical evaluation or recommendation of any method is meant or implied

The specimens examined for erionite in this study were prepared, inspected, and analyzed in the following manner:

1. Stereomicroscopy inspection of material

    - Material was fragmented rock and rock with layered material, etc.

    - If rock material, some reduction in size was necessary to look for internal matrices.

    - Looked for fibrous/semi-fibrous material and tufts. (Erionite is not known to occur in other than fibrous form, in single needles or in tufts.)

    - Estimated the percentage of tufted and fibrous/semi-fibrous materials.

    - Removed fibrous/semi-fibrous material and tufts with forceps, scalpel, or other tool.

    - If enough material was available, prepared material for PLM examination.

2. PLM/DS examination of material

    - Took a portion and placed in appropriate oil for erionite analysis. (Under the petrographic microscope, erionite fibers are often colorless and normally terminate with a needle-like appearance or with a rectangular profile suggesting the possible development of weak basal cleavage. Generally erionite fibers have a maximum length of approximately 50 μm, which is shorter than amphibole asbestos fibers.).

    - Examined for fibrous nature.

    - If fibrous, then the material was set aside for TEM/XRD analysis.

3. TEM analysis (Particle length and width, i.e., fibrosity indices (F), characteristics are obtained from TEM data and the TEM technique can discriminate intergrowth fault planes and stacking faults of mineral intergrowths, e.g., erionite-offretite intergrowths.)

    - For TEM preparation, ground a portion of the material in an agate mortar and pestle.

    - Placed a small amount in distilled water.

    - Mixed and placed about 6 μl drop on a carbon-coated TEM grid.

    - Examined for fibers.

    - If fibers were seen, recorded diffraction pattern for later analysis.

    - Performed EDS quantitative analysis on fiber.

- Only fibers with Na, Mg, Al, Si, K, Ca elements were evaluated.

- Performed ratio of elements to determine erionite composition.

4. XRD analysis

   - If sufficient quantity of sample was available, prepared a powder sample and placed in an XRD cup.

   - Analyzed by XRD from 5-70 degrees 2θ (erionite 100 reflection at approximately 7.67° 2θ is commonly used as a structural match and indication of the presence of erionite).

   - If insufficient quantity of sample was available, then pre-weighed an Ag membrane filter.

   - Filtered about 100-200 mg of sample onto Ag membrane filter. (Material from a sample is suspended in a suitable liquid and the fine portion decanted into a filter apparatus.)

   - Analyzed by XRD from 5-70° 2θ.

   - Compared to erionite standard.

4.7 ASBESTOS DETERMINATION

For this study, asbestos testing was done according to The National Institute for Occupational Safety and Health analyzing method, named NIOSH 9002 (*NIOSH 1994*). This method is USEPA approved and the method most commonly used by USEPA and its contractors. Lab/Cor, Inc., is a USEPA certified asbestos testing laboratory.

The NIOSH 9002 method is a PLM/DS qualitative and semi-quantitative means for the determination of asbestos in soil/solid materials. Below in Table 4.9 is a compilation of available (published) analytical methods used in NOA studies that have been applied to soils/solid materials (*Clinkenbeard et al. 2002*).

Table 4.9: Summary information on the more common analytical methods applied to NOA studies

Method[*]	Information Provided	Advantages and Disadvantage
PLM/DS	Most fibers thicker than 1 μm can adequately be defined in the light microscope. The light microscope remains the best instrument for the determination of mineral type. This is because the minerals under investigation were first described analytically with the light microscope. It is inexpensive and gives positive identification for most samples analyzed.	Light microscopy requires a great deal of experience and craft. This method is useful for the qualitative identification of asbestos and the semi-quantitative determination of asbestos content of bulk samples. The method measures percent asbestos as perceived by the analyst in comparison to standard area projections, photos, and drawings, or trained experience. The method is not applicable to samples containing large amounts of fine fibers below the resolution of the light microscope.
XRD	Provides useful corroborating information when the presence of asbestos has been shown by microscopy. Identification of mineral type(s) present in bulk samples; may be used to estimate mineral abundance.	XRD is partially successful in determining the mineral types but was unable to separate out the fibrous portions from the non-fibrous portions. Also, the minimum detection limit for asbestos analysis by XRD is about 1%.
DTA	Provides useful corroborating information when the presence of asbestos has been shown by microscopy.	No more successful than XRD.
IR	Provides useful corroborating information when the presence of asbestos has been shown by microscopy.	No more successful than XRD.
EPMA	Quantitative chemical analysis of areas on individual mineral particles is possible.	Chemical composition can be used for mineral identification, included results on major and minor trace elements. Requires sample to be flat and have a finely polished surface.
SEM	High magnification imaging of particles and fiber morphology. The SEM can provide two of the three pieces of information required to identify fibers by electron microscopy: morphology and chemistry.	When fibers are present, but not identifiable by light microscopy, use either SEM or TEM to determine the fiber identity. Chemical analysis by EDS (Energy Dispersive Spectroscopy) is semi-quantitative and may not be sufficient for distinguishing different minerals with similar chemical compositions
TEM	High magnification imaging of particle morphology, semi-quantitative chemical analysis by EDS, and crystal structure information by Selective Area Electron Diffraction (SAED) can all be used to aid in positively identifying mineral grains and fibers. The TEM is a powerful tool to identify fibers too small to be resolved by light microscopy and should be used in conjunction with XRD and PLM/DS methods when necessary.	When fibers are present, but not identifiable by light microscopy, use either SEM or TEM to determine the fiber identity. Definitive for asbestos mineral identification.

PLM/DS – Polarized Light Microscopy with Dispersion Staining, XRD – X-ray Powder Diffraction, DTA – Differential Thermal Analysis, IR – Infrared Absorption, Electron Probe Microanalysis, SEM – Scanning Electron Microscopy, TEM – Transmission Electron Microscopy, EPMA – Electron Probe Micro-Analysis
[*] no critical evaluation or recommendation of any method is meant or implied

5.0   ANALYTICAL RESULTS

As a "proof-of-concept" study, the synoptic sampling approach that was employed here has succeeded to a certain degree. However, these so called "spot tests", will, by their very nature, be subjective in their interpretation. The limitation of this sampling and detection exercise should be apparent:

- A small number of samples and the use of composite samples intended to be representative of the geologic material it represents.

- Sample collection was not conducted according to a systematic collecting plan.

- The intent was not to conduct a full site characterization.

5.1   ELEMENTAL ANALYSIS

Results of the four elemental analyses are reported in Table 5.1. In this table, the concentration of elements found in the samples are compared with USEPA soil industrial standards and mean USGS western U.S. soil concentrations (*Shacklette and Beorngen 1984*). The analytical data for some elements include values that are below the limits of detection, and these values are expressed as less than (<) a stated value.

Sample 3 (Painted Hill Quarry) exhibits elevated levels of As, Ca, Fe, Hg, Mo, Ni, and S. These elements, especially As, are indicator elements of hydrothermal systems, the presence of which at this quarry was suspected beforehand. As can be seen in Table 5.2, arsenic in all samples exceeds its Risk-Based Concentration (*USEPA 2004, 2006, 2009a*). The most striking is Sample 3's arsenic content of 479 ppm. It far exceeds the Risk-Based Concentration values. From a mineral exploration standpoint, the 57 ppm molybdenum is anomalous. There are also anomalous geochemical zones at I-84/Weiser Exit 206 (Sample 10) and I-5 Mile Post 69, Sexton Summit (Sample 15) indicated by hydrothermal alteration elements such as Zn, Ba, Ag, and As.

5.2   ZEOLITE DETECTION AND ERIONITE DETERMINATION

Samples from three sites contained fibrous material in suspension: Painted Hill Quarry (Sample 1), I-84/Weiser Exit 206 (Samples 8 and 9), and Refuge Road (Sample 11). LabCor, Inc. was unable to match the fibrous material with zeolite XRD pattern matching standards, but further examination by TEM/EDS did find some evidence (Table 5.3). The TEM/EDS quantitative results for the fibrous materials possibly fall into offretite's chemistry field, a zeolite species closely associated with erionite, or erionite itself. However, this incongruity between the XRD and TEM results tend to confound analytical interpretation and the results are unfortunately viewed as inconclusive.

Table 5.1: The geochem results compared with USEPA industrial standards for soils and USGS mean Western U.S. rock concentrations.
Sample 3 – Painted Hill Quarry; Sample 5 – Sheaville Quarry; Sample 10 – I-84/Weiser Exit 206; and Sample 15 – I-5 Mile Post 69 (Sexton Summit); units are converted to parts per million (ppm) for easier comparison

ELEMENT	SAMPLE 3	SAMPLE 5	SAMPLE 10	SAMPLE 15	USEPA[†]	MEAN WESTERN U.S. CONCENTRATION[‡]
Ag	<0.2	<0.2	0.4	0.2	5,100	NPV
Al	26,000	3,300	26,900	30,200		58,000
As	479	3	11	25	1.7	5.5
B	<10	<10	<10	<10	100,000	23
Ba	10	30	280	130	67,000	580
Be	<0.5	<0.5	1.6	<0.5		NPV
Bi	<2	<2	2	2		18,000
Ca	58,000	1,900	1,600	20,100		NPV
Cd	<0.5	<0.5	<0.5	<0.5	9000	71
Co	4	<1	11	7	1,900	41
Cr[*]	11	6	2	63	190	21
Cu	5	2	7	10	41,000	21,000
Fe	166,000	5,700	83,000	46,300	100,000	16
Ga	<10	<10	10	10		0.68
Hg	0.36	0.03	0.12	0.09	310	16
K	100	300	1,800	4,400		0.046
La	<10	<10	30	10		18,000
Mg	8,700	1,100	8,700	11,600		30
Mn	1,085	61	2,200	715	19,000	7,400
Mo	57	<1	1	<1	5,100	380
Na	300	900	1,100	700		85
Ni	104	<1	<1	12	62,000	9,700
P	50	140	1,980	2,930		15
Pb	11	3	13	4	800	320
S	>100,000	500	900	4,300		1,300
Sb	<2	<2	<2	<2	410	0.47
Sc	3	1	21	13		8.2
Sr	103	17	620	61	100,000	200
Th	<20	<20	<20	<20	67	9.1
Ti	<100	300	4,500	3,200	100,000	2,200
Tl	<10	<10	<10	<10		NPV
U	<10	<10	<10	<10	200	2.5
V	24	15	35	181	1,000	70
W	<10	<10	<10	<10		NPV
Zn	14	9	154	64	100,000	55

Note: Unless otherwise specified, these listings are defined as including any unique chemical substance that contains the named chemical (i.e., antimony, arsenic, etc.) as part of the chemical infrastructure.
1 mg/kg = 1 ppm, percent to ppm multiply by 10,000
NPV – No published values
[*] Total Chromium (Cr^{+6}; Cr^{+3})
<, less than; >, greater than
[†] Acceptable Risk Level obtained from EPA, Region IX Preliminary Remediation Goals as of October 20, 2004 (updated December 28, 2004; http://www.epa.gov/region09/waste/sfund/prg/index.htm).
[‡] Shacklette and Beorngen (*1984*)

Table 5.2: Risk-based concentration for selected metals in soil (*USEPA 2009b*)

Contaminated Medium	RISK-BASED CONCENTRATION (RBC)									
	SOIL ppm (mg/kg)									
Exposure Pathway	Soil Ingestion, Dermal Contact, and Inhalation (RBCss)									
Receptor Scenario	Residential		Urban Residential		Occupational		Construction Worker		Excavation Worker	
Direct or Indirect Pathway	DCS		DCS		DCS		DCS		DCS	
Contaminant of Concern		Note		Note		Note		Note		Note
Arsenic (c, v)	0.39		1		1.7		13		370	
Cadmium* (c, nv)	1800		9700		9000		>Max		>Max	
Chromium III (nc, nv)		>Max		>Max		>Max		>Max		>Max
Chromium VI* (c, nv)	38		210		190		4800			>Max
Copper (nc, nv)	3100		6200		41000		12000			>Max
Lead (NA, nv)	400	L	400	L	800	L	800		800	L
Mercury (nc, nv)	23		47		310		93		2600	
Nickel (c, nv)	12000		67000		62000		>Max		>Max	

* This chemical has both cancer and non-cancer toxicity values and the lowest RBCs (non-cancer vs. cancer) vary by medium and exposure scenario. Both should be calculated to ensure the lowest applicable RBC is used. DCS means it is a direct contact pathway equal to the solubility.

c = This chemical is a known or suspected carcinogen. The RBCs in this row were calculated using equations for carcinogens.

L = The values for lead reported in this table are not derived from the equations developed in Appendix B. See Section B.3.4 for the source of the lead numbers and information on applying them.

>Max = The constituent RBC for this pathway is greater than 100,000 ppm or 100,000 mg/L. The DEQ believes it is highly unlikely that such concentrations will ever be encountered.

NA = This pathway is not applicable to the chemical of interest.

nc = This chemical is a non-carcinogen. The RBCs in this row were calculated using equations for non-carcinogens.

nv = This chemical is considered "nonvolatile" for purposes of the exposure calculations.

v = This chemical is classified as "volatile" for purposes of the exposure calculations in this document

Table 5.3: TEM quantitative results

SITE	SAMPLE	COMMENT	Mg/Ca	Si/Al	RUN
Painted Hill	1	Offretite?	0.56	3.07	H17604SP
Painted Hill	2	Gypsum?			
Sheaville	4	Amorphous particulate			
I-84/Weiser Exit 206	8	Probable Erionite	0.28	1.10	H17606SP
I-84/Weiser Exit 206	8	Probable Erionite	0.30	1.23	H17607SP
I-84/Weiser Exit 206	9	Probable Erionite	0.00	3.43	H17608SP
I-84/Weiser Exit 206	9	Probable Erionite	0.00	4.24	H17609SP
Refuge Road	11	Possible Zeolite	0.37	4.46	H17610SP
Refuge Road	11	Probable Erionite	0.00	1.85	H17611SP
Sears Creek	12	Chunky Particulate	0.23	0.00	H17643SP
Hwy95/Rome	13	Gypsum			
I-5/MP80	14	Probably Magnesio-Hornblende	0.93	20.63	H17612SP
Fulton Canyon	16	Possible Gypsum			

5.3   ASBESTOS TESTING

PLM results are reported as a percentage of the total sample. At the Chancellor Quarry, chrysotile asbestos fibers were detected in Sample 4. Field of View count for chrysotile is 15 counts over 400 fields, roughly 0.75 percent. Anthophyllite is present in Sample 5. Field of View count is 4 counts over 400 fields. Small, chunky fiber bundles (≥3:1 aspect ratio) with moderately-high BR (birefringence) were also counted (11 Field of View counts over 400 fields).

At this point, it can't be said that the presence of chrysotile and anthophyllite in the respective samples necessarily means that the rock where these samples were collected, or the quarry itself, is inherently hazardous. However, the results raise concerns; therefore, further representative sampling is probably warranted. If additional sampling determines that the asbestos levels hold true, then ODOT can determine the asbestos' impact and what response actions are appropriate.

6.0   NOHM GIS INFORMATION LAYER

One of the key products of this project is the NOHM-GIS data layer to convey NOHM awareness to ODOT personnel. This layer is called NGIL; the initialism for NOHM GIS Information Layer. The layer portrays problem areas involving NOHM hazards in a spatial context, and, through that, a basis for proactive decision making. The resulting spatial and geological data was processed using ArcGIS software.

NGIL considers NOHMs for their relative hazard potential. The relative NOHM hazard potential is expressed in qualitative terms of "Most", "Moderate", or "Least" likely and "No". These terms are defined below in Table 6.1.

Table 6.1: NOHM hazard classification

CLASS	DESCRIPTION*
Most likely	Most likely hazard potential is assigned to areas where a NOHM occurrence or geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for a NOHM occurrence, where interpretations of the data indicate high degree of likelihood for NOHM accumulation, where data support mineral-deposit models indicating presence of a particular NOHM, and where evidence indicates that NOHM concentration has taken place. Assignment of a most likely hazard potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.
Moderately likely	Moderately likely hazard potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for NOHM occurrence, where interpretations of the data indicate high degree of likelihood for NOHM accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.
Least likely	Least likely hazard potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of the NOHM is permissive. This broad category embraces areas with dispersed but insignificantly NOHM-bearing rock, as well as areas with obvious site limitations and little or no indication of having had NOHM potential.
NO	Existence of a NOHM is unlikely.

* Descriptions are modified after Goudarzi (*1984*)

To arrive at "most likely" or "moderately likely" NOHM hazard classifications, various data rules were devised based on geological factors, expert knowledge, and inclusion of the aforementioned databases (see Section 2.1). The data rules are tabulated in Table 6.2; the criteria for the "Least likely" classification are fairly generic and broad, and consequently, not included. Given the desired product and NGIL's intended use, an effort was made to edge-match across map boundaries. Consequently, this generalization of the geologic units is also reflected in the hazard classification, which means the NOHM hazard classification for some geologic unit polygons could be questionable.

Table 6.2: Tabulation of data rules that guide geologic unit hazard potential[‡]

HAZARD THEME	MOST LIKELY	MODERATELY LIKELY
ASBESTOS_H[*]	• When a point represents a mine, prospect, or occurrence of asbestos and/or talc is inside a geologic unit polygon • Ultramafic geologic unit polygons in which the names are clearly ultramafic lithologies, e.g., dunite, peridotite (harzburgite, lherzolite, and wehrlite), pyroxenite (bronzite, clinopyroenite, orthopyroxenite, websterite), serpentinite (meta-serpentinite), metatrocolite, etc. • Lateritic soil unit polygons	• Geologic unit polygons in which the unit name or rock type are clearly amphibolite, blueschist or glaucophane schist, and metamorphosed limestone and/or marble • Melange rocks, gabbro, and metagabbro are included if associated with aforementioned ultramafic geologic unit names or rock types and edge-matched across map boundaries • Shear zone geologic unit polygons
ZEOLITE_H[**]	• When a point representing a mine, prospect, or occurrence of zeolite minerals is inside a geologic unit polygon • Geologic unit polygons in which the unit name or rock type are clearly lacustrine, lake, pluvial, playa, obsidian, and pillow lavas • Rocks belonging to the following terranes: Little Butte Volcanics and Late High Volcanics	• Geologic unit polygons in which the unit name or rock type are clearly rhyolite and rhyodacite, claystone, and tuffaceous, includes palagonite tuff, silicic tuff, ash flow tuff (welded and non-welded), and sedimentary tuffaceous rocks • Volcanic rocks in general have a geologic environment favorable for zeolite formation • When a point inside of geologic unit polygons represents a bentonite (expansive clays) mine, prospect, or occurrence
MINERAL_H[†] (ARSENIC_H[††], MERCURY_H[††], ANTIMONY_H[††], COPPER_H[††], LEAD_H[††], CADMIUM_H[††])	• When a point representing a mine, prospect, or occurrence of metallic and/or nonmetallic minerals (including gold) is inside a geologic unit polygon • Mine tailings and gossan, travertine, and sinter geologic unit polygons • Geologic unit polygons in which the unit name or rock type are clearly metamorphic, e.g., schist, amphibolite, gneiss, quartzite, greenstone/greenschist, argillite, etc.; also hornfels, mélange, plutonic rocks • Rocks belonging to the following terranes: Little Butte Volcanics, Late- and Early Western Cascades, Applegate Group, Sexton Mountain, Western Klamath, John Day/Claro, Baker, Wallowa	• Geologic unit polygons in which the unit name or rock type are clearly tuffaceous sedimentary rocks, tuff (palagonite tuff, silicic tuff); ash flow tuffs, (welded and non-welded); claystone; felsic intrusives • When a point represents a hot or warm spring (active & fossil) and gemstones is inside a geologic unit polygon • Geologic units in which the unit name or rock type is clearly rhyolite and rhyodacite, includes tuffs • Rocks belonging to the following terranes: Early High Cascades and Late high Cascades
NORM_H	• When a point representing a mine, prospect, or occurrence of a NORM	• Travertine geologic unit polygons • Sinter geologic unit polygons

HAZARD THEME	MOST LIKELY	MODERATELY LIKELY
	mineral is inside a geologic unit polygon • Geologic units in which the unit name or rock type are clearly rhyolite and rhyodacite and sedimentary tuffaceous rocks, includes tuffaceous rocks, tuffs, and claystone • Rocks belonging to the following terranes: Little Butte Volcanics, Late Western Cascades, John Day/Claro	• When a point represents a hot or warm spring (active & fossil) and gemstones is inside a geologic unit polygon • When a point representing major oxide geochemistry is $SiO_2 > 76$ wt percent (*Nash 2010*) • Batholitic rocks consisting of granites, granodiorites, diorites
COBALT_H	• When a point representing a mine, prospect, or occurrence of cobalt (Co) minerals is inside a geologic unit polygon • Mine tailings and gossan geologic unit polygons • Lateritic soil unit polygons • If <u>no</u> point is inside a geologic unit but the geologic unit's name or rock type are clearly ultramafic, e.g., dunite, peridotite (harzburgite, lherzolite, and wehrlite), pyroxenite (bronzite, clinopyroenite, orthopyroxenite, websterite), serpentinite (meta-serpentinite), metatrocolite, etc.	• Geologic unit polygons in which the unit name or rock type are clearly amphibolite, blueschist or glaucophane schist, and metamorphosed limestone and/or marble • Shear zone geologic unit polygons • Geologic units in which the unit name or rock type is clearly beach sand, marine coastal terrace, fluvial/estuarine • Mélange rocks, gabbro, and metagabbro are included if associated with aforementioned ultramafic geologic unit names or rock types and edge-matched across map boundaries • Shear zone geologic unit polygons
Ni_Cr_H	• When a point representing a mine, prospect, or occurrence of nickel (Ni) and/or chromium (Cr^{+3}, Cr^{+6}) minerals is inside a geologic unit polygon • Lateritic soil unit polygons • If <u>no</u> point is inside a geologic unit but the geologic unit's name or rock type are clearly ultramafic, e.g., dunite, peridotite (harzburgite, lherzolite, and wehrlite), pyroxenite (bronzite, clinopyroenite, orthopyroxenite, websterite), serpentinite (meta-serpentinite), metatrocolite, etc.	• Geologic unit polygons in which the unit name or rock type are clearly amphibolite, blueschist or glaucophane schist, and metamorphosed limestone and/or marble • Shear zone geologic unit polygons • Geologic units in which the unit name or rock type is clearly beach sand, marine coastal terrace, fluvial/estuarine • Mélange rocks, gabbro, and metagabbro are included if associated with aforementioned ultramafic geologic unit names or rock types and edge-matched across map boundaries • Shear zone geologic unit polygons
MINFUEL_H	• When a point representing a mine, prospect, or occurrence of coal and oil shale is inside a geologic unit polygon	
Se_H[***]	• Data points not available; see note below	
TIN_H	• Geologic unit polygons in which the unit name or rock type are	

HAZARD THEME	MOST LIKELY	MODERATELY LIKELY
	clearly batholith/intrusive/plutonic rock of the variety: aplite, syenite, granite-granodiorite, monzonite, and diorite	
Be_H[***]	• When a point representing a mine, prospect, or occurrence of beryllium (Be) minerals is inside a geologic unit polygon (not reliable); see note below	• Geologic unit polygons in which the unit name or rock type are clearly batholith/intrusive/plutonic rock of the variety: aplite, syenite, granite-granodiorite, monzonite, diorite, and diabase, including some schist
LITHIUM_H[***]	• When a point representing a mine, prospect, or occurrence of lithium (Li) minerals is inside a geologic unit polygon; see note below	

[*] Includes both fibrous asbestos and talc

[**] Includes both sedimentary and other zeolite (volcanic) deposits

[***] Selenium, beryllium, and lithium all share a spatial association with uranium. Thus, to arrive at their hazard classifications, a modification of NORM_H's assignments were used for depiction

[†] All mineral mines, prospects, and occurrences

[††] It is assumed that arsenic, mercury, antimony, lead, and cadmium, either as minerals or as trace metals, are present in all metallic and nonmetallic mineralization, including gold

[‡] The "narrowing" process for relative NOHM hazard potential areas where a point representing a mine, prospect or occurrence involved calculation of the number of the NOHMs (points) which exist inside OGDC's map unit polygons. To do this, a count points in polygons tool was employed. A value is written to the polygon attribute table

6.1 LIMITATIONS OF NGIL

The data user should keep the following limitations in mind when applying this interpretive layer:

- NGIL is not a model in the sense of an analysis to determine susceptibility or favorability based on grid point interpolation, rather it simply identifies the geologic units within which there is the likelihood of a relative NOHM hazard potential. This means NGIL is obviously empirical; the hazard classes are not based on quantitatively defined weight- and /or normalized-values or statistical analysis. As with any hazard assessment in which subjective information is presented, the inclusion of some geologic unit polygons for a particular NOHM hazard could be questioned. It is left as an exercise for the user to evaluate how well a particular geologic unit polygon is represented by examining the actual point data/data rules for the NOHM of interest and surround geologic unit polygons. Furthermore, NGIL is not designed to produce specific mitigation results.

- It is important to emphasize that the relative NOHM hazard potential of a geologic unit polygon is generalized; only indicating how favorable it is that the NOHM will occur in the unit. Remember NOHMs by nature are localized, usually covering a fraction of the geologic unit polygon, and may not be representative of the entire geologic unit polygon.

- It cannot be ruled out either that a particular NOHM may in fact be found in geologic units that are classified as "least likely", or that NOHMs may not be present in "most likely" and/or "moderately likely" classified geologic units. The user should use caution, and, again, should always examine the actual point data/data rules to gain a better understanding of local variability.

- OGDC presents many challenges of compilation related to vintage, scale, definition of units, and edge-matching across map boundaries. The scale of geological map compilation, and consequently, the generalization of the geologic unit effects the extent to which the hazard classification is reflected by the NOHM's occurrence and its local variability.

- The use of NGIL requires knowledge of local conditions and the application of professional judgment and common sense.

7.0   CONCLUSION

This project has compiled a list of Naturally Occurring Hazardous Materials for Oregon. A subset of those materials has been looked at in greater detail regarding their occurrence, hazard, and risk. Methods for analyzing and detecting these NOHMs have been devised and tested. This information has been combined with geologic data for Oregon to compile GIS data, named the NOHM GIS Interpretive Layer (NGIL) for the purposes of helping the Oregon Department of Transportation (ODOT) take these NOHMs into consideration during the course of its activities. The NGIL can be combined with information compiled for the project, and on-line information about NOHMs, to devise ODOT policies and procedures that can insure the health and safety of ODOT personnel, as well as construction workers and members of the traveling public. It is envisioned that the use of the NGIL will be automated so as to make compliance with NOHM related policies and procedures simple and straight forward. Until the policies and procedures are put in place, the NGIL and its supporting data can still be used by those wishing to be aware of NOHMs that might relate to their work activities. Until the automation of the policies and procedures is accomplished, the NGIL and its supporting data can be readily accessed using simple desktop tools to answer questions about:

- Where NOHMs are likely to be encountered.

- What health hazards NOHMs present.

- How one might protect one's self and others from NOHMs.

- How to test for the actual presence of NOHMs.

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