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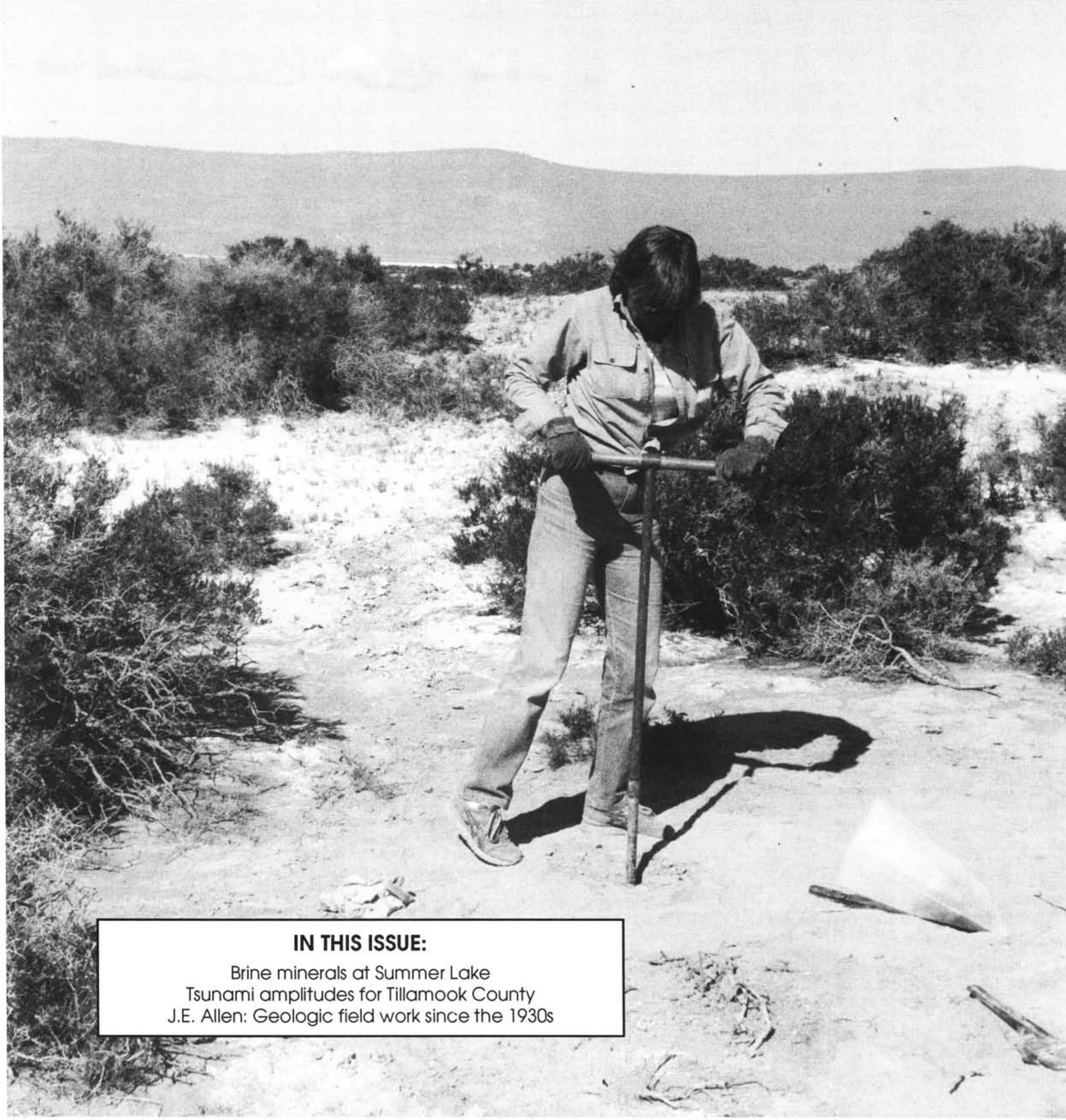

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Information for contributors

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The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

Cover photo

Augering for samples in a wind-deflated basin between sand dunes east of Summer Lake in Lake County. Resource studies of the Diablo Mountain Wilderness Study Area located here are the background for the discussion of brine minerals in article beginning on next page.

DOGAMI PUBLICATIONS

Released March 23, 1994:

Geology and mineral resources map of the Cleveland Ridge quadrangle, Jackson County, Oregon, by Thomas J. Wiley. Released as map GMS–73. Price $5.

The Cleveland Ridge 7½-minute quadrangle extends north from Boswell Mountain to the county border and includes Round Top near its western edge and a portion of West Fork Trail Creek in its northeast corner. The west half of the quadrangle includes outcrops of very old metamorphic rock. The area has been mined and prospected for mercury, copper, zinc, uranium, chromite, coal, and clay; and various kinds of stone have been mined for road construction.

Geology and mineral resources map of the McLeod quadrangle, Jackson County, Oregon, by Frank R. Hladky. Released as map GMS–80. Price $5.

The McLeod 7½-minute quadrangle includes Lost Creek Lake, Elk Creek Dam, and portions of the Rogue River and Elk Creek. The area is dominated by volcanic rocks that built the Western Cascades in this region. Hard rock—especially for construction of Elk Creek Dam—and pumice have been produced, while mercury and beryllium have been sought but not produced in the quadrangle. Some rocks from areas north of the quadrangle where the geology is similar have been found to contain significant anomalies of gold, silver, mercury, lead, and zinc.

Both maps are two-color maps at the scale of 1:24,000 (1 inch equivalent to 2,000 feet) and are accompanied by a separate sheet with tables of geochemical data and a text that explains rock units and discusses structure, geologic history, and ground-water and mineral resources.

Released March 28, 1994:

Beach-shoreline database, Pacific Northwest region, U.S.A., by Curt D. Peterson and a team of scientists from Portland State University, Oregon State University, and Western Washington University. Released as Open-File Report O–94–2. Price $12.

This report presents the first regional database of shoreline characteristics in Washington, Oregon, and California. It consists of one computer diskette and a 29-page text explaining the data sources, field methods, database access, and database components.

The ocean shoreline studied extends for about 1,000 km (621 mi) from Cape Flattery in Washington to Cape Mendocino in California. The database was developed from aerial photogrammetry data collected at about 2,000 reference points spaced at regular intervals and from profile data of representative littoral cells of the coastal zone.

The data in this report can be used to map and analyze the regional distributions of different types of shorelines, including rocky headlands, sandy beaches, tidal inlets, dune fields, and coastal terraces. Specific shoreline variables and beach parameters can be used to help predict regional shoreline susceptibility to (1) chronic and catastrophic hazards, (2) impacts from shoreline protection structures, (3) shoreline instability from sand mining or dredge spoil disposal, and (4) contamination from pollutants. Finally, the database can be integrated with other databases of, for example, wildlife habitat, recreational-economic interests, and jurisdictional boundaries for a wide variety of coastal inventory and planning uses.

The database is divided into three data files containing (1) beach physiography, (2) beach survey, and (3) beach deposit data. The files are in Excel version 4.0 spreadsheet format for either the Apple or DOS operating systems. The data can be used in compatible spreadsheet programs or loaded into relational database programs or geographic information systems (GIS). **Orders for this report must specify Apple or DOS format for the diskette.**

Earthquake database for Oregon, 1833 through October 25, 1993, by A.G. Johnson, D.H. Scofield, and I.P. Madin. Released as Open-File Report O–94–4. Price $10. *(Continued on page 64)*

Brine mineral occurrence in the Diablo Mountain Wilderness Study Area, Oregon, and its possible significance to Pacific Rim trade

by Thomas J. Peters[1]*, Michael F. Diggles*[2]*, and Dennis S. Kostick*[3]

ABSTRACT

The western or "Additional," part of the Diablo Mountain Wilderness Study Area, which borders the east shore of saline Summer Lake, has potential for undiscovered resources of soda ash, boron compounds, and sodium sulfate. Possible byproducts include potash, salts, bromine, lithium, magnesium compounds, and tungsten. Limestone from the study area could be used in the recovery process of brine components or in agricultural applications. Local power production from geothermal resources may be economically feasible.

Geologically, the study area lies on the northwest edge of the Basin and Range physiographic province, a region of fault-block-formed mountains and basins characterized by interior drainage. Consolidated rocks are mostly Tertiary basalt and tuffaceous sedimentary rocks. Low-lying areas are covered by Quaternary alluvial-fan, sand-dune, playa, lacustrine, and landslide deposits. The principal structural features are normal faults that have large vertical offsets; these faults are typically concentrated at the margins of large horst and graben structures.

Soda ash, soda ash products, and boric acid are widely used in the fluxing of metals and have important applications and markets in the aluminum industry in the Pacific Northwest and the developing Pacific Rim. Evaporite commodities are essential to many "backbone" industries and to many new applications and advanced materials. Markets for brine mineral products appear to be undergoing steady and strong growth, especially in the Pacific Northwest and in Pacific Rim countries. Soda ash produced near the study area would be 55 percent closer by rail to marine export at Portland, Oregon, than trona deposits of the Green River (Wyoming) district.

Soda ash and a daughter product, caustic soda, and sodium borohydride will receive increased application in the bleaching of paper pulp for environmental reasons. Caustic soda, used in many industrial processes, is more environmentally friendly when derived from soda ash than when produced from sodium chloride salt, because of the absence of a chlorine byproduct. Sodium sulfate is increasingly substituted for less environmentally friendly phosphates in laundry detergents. Producing soda ash from brines, a type of "in situ" mining, can be done with minimal environmental degradation, and mining natural soda ash is environmentally as well as economically preferable to synthetic soda ash production.

INTRODUCTION

A brine mineral occurrence of possible economic significance was documented along the east shore of Summer Lake, Lake County, Oregon, in the 34,310-acre western or "Additional" portion of the Diablo Mountain Wilderness Study Area as the result of a mineral survey requested by the U.S. Bureau of Land Management. The various phases and conclusions of this survey, as described by Diggles and others (1990b), resulted from a cooperative effort by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS) and form the basis of the present paper.

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The Diablo Mountain Wilderness Study Area is situated 45 mi north of Lakeview and 5 mi north of Paisley in Lake County, Oregon (Figures 1 and 2). Elevations in the area range from 4,300 ft near the shore of Summer Lake to 6,147 ft at the summit of Diablo Mountain. Access to the region is via Oregon State Route 31, connecting with U.S. Highways 395 north of Lakeview and 97 south of Bend. Access to the study area is provided by dirt roads leading off State Highway 31. Access within the study area is by four-wheel-drive vehicle on jeep trails, by mountain bicycle, and by foot.

The climate is semiarid, and the average annual precipitation is about 12 in. The sparse rainfall in the area results in only intermittent stream flow. The region contains several lakes, of which Summer Lake is one, that occupy closed basins. Vegetation consists of low-growing desert shrubs, mostly sagebrush, greasewood, creosote bush, burroweed, and boxthorn (Figure 3).

GEOLOGY

The Diablo Mountain Wilderness Study Area is underlain by sedimentary and volcanic rocks of Tertiary and Quaternary age (Diggles and others, 1990a) (Figure 4). They are generally flat lying

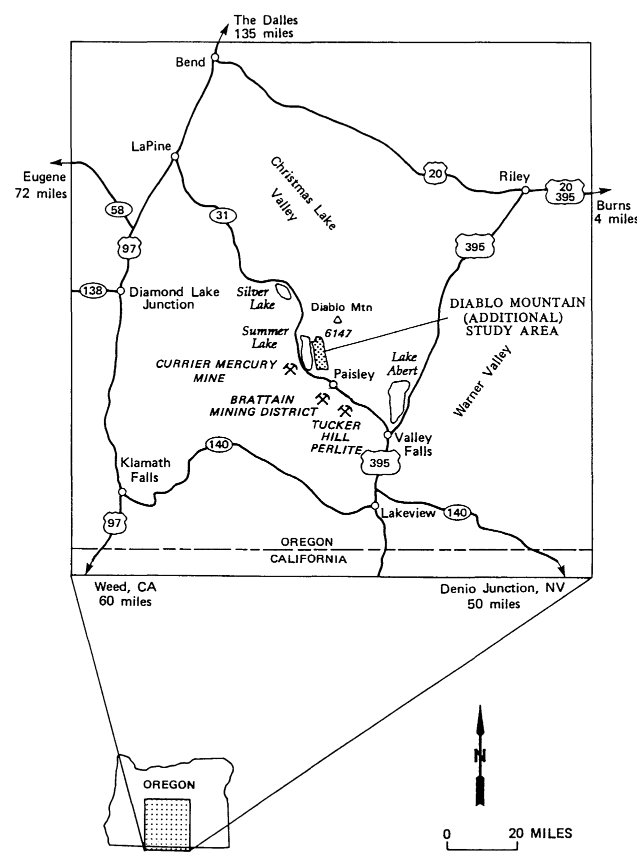

Figure 1. Location of the Diablo Mountain (Additional) study area, Lake County, Oregon (from Peters and Willett, 1989).

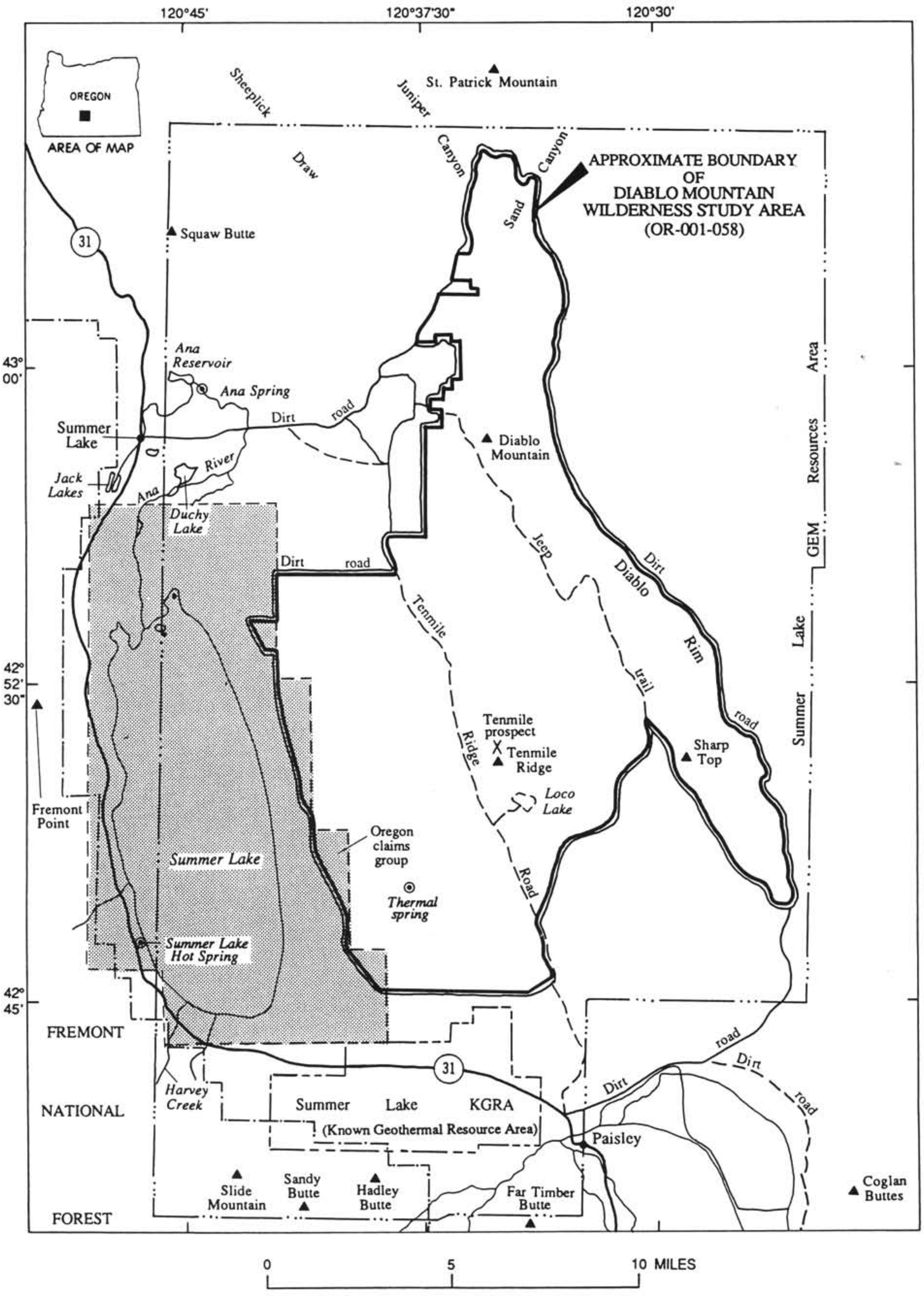

Figure 2. Diablo Mountain Wilderness Study Area, Lake County, Oregon. "Additional" study area discussed in this paper is located mostly west of Tenmile Ridge Road. Shaded area marks Oregon Prospect (Oregon claims group). From Diggles and others, 1990b.

Figure 3. Playa area east of Summer Lake, capped by intermittent sand dunes that are anchored by vegetation. Location is auger site R (see Figure 5); view is to the northeast.

but are broken by normal faults. Tertiary rocks in the study area consist of basalt flows, basaltic pyroclastic rocks, tuffaceous sedimentary rocks, rhyolitic tuff, and dolomitic limestone.

The Summer Lake basin was occupied by pluvial Lake Chewaucan. Sediments in the basin include tephra from several large volcanic eruptions. Landslides from Winter Rim, west of Summer Lake, between 19,000 and 12,000 years ago locally compressed and deformed the sediments (Simpson, 1989).

Structurally, the study area lies on the northwest edge of the Basin and Range physiographic province. Summer Lake occupies a closed basin bounded by ridges that have fault-scarp fronts (Phillips and Van Denburgh, 1971). The structural geology of the study area is dominated by high-angle north-northwest-trending normal faults that have cut the range into blocks. J.J. Rytuba (personal communication, 1987) suggested that the Summer Lake area, including the area to the east, now covered with dunes, may be a large caldera.

The Diablo Rim is the most extensive scarp resulting from the faulting (Figure 4). The study area is bounded on the northeast by the north-northwest-trending Brothers fault zone that has been interpreted as a transcurrent structure that bounds the northwest edge of the Basin and Range physiographic province (Lawrence, 1976). The area on the west side of Summer Lake and south of the study area is part of the poorly defined Modoc Plateau physiographic province that separates the Basin and Range and the Cascade Range physiographic provinces (Macdonald, 1966). Vertical offset in the study area is apparent at the margins of large fault-bounded horst and graben structures typical of the Basin and Range.

THE OREGON PROSPECT

Exploration history

Lake County mining records indicate that a large block of 326 placer claims was located in 1901 by an eight-person association and was relocated by the same claimants in 1906. Historically known as the Oregon claims group (Figures 2 and 5) and discussed here as the "Oregon prospect," the claims area extended from 2 mi north to 1 mi south of Summer Lake and as much as 2 mi east and 1 mi west; it included the entire lake and the surrounding playa. The discovery, according to the records, was for "the valuable metals, sodium and potassium and their compounds of bicarbonate of soda, carbonate of soda and potassium sulfate, in paying quantities held in solution and in deposit." The claimants were Charles M. Sain; John T. Reid; Schuyler Duryee; W.F. Brock; and William, Charles, Canby, and Elwood Balderston. The eastern claim block boundary extended north-south along the western part of the study area.

With the outbreak of World War I, foreign potash supplies were cut off, and the price for potash increased from \$0.80 to \$8.00 per unit (20 lb). In 1916, the first successful plants to produce potash and other evaporite minerals from brine came on line at Searles Lake, California (Teeple, 1929). On December 16, 1914, the State of Oregon leased the mineral rights to soda salts in Abert and Summer Lakes on a royalty basis (Hartley, 1915). Ambitious development plans included a 270-mi pipeline north to the Columbia River and a large hydroelectric plant, an investment of about \$7 million (Phalen, 1916, p. 107-108). Outside but adjacent to the south boundary of the study area are remnants of a water retention levee and an evaporation pond (Figure 6). These were apparently developed in 1918; John Withers, a local rancher, recalls that much money and effort was spent that year by a crew of men led by one Jason Moore. After the armistice, the potash price dropped and by mid-1919 was at \$1.75 to \$2.00 per 20-lb unit. Perhaps this was the main reason for not continuing the work at Summer Lake.

Resource

The Oregon claims group, inactive since 1918, covered all of Summer Lake, including the west margin of the Diablo Mountain Wilderness Study Area (Figure 2). The prospect was primarily for brines; no conventionally minable beds of evaporite minerals are known. Summer Lake waters are not sufficiently concentrated to

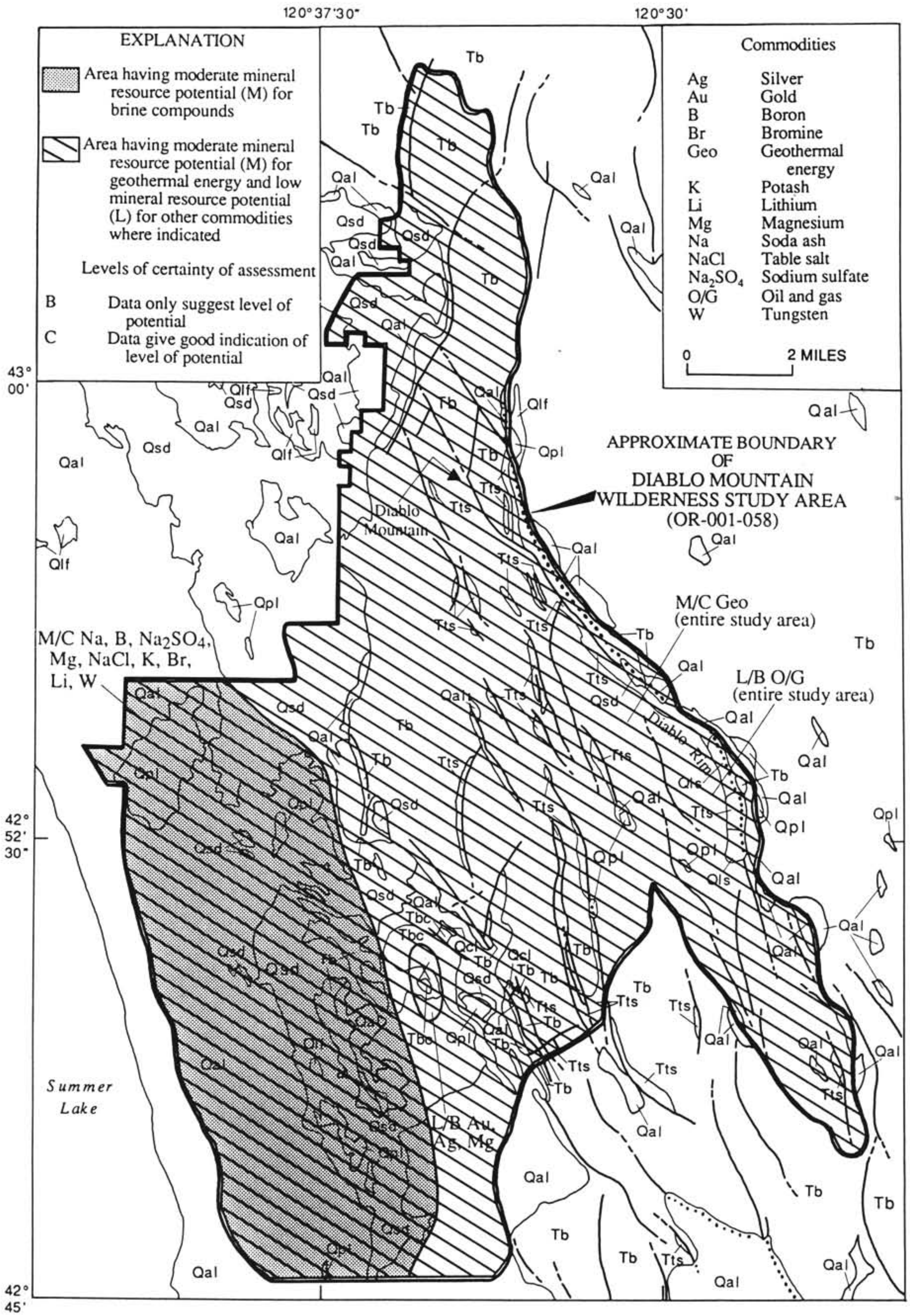

Figure 4. Generalized geology and mineral potential of the Diablo Mountain Wilderness Study Area, Lake County, Oregon, from Diggles and others (1990b). Geologic units: Qal = alluvium, Qsd = sand dunes, Qpl = playa deposits, Qlf = lacustrine and fluvial deposits, Qls = landslide deposits, Qcl = claystone, Tbc = basaltic cinders, Tb = basalt, Tts = tuffaceous sedimentary rocks. Faults are marked by solid lines that are changed to dashed where approximately located and to dotted where concealed.

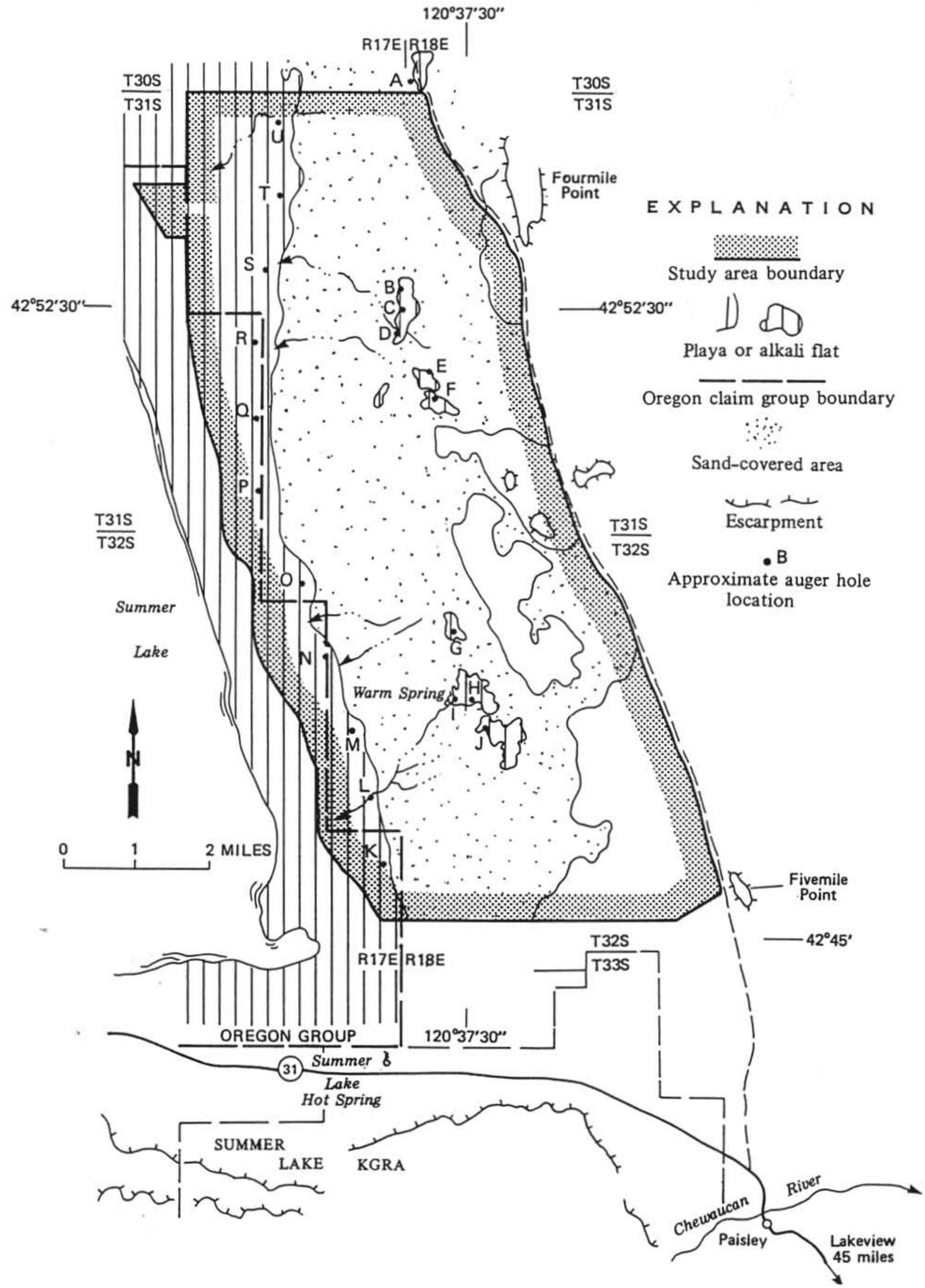

Figure 5. Auger hole localities (A–U) in the Diablo Mountain (Additional) study area. Dashed line along the east boundary of the study area is the Tenmile Ridge Road. From Peters and Willett, 1989.

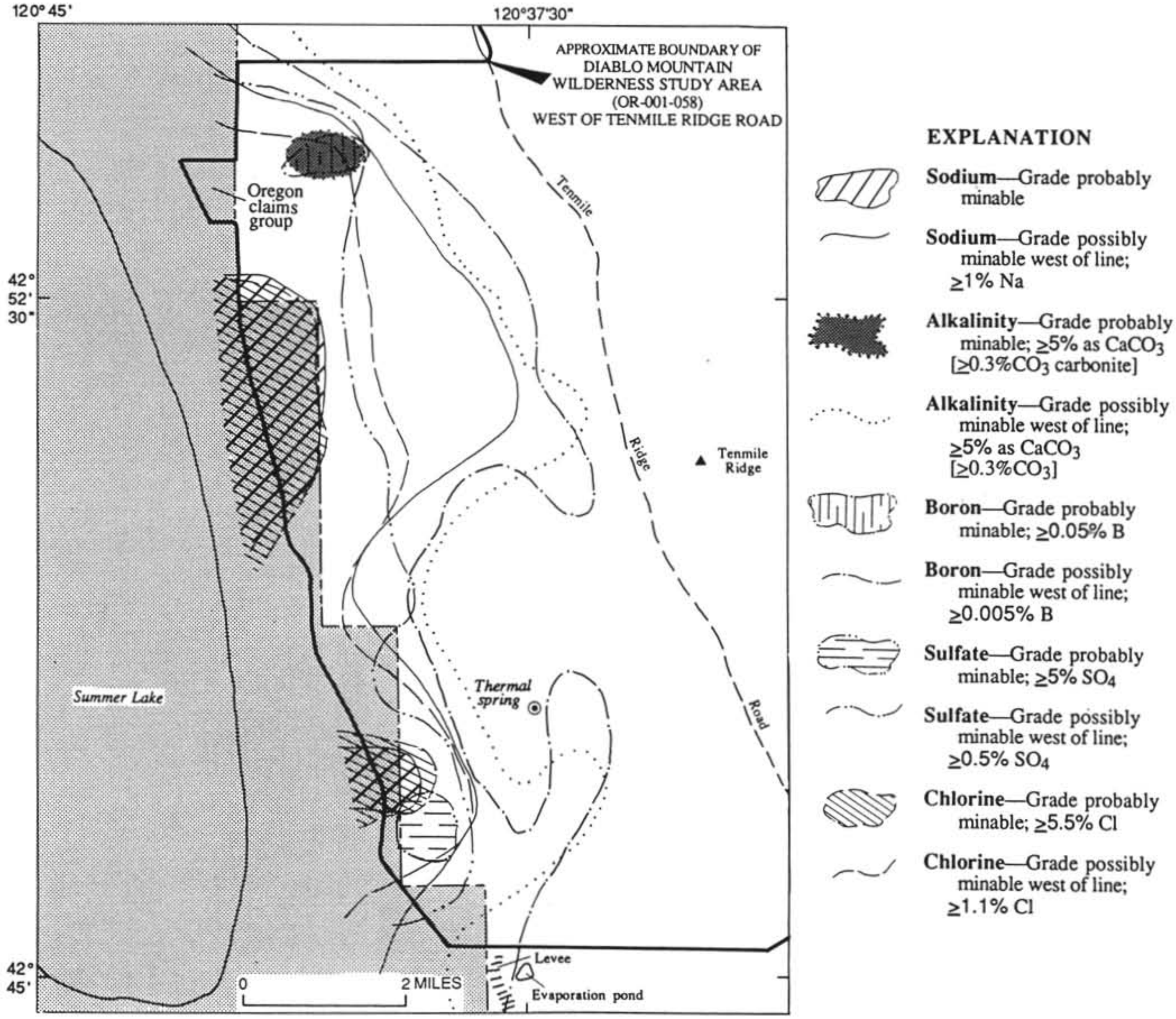

Figure 6. Concentrations of chemical components of brine commodities in ground water in the Diablo Mountain (Additional) Study Area (from Diggles and others, 1990b).

be a source of resource-bearing brine. In 1969, the lake, with a maximum water depth of about 3 ft, contained a calculated total of only 1 million tons of mineral salts; however, the top 5 ft of lake-bottom and marginal sediments contained 15 to 20 million tons of evaporite minerals. The greatest quantities of evaporite minerals are under the eastern playa rather than under the lake (Van Denburgh, 1975). Seasonal variation of fresh water and evaporation renders the solute concentration too inconsistent for the lake waters to constitute a brine source for year-round processing. Interstitial brines sampled from auger holes (Peters and Willett, 1989, Tables A-1 and A-2) are much higher in solutes than the lake-water samples reported by Van Denburgh (1975, Table 4).

Within the study area, brine-hosting lake and playa sediments define a mineral area extending more than 2 mi east of the claims group. Much of this area is covered by a veneer of windblown sand as much as several tens of feet thick. Several flat-floored blowout basins, displaying the white surface efflorescence that is characteristic of areas underlain by evaporative brine, have formed windows through the sand.

Brine commodity evaluation

Sampling of the mineral area by hand auger (Figure 7) yielded data on the mineral and brine composition of the top few feet of sediments and allowed comparison with chemical data from analogous mineral systems that are better understood. An appropriate place for comparison is Searles Lake, California, about 500 mi to the southeast, where evaporite commodities have been extracted from brines and evaporite deposits for more than 50 years (Smith, 1979).

Brine samples were analyzed for cation (+) and anion (–) components of evaporite commodities that include soda ash, boron compounds, sodium sulfate, salts, potash, and lithium. Samples were also analyzed for arsenic and antimony, which are not only possible toxic contaminants but are also indicators of nearby epithermal mineralization or mineralizing processes. The auger-hole sediments and alkali crusts were analyzed for major-element oxides and 36 trace elements. Possible products, based on component concentrations (Figure 6) and commodity economics, include soda ash (sodium carbonates), boron compounds, and sodium sulfate. Possible

Figure 7. Hand auger for collecting water and sediment samples on playa, east of Summer Lake. (See also cover photo.) Location is auger site L; view is to the northwest.

byproducts include potash, salts, bromine, lithium, magnesium compounds, and tungsten; their production may be feasible in conjunction with other commodities. Processing of many of the products could be facilitated by treating them with dolomitic limestone, which is also present in the study area.

Our brine analyses were compared to published analyses of brines from Searles Lake, California (Smith, 1979, Tables 5, 16, and 22) (Figure 8). Ranges of concentration of possible significance now or in the foreseeable future were chosen by using the Searles Lake operation as a guide. Our cutoffs are lower than those for the Searles Lake brine concentrations because (1) low concentrations in surface samples do not preclude higher concentrations at depth, (2) advances in extractive technology allow utilization of lower grade brines (Smith, 1979), (3) the advantage of large-scale application of such technology is inherent in designing new facilities, and (4) possible markets may be closer.

Two categories of brine commodity occurrence, based on their chemical component concentrations, were chosen: a grade probably minable, and a grade possibly minable (Figure 6). Occurrences of probable economic concentrations are defined as approximately equal to or greater than 50 percent of the grade of Searles Lake brines for all products except boron, which is of higher unit value. The grades of possibly minable brines in the study area are equal to or greater than 10 percent of the grade of Searles Lake brines. Boron could possibly be mined economically from lower grade brines than those at Searles Lake by the use of advanced technology in new plant design (Gail Moulton, personal communication, 1989). Grades of brine components at least as good as the possibly minable grade were observed at 12 auger sites and 4 seeps (Table 1).

In Figure 6, isocon maps (contour maps of chemical concentrations) of the sodium, alkalinity (as $CaCO_3$), boron, sulfate, and chlorine concentrations (Peters and Willett, 1989, Figures 3–6) were generalized and combined. Areas interpreted to have probably minable grades were denoted by patterns. Grades of brine components having possible economic significance extended east of the Oregon claims group but were highest in the claim block vicinity.

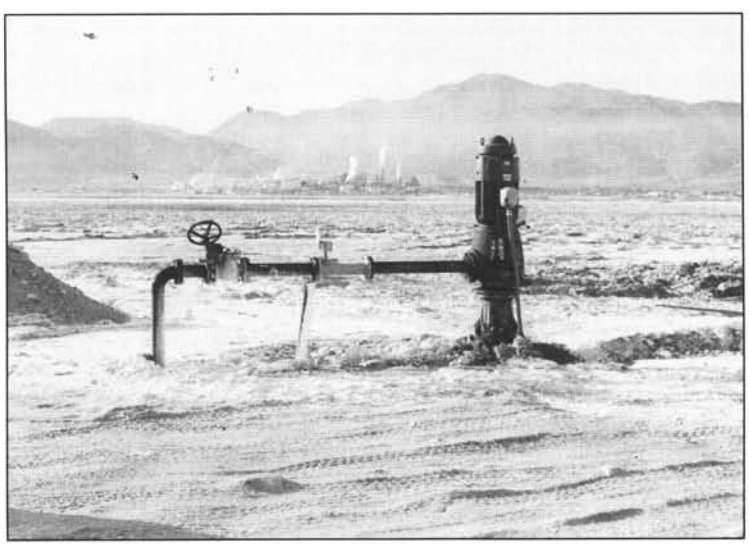

Figure 8. Brine well on Searles Lake, California. View toward northwest shows Trona plant of North American Chemical in the distance.

The Tenmile and other dolomitic limestone prospects

In addition to the potential resources in the Oregon prospect, a dolomitic limestone of Pliocene(?) age is locally interbedded with basalt flows at the Tenmile and other dolomitic limestone prospects. This limestone appears to have formed as an apron along the east, northeast, and north flanks of Tenmile Ridge and may extend for 2 mi to the northwest. It crops out discontinuously through a veneer of sand dunes and desert pavement. The rock is suitable for brine mineral processing and agricultural applications. Usually, the thickness could not be determined, but Harold Dyke of Adel, Oregon, (personal communication, 1988) reports the rock is as thick as 30 ft northeast of Tenmile Ridge.

In March 1974, a group of claims including the Tenmile prospect and six others was located for limestone on the northeast side of Tenmile Ridge. Claimants included Harold J., and Marie Dyke of Adel, Oregon; Frances M. Foster; Con O'Keefe; Laura Shine; Jerry and Julia Singleton; and Morgan Verling. John Cremin (Lakeview, Oregon) examined the prospect in 1980, brought it to the attention of the authors, and reported that exposures of the limestone extend into the study area.

Geothermal energy

Summer Lake Hot Spring (Figure 5) produces 116°F water at a rate of 21 gallons per minute (Peterson and McIntyre, 1970) and is developed as a resort. The presence of the thermal spring, in part, resulted in the designation of the Summer Lake Known Geothermal Resource Area (KGRA) 2 mi south of the study area. The KGRA includes three additional geothermally significant wells (Oregon Department of Geology and Mineral Industries, 1982, wells Lk-7, -8, -9, -10). Of special interest are the Collahan wells Lk-9 and Lk-10, which have water temperatures of 212°F and 231°F, respectively, but do not produce dry steam, the most efficient medium for electric power generation. However, water temperature at the Summer Lake KGRA is much higher than the 100°F minimum needed for electric power production by the binary systems process (Rinehart, 1980).

MINERAL ECONOMICS

Soda ash

Soda ash (sodium carbonate, Na_2CO_3) has been recovered from brines at Searles Lake by two methods: an older evaporation process, and a direct carbonation process. The evaporation process involves heating the brines, which causes the double salt burkeite ($Na_2CO_3 \cdot 2Na_2SO_4$) and table salt ($NaCl$) to precipitate. The remaining liquor is rapidly cooled, and potassium chloride is precipitated and filtered out. The remaining brine is supersaturated with sodium borate, which

Table 1. *Occurrence of brine commodity components in the Diablo Mountain (Additional) study area, Lake County, Oregon. * = Concentration possibly minable[1]; ** = Concentration probably minable[2]; n.a. = not applicable; — = not available; ppm = parts per million*

Auger hole (A-U)	Brine sample number	Hole depth (ft)	Weight percent water[3]	Alkalinity as $CaCO_3$ percent	Concentration[4] B+ (percent)	Cl– (percent)	K+ (percent)	Li+ (ppm)	Na+ (percent)	SO_4^{--} (percent)
D	18 b	8	21.68	*4.48	*0.0250	0.68	0.100	< 0.1	*3.40	0.10
F	31 b	8.4	34.16	*0.91	*0.0075	*1.30	0.022	< 0.1	*1.30	0.27
H	47 b	6	22.46	*0.74	*0.0063	0.50	0.022	< 0.1	0.97	0.21
J	65 b	5.6	28.44	*1.52	*0.0124	0.97	0.038	< 0.1	*1.30	*0.41
K	69 b	4	29.74	0.44	*0.0080	0.27	0.053	2.0	0.57	0.29
Seep	70 b	n.a.	—	*0.66	*0.0067	0.35	0.025	< 0.1	0.69	0.39
Seep	71 b	n.a.	—	*0.72	*0.0059	0.33	0.017	< 0.1	0.55	0.29
L	75 b	4	31.61	*2.63	*0.0230	*3.00	0.090	< 0.1	*3.30	**6.90
M	78 b	4	39.97	*2.58	*0.0230	**5.70	0.110	0.3	**5.20	0.62
N	81 b	4	34.71	*1.77	*0.0140	*1.50	0.045	< 0.1	*1.90	0.35
Seep	82 b	n.a.	—	*0.75	*0.0059	0.32	0.017	< 0.1	0.59	0.16
O	85 b	4	40.44	—	*0.0065	—	0.053	0.9	0.68	n.a.
P	88 b	4	36.59	*2.47	*0.0250	—	0.045	< 0.1	*4.90	*0.58
R	94 b	5.9	42.84	*2.92	*0.0390	**5.60	0.130	< 0.1	**5.30	*0.60
Seep	97 b	n.a.	—	*1.94	*0.0160	*1.30	0.032	< 0.1	*2.00	*0.40
T	100 b	4	28.30	**5.43	**0.0500	*2.70	0.110	< 0.1	*4.70	*1.20

[1] Possibly minable concentrations are within one order of magnitude of those of Searles Lake brines (Smith, 1979, tables 9, 16, and 22), except boron is within two orders of magnitude.
[2] Probably minable concentrations are equal to or greater than one-half of those of Searles Lake brines (Smith, 1979), except boron is within one order of magnitude.
[3] Weighted average weight percent water of wet sediment sample from auger hole.
[4] Percent multiplied by 10,000 equals mg/L; ppm approximates mg/L.

is precipitated after the addition of "seed" crystals (Gail Moulton, North American Chemical Corporation, personal communication, 1989). In the direct carbonation process, brine is mixed with carbon dioxide (CO_2) gas. At Searles Lake, carbon dioxide is produced from power-plant flue gases (Parkinson, 1977); but traditionally, carbon dioxide has been produced from lime kilns.

The soda lakes of south-central Oregon are similar in appearance and composition to other surface lakes with evaporite crusts and subsurface brines found worldwide. These types of soda deposits provided the crude sodium carbonate used about 3,500 B.C. by the Egyptians to make glass ornaments and containers and in medical and food-additive applications. Although people in Europe and America used the ashes of wood to obtain alkali by burning plants found in salt-bearing soils or seaweed and leaching the residue to produce "soda ash" (a term that is still in use today), they soon discovered natural soda in many surface evaporite deposits.

The first commercial soda ash operation in the United States began in the 1860s at Little Soda Lake at Ragtown, Nevada, near the present town of Fallon. Workers excavated the evaporated crude sodium carbonate found along the margin of the lake. Imports of soda ash from Europe supplemented the soda alkali needed for glass and detergent manufacturing. Although the Leblanc process that originated in France produced an impure soda ash, it was not until the 1860s that a technique to make synthetic soda ash was developed. Because the continued use of burning seaweed and plants became economically impractical, and supplies were becoming scarcer, synthetic soda ash production increased throughout the world. In addition, because trona (the primary ore of soda ash) and some of the other carbonate-bearing minerals are water soluble, there are not very many economic surface deposits found in the world despite the numerous occurrences of sodium carbonate commonly associated with many evaporite resources.

The birth of the modern natural soda ash industry began in California in 1887 at Owens Lake and was further developed in 1931 at Searles Lake and in 1948 at Green River in Wyoming. Because deposits were in the west, the majority of markets tended to be within that region. The remainder of the nation used synthetic soda ash, which was first produced in the United States at Syracuse, New York. At one time, ten synthetic plants were operating in the northeast, east, upper midwest, and on the Gulf coast. The rivalry between natural and synthetic soda ash continued for many years. Because world production capacity was adequate to meet demand, the United States exported very little soda ash prior to 1970.

During 1992, soda ash was produced by five companies in Wyoming and one company in California; total estimated value was $837 million. Industrial use of soda ash was in the following proportions: glass, 48 percent; chemicals, 24 percent; soap and detergents, 13 percent; distributors, 6 percent; flue gas desulfurization, 3 percent; pulp and paper, 2 percent; water treatment, 2 percent; and other, 2 percent (Kostick, 1993). In 1992, the United States exported 3.3 million tons of soda ash; a total of 43 percent went to all Asian countries, the largest export market.

Boron compounds

Generalized boron concentrations of the brines in the study area are shown on Figure 5. Processing of these brines probably would be similar to extraction methods at Searles Lake, California, where brines containing boron are mixed with a liquid extractant that removes boron from the brine. Boron is then purged from the extractant with sulfuric acid, producing boric acid [$B(OH)_3$]. Sodium and potassium sulfate remain in the liquor and can be recovered.

Boron, though unfamiliar to most people, has many uses. Borates have been used as a flux in metal smithing since their introduction into Italy from Mongolia in the 13th century, and they were used to add strength to glass made by medieval European artisans. Elemental boron was isolated in 1808. The boron mineral tincal ($Na_2B_4O_7 \cdot 10\,H_2O$) was discovered at Teel's Marsh, Nevada, in 1872 and ulexite ($NaCaB_5O_9 \cdot 8\,H_2O$) was discovered in Death Valley, California, in 1881. By 1927, underground mining of a massive tincal and kernite ($Na_2B_4O_7 \cdot 4\,H_2O$) deposit had begun at Boron, California. Mining was converted to open-pit methods in 1957. U.S. Borax annually produces about one-half of the world's boron from these deposits. North American Chemical Company produces boron compounds as coproducts of solution mining of soda ash at Searles Lake (Trona, California; Figure 8). For further detail about the boron industry, see Lyday (1985).

The United States is currently the largest producer of boron compounds (Lyday, 1993). Of the total production, 62 percent is used in glass making, 9 percent in soaps and detergents, 5 percent in fire retardants, and 24 percent in other uses (Lyday, 1993). Borosilicate glass withstands severe temperature changes without cracking. Borate compounds are used as metal solvents and fluxes in the metals industry, as both herbicides and plant nutrients in agriculture, in fire retardants, and in heat-resistant ceramic products such as the tiles that protect the space shuttle during reentry. Elemental boron fibers are used with tungsten-steel alloys for high strength in helicopter rotors; boron nitrite approaches the hardness of diamond and is more heat resistant. Sodium borohydride is used in the bleaching of ground wood (Rex McKee, personal communication, 1989), and there are many additional applications for boron compounds.

Sodium sulfate

Sodium sulfate occurs in two economically important mineral forms: mirabilite or Glauber's salt ($Na_2SO_4 \cdot 10\,H_2O$) and thenardite (anhydrous Na_2SO_4). Almost all commercial deposits are lacustrine evaporites (Weisman and Tandy, 1975). Sodium sulfate can be extracted from brine as a coproduct of soda ash and boron compounds. Only about 48 percent of comes from natural sources; most is manufactured as a byproduct of chemical and rayon factories. End uses are in soap and detergents, 44 percent; pulp and paper, 24 percent; textiles, 16 percent; glass, 5 percent; and miscellaneous uses, 11 percent (Kostick, 1993). Increasingly, sodium sulfate is used as a substitute for phosphates in laundry detergents. Phosphates endanger the oxygen content of streams and lakes because they encourage excessive growth of algae.

In the study area, sodium sulfate as a mineral commodity is closer to pulp and paper markets in the northwestern states than are current sources of sodium sulfate.

Byproduct brine commodities

Production of six byproduct commodities from the study area may be feasible: table salt (NaCl), potash (K_2O; and muriate of potash, KCl), bromine, lithium, magnesium compounds, and tungsten. Byproduct salts are produced at Searles Lake, California. Two companies in Portland, Oregon, currently buy imported Mexican salts for the manufacture of caustic soda and chlorine compounds. It may be economical to recover magnesium compounds from the site of the Oregon claims group. A local source of dolomitic limestone to be used in processing the brines would make additional magnesium available for byproduct compounds. The additional investment needed to extract byproducts from a resource-producing brine, even at low concentration, may be somewhat small. Distribution of byproduct concentrations and uses are discussed in more detail by Peters and Willett (1989).

Dolomitic limestone

The dolomitic limestone occurrence along Tenmile Ridge may be useful for its possible application in brine commodity processing. Carbon dioxide produced from the calcination of limestone or dolomite is used to remove calcium from brines, thus allowing further separation of soda ash, boron compounds, and sodium sulfate. A calcination byproduct, calcium hydroxide can then be used to convert soluble magnesium salts into insoluble magnesium hydroxide, which in turn can be calcined to produce magnesia. Another proposed use of the limestone is as a soil conditioner; this may be feasible if there is enough limestone and if low-cost rail transportation is available in conjunction with development of other mineral commodities.

MARKETS AND TRENDS

Of the 10.4 million short tons of domestic soda ash produced in 1992, 3.3 million tons was exported to 51 countries throughout the world (Figure 9). The soda ash was used to manufacture glass bottles, window glass, soaps and detergents, and various inorganic chemicals.

The United States is the world's largest producer of soda ash, comprising about one-third of total world output. The majority of the world's production is synthetic soda ash, made with salt and limestone as feedstocks. Synthetic soda ash is more expensive to manufacture than natural soda ash. It also generates more pollution and is very labor intensive. Because of the higher cost of synthetic soda ash, exports of U.S. soda ash are expected to increase throughout the remainder of the decade.

The emergence of the United States as a soda ash exporter has its roots in two important events of the early 1970s. These were (1) the Arab oil embargo in October of 1973 that caused fuel prices to soar and (2) the ecology movement within the United States that prompted enactment of antipollution legislation. Producing a ton of synthetic soda ash takes about twice the amount of energy as producing a ton of natural soda ash. The synthetic process also generates byproduct sodium chloride and calcium chloride, both of which were usually discharged by plants as waste effluents and are considered detrimental to the environment. Of the ten synthetic soda ash plants that were constructed in the nation, seven were in operation when the energy and environmental problems emerged in 1973. By the end of 1979, only one remained in production: Ironically, it was the Syracuse plant, which was the first one built in the United States. This plant finally ceased operation in 1986, ending the era of synthetic U.S. soda ash production.

The energy and environmental issues that led to the demise of the U.S. synthetic soda ash industry began to surface in Europe and elsewhere in the world in the early to mid-1980s. The "green movement" in Europe identified some of the "synthetic" plants as contributors to Europe's air and water pollution, which forced less economic plants in Czechoslovakia, England, France, and Switzerland to close. A similar situation occurred in Asia and South America. Foreign manufacturers of glass and chemicals wanted to obtain less

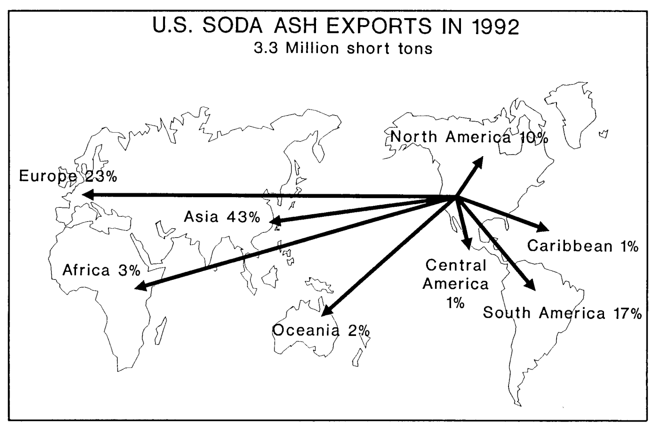

Figure 9. U.S. soda ash exports in 1992.

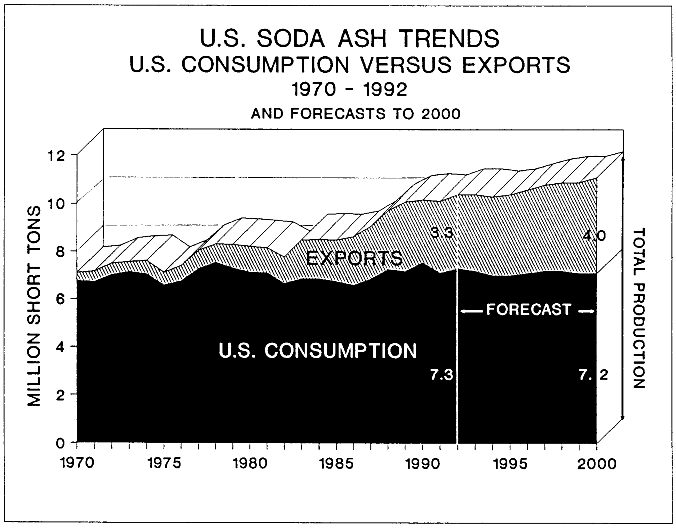

Figure 10. U.S. soda ash trends.

expensive soda ash, and the United States began to increase exports to these markets.

By 1982, five companies in Wyoming and one in California were exporting 14 percent of domestic output (Figure 10). The industry formed the American Natural Soda Ash Corporation (ANSAC) to promote export sales and was able to ship natural soda ash more efficiently. From 1970 through 1992, U.S. apparent consumption increased 6 percent, while exports rose a dramatic 869 percent.

The Pacific Northwest

Markets for brine-mineral products appear to be undergoing steady growth, especially in the Pacific Northwest (Figure 11) and in Pacific Rim countries. By volume, soda ash, also known as sodium carbonate, ranks 11th among the inorganic chemicals produced in the United States. It is obtained domestically by processing trona ore from the world's largest deposit in Green River, Wyoming, or from underground sodium carbonate-bearing brines found at Searles Lake, California. Other sodium carbonate deposits, such as those in Summer Lake and Lake Abert in Oregon, are potentially important.

Soda ash and a daughter product, caustic soda, and sodium borohydride have found increased use in the bleaching of wood pulp. At present, for most pulping an alkali process is used. Only a few older and specialty mills use an acid process. Most paper bleaching is still done by the Kraft process, which produces chlorinated wood wastes that can evolve into dioxin and chloroform waste that is disposed of through smoke stacks. The next several years will see a complete transfer to alkali bleaching, which will use large tonnages of caustic soda from a soda ash source through a modified Solvay process (Jerry Gess, 1993, personal communication). The new process will be more energy efficient, and many chemicals will be recovered from waste products.

Alkali bleaching is ecologically preferable to the current acid process that uses chlorine compounds and produces a carcinogenic dioxin waste product. Soda ash, soda ash products, and boric acid are widely used in the fluxing of metals, also in the aluminum industry in the Pacific Northwest and in developing Pacific Rim countries. Evaporite commodities are essential to the backbone industries of many civilizations and to many new applications and advanced materials.

For products from the Oregon prospect, bulk commodity transport by railroad is available from Lakeview, Oregon, 45 highway miles to the southeast. There are no weight restrictions on the 55-mi-long Great Western Railroad shortline from Lakeview to Alturas, California; rail distance from Alturas to Portland, Oregon, is 415 mi. Railroad infrastructure could be extended from Lakeview to a new mine site for about $300,000 per mile (land not included) (Edward Emmel, Oregon Department of Transportation, Salem, personal communication, 1994), possibly in conjunction with other bulk product development such as perlite from the Tucker Hill deposit 14 mi southeast of the study area (Wilson and Emmons, 1985). In this scenario, brine minerals could be shipped by rail directly to Portland or Coos Bay, in either case a distance of about 520 mi. This distance is only 55 percent of the 912 mi of rail distance between Portland and the premier trona producing area, the Green River district in southwest Wyoming.

Although soda ash currently is produced in the United States by five companies in Wyoming and by one in California (with another in the pre-development stage at Owens Lake), the Oregon soda lakes could be important to soda-ash-consuming industries in the Pacific Northwest. The lakes are also within the range of some of the glass container plants of northern California, as well as Portland port facilities that handled about 60 percent of the U.S. soda ash export business and the port of Coos Bay, which can provide suitable facilities for new customers.

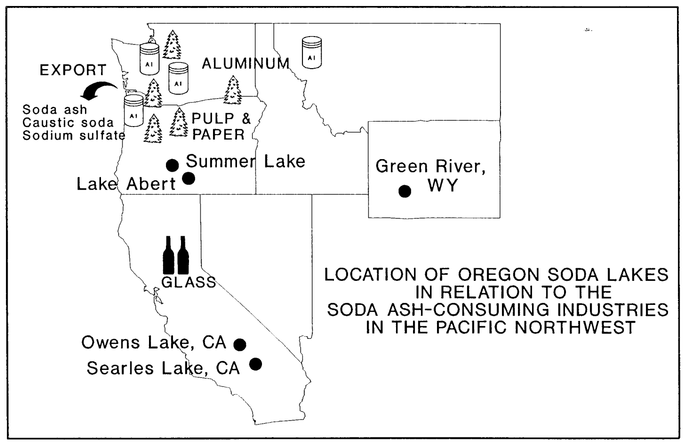

Figure 11. Location of Oregon soda lakes in relation to the soda ash-consuming industries in the Pacific Northwest.

The Pacific Rim

The Pacific Rim represents an important region for U.S. soda ash exports. In 1992, 60 percent of total export sales was to this area, including Canada and Mexico (5 percent each; Figure 12). Asia was the primary destination of U.S. soda ash exports, representing 43 percent of total foreign shipments. Japan and the Republic of Korea were the major importers in 1992. Some of the Pacific Rim countries, such as Australia, Japan, and the Republic of Korea, produced synthetic soda ash, which competed with U.S. exports. In 1987, partial or total foreign acquisition of U.S. producers began to occur. Foreign soda ash companies experiencing the higher operating economics of running synthetic operations saw the advantages of producing from natural resources in the United States.

Japanese and Korean companies are now joint venture partners with three of the U.S. soda ash companies. Japan's TOSOH Corporation and Asahi Glass Company own 24 percent and 20 percent, respectively, of General Cemical and Solvay Minerals, respectively, in Green River, Wyoming. Oriental Chemical Industries of Korea owns a 27-percent share of North American Chemical Company in California. Total foreign ownership of the U.S. soda ash industry stands at 49.4 percent. Only one of the six companies is exclusively U.S. owned—FMC Wyoming Corp.

As the demand for consumer products increases in many of the nations of the Pacific Rim, which have burgeoning population and rapidly developing economies, the long-term outlook for soda ash, borate compounds, and sodium sulfate supplied by the United States is very favorable. The region has been very important to the U.S. soda ash industry and will continue to be so into the 21st century.

The soda lakes of Oregon have the potential to supply a portion of the soda ash demand in the Pacific Northwest and possibly supply a portion of the soda ash, or value-added soda ash products, for export. More physical and economic evaluation of the Oregon soda lakes will be needed to determine the potential of the occurrences.

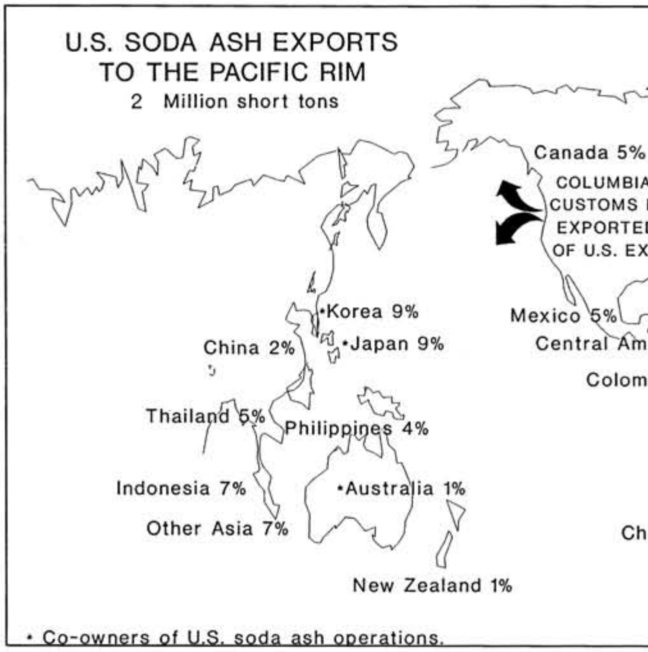

Figure 12. U.S. soda ash exports to the Pacific Rim.

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Expected tsunami amplitudes off the Tillamook County, Oregon, coast following a major Cascadia subduction zone earthquake

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As evidence accumulates indicating that the Cascadia subduction zone has produced major earthquakes and that at least some of the earthquakes were followed by large tsunamis (e.g., Atwater and Yamaguchi, 1991; Atwater, 1992), emergency planners along the Pacific Northwest coast have been trying to get an idea of how large a wave can be expected. Will it be 1 m, 10 m, or 100 m high?

One method of estimating the potential wave height is through numerical modeling of the earthquake source and tsunami propagation. Given a hypothetical set of earthquake source parameters, the sea-floor displacement can be computed. This displacement produces the sea-level perturbation that provides the impetus for a tsunami.

Whitmore (1993) computed wave amplitudes and currents at 131 sites along the North American coast for three hypothetical Cascadia subduction zone earthquakes. Here, the same tsunami modeling technique is used as in that study, and eight additional sites in Tillamook County, Oregon, are examined. The three earthquakes modeled in the original study were $M_W = 8.8$, 8.5, and 7.8. In this study only the magnitude 8.8 quake, which ruptures from the South Gorda plate to the subduction zone bend off the Washington coast (Weaver and Shedlock, 1989), is examined as that produced the largest tsunami along the Oregon coast. The tsunami model used here, described by Kowalik and Whitmore (1991), can determine the tsunami amplitude near the coast. The inundation level or runup of the tsunami is not computed. Amplitude can be thought of as the water column height over mean sea level at a point near the coast. Runup, though, is the vertical elevation which the tsunami reaches as it inundates the shore. Runup elevation often varies from the wave amplitude. Factors such as the beach slope, wave period, and beach roughness cause the runup to be higher or lower than the wave amplitude near the coast.

The fault parameters for the $M_W = 8.8$ earthquake are moment = 2.0E29 dyne-cm, strike = 358°, dip = 13°, slip = 90°, length = 650 km, width = 80 km, and fault bottom depth = 20 km. These were taken from studies of the Cascadia subduction zone by Spence and others (1985), Weaver and Baker (1988), Weaver and Shedlock (1989), and Savage and others (1991) and are explained further in Whitmore (1993). Static sea-floor displacement is computed from these parameters by dislocation formulae (Okada, 1985) and is shown in Figure 1. This is a typical subduction-zone, underthrusting pattern with uplift seaward of the trench and subsidence toward the continent. Maximum uplift is near 3.7 m, and subsidence along the coast is up to 1.8 m. The computed subsidence compares well with paleoseismic studies which indicate coseismic subsidence of 1.0–1.5 m along the northern Oregon coast (Darienzo and Peterson, 1990).

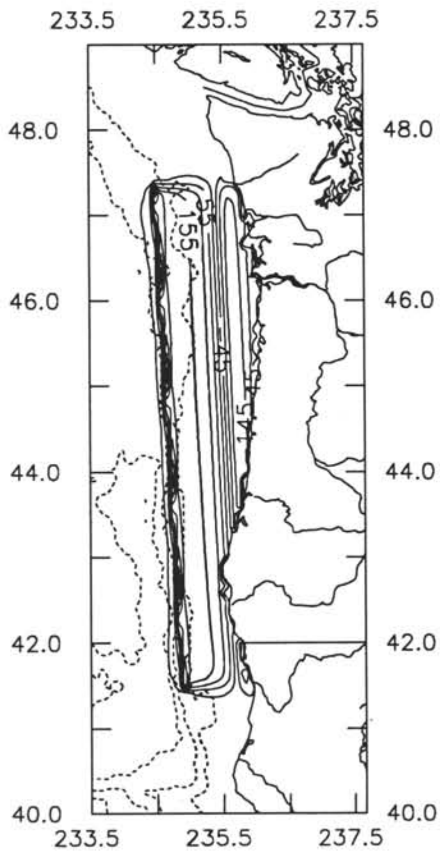

Figure 1. Vertical sea-floor displacement computed for $M_W = 8.8$ earthquake. Contour interval is 0.5 m. Maximum uplift is 3.7 m, while maximum subsidence near coast is 1.8 m. Dashed lines are bathymetric contours with a 1,000-m increment.

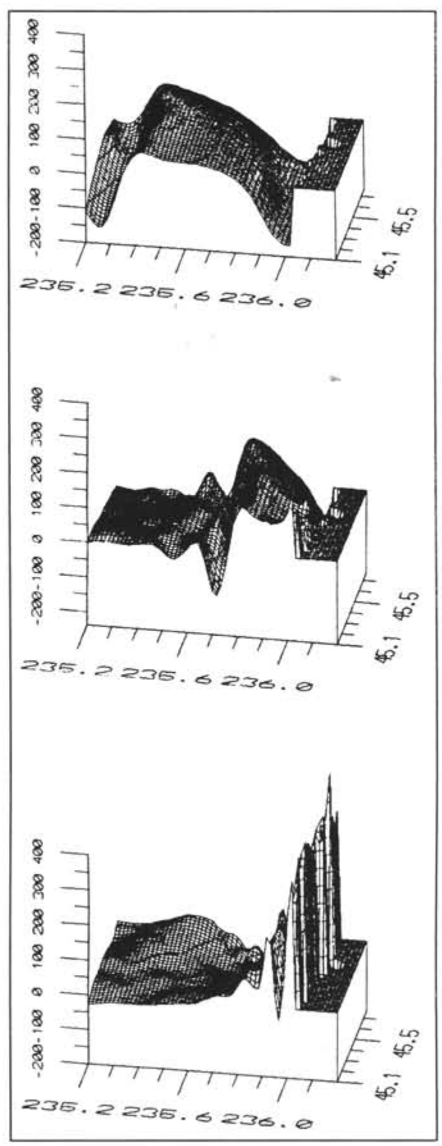

Figure 2. Time slices of the tsunami impinging on the Tillamook County coast at 10, 20, and 30 minutes after generation. Vertical scale is greatly exaggerated.

The nonlinear, shallow-water equations of motion and continuity equation are used to model the tsunami, given the initial sea-level configuration defined by sea-floor displacement. Friction is accounted for in shallow water (i.e., continental-shelf depths). An explicit-in-time finite difference technique is used to solve the equations. This finite difference technique and the basic equations are explained in greater detail in Kowalik and Whitmore (1991). Briefly, the model computes a new north/south velocity, east/west velocity, and sea level at each grid point based on the old velocities and sea level every 11 seconds. This produces a "motion picture" of the wave with 11 seconds between frames. Figure 2 shows the tsunami as it moves to-

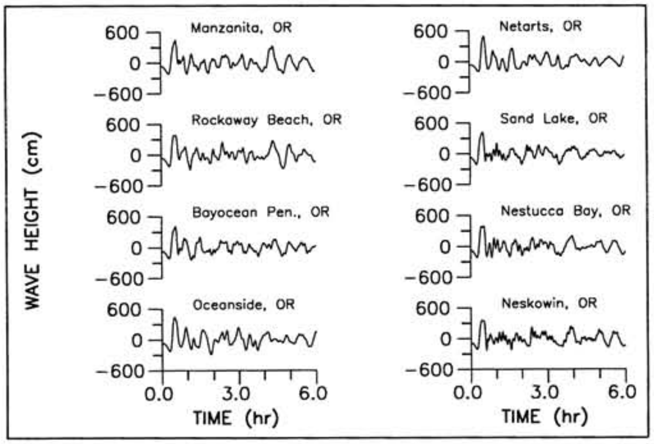

Figure 3. Modeled tsunamis at eight sites in Tillamook County, Oregon (locations shown in Figure 4 and Table 1).

Table 1. *Maximum modeled tsunami amplitudes along the coast of Tillamook County, Oregon*

Site	Lat (°N.)	Long (°W.)	Amplitude (m)
Manzanita	45.72	123.95	5.01
Rockaway Beach	45.62	123.97	4.45
Bayocean Peninsula	45.53	123.97	4.71
Oceanside	45.45	123.97	5.08
Netarts	45.43	123.95	5.53
Sand Lake	45.28	123.98	4.85
Nestucca Bay	45.18	123.98	4.67
Neskowin	45.12	124.00	4.35

ward the Oregon coast. The tsunami inundates the shore when the coast is reached. The model used here, though, does not account for this inundation. Pure reflection is assumed at the coast.

Shuto and others (1985) showed that 10 to 20 grid points per tsunami wavelength are necessary to accurately reproduce a wave numerically. This is accomplished here by using an edited version of the NOAA ETOPO5 five-minute bathymetry grid over the open ocean and a more detailed one-minute grid over the continental shelf where wavelengths decrease. At 45°N., a 1′ x 1′ grid has a spacing of approximately 1.3 km x 1.8 km. The two grids dynamically interact with each other at the five-minute to one-minute boundary. Some places along the coast such as within Tillamook Bay require higher detail than provided in the one-minute grid. This model can be considered accurate only along the outer coast, where one minute accurately defines the coastline and bathymetries.

Modeled tsunamis at eight sites along the Tillamook County coast are shown in Figure 3. In all cases, the initial wave is the largest of the tsunami series, although significant waves continue for over six hours. The first wave arrives about 23 minutes after the earthquake and is preceded by a recession. The time between successive crests varies from less than eight minutes to over an hour. The maximum zero-to-peak amplitude at these eight sites is 5.53 m at Netarts. This amplitude includes apparent amplitude due to subsidence at the site. Table 1 and Figure 4 summarize the maximum zero-to-peak amplitudes inclusive of local subsidence.

Several potential sources of error could modify the computed tsunami amplitude. The main factors controlling amplitude are size, configuration, and location of the source. Here the source is a simple planar fault with uniform slip. Other complexities such as submarine landslides, secondary faulting, nonuniform slip, faulting through the sedimentary wedge, or variations in the fault parameters could produce large local variations. The numerical model will also introduce some error. Problems such as locally insufficient resolution, pure reflection assumed at the coast, and variations in the tsunami from the assumed shallow-water wave behavior can cause differences between an actual tsunami and a model. Even with these possible sources of error, the results computed here should give planners along the coast a good ballpark figure.

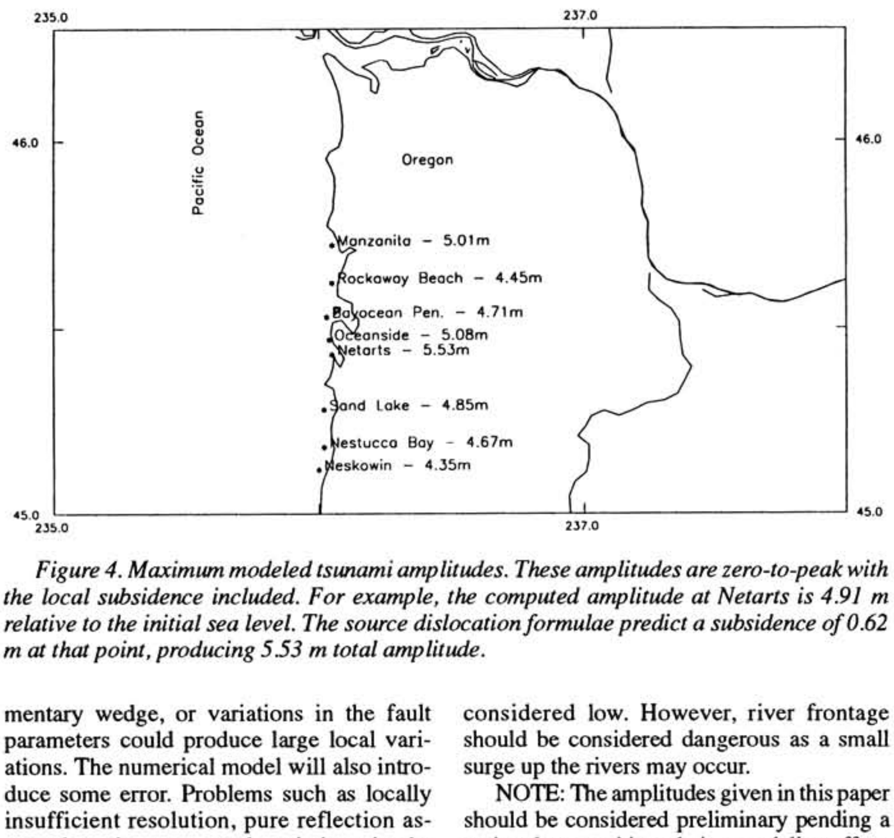

Figure 4. Maximum modeled tsunami amplitudes. These amplitudes are zero-to-peak with the local subsidence included. For example, the computed amplitude at Netarts is 4.91 m relative to the initial sea level. The source dislocation formulae predict a subsidence of 0.62 m at that point, producing 5.53 m total amplitude.

The largest population center along this coast is Tillamook. The tsunami could not be accurately modeled at Tillamook due to the narrow entrance to Tillamook Bay and the bay's extensive mud flats. Considering that there are 2 mi of land and over 1 mi of mud flats at low tide between Tillamook and the bay, the tsunami danger at Tillamook can be considered low. However, river frontage should be considered dangerous as a small surge up the rivers may occur.

NOTE: The amplitudes given in this paper should be considered preliminary pending a national tsunami inundation modeling effort.

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Columbia stopped flowing in 1872!

Reprinted, with permission, from The Oregon Scientist, *v. 7, no. 1 (Spring 1994), p. 11.*

This report from *Best of the Old Northwest* [1980, Paddlewheel Press, P.O. Box 230220, Tigard, Oregon 97281], by Marge Davenport, is a collection of stories gathered from family records, old books, and papers from early days in the Northwest. Since there were no seismographs and probably no geologists in the Northwest in those early times, documentation of catastrophic events is difficult.

Suddenly, in 1872, the Columbia River stopped flowing! It was a quiet, calm night when the big earthquake hit the North Cascades. To the few residents, the travelers, and the Indians in the area, it seemed that the world was coming to an end.

The ground rocked and shook as if it was going to buck the few little cabins of the pioneers off the face of the earth. Trees swayed and snapped. Dogs howled, and the screams of terrified Indians echoed through their camps. A family near where the town of Entiat, Washington, would be founded testified in family records to the severity of the quake. The rumbling, roaring noise that accompanied the quake was deafening, they said.

Then, just as the quake began to subside and the noise stopped, there was a deafening roar, as if the surrounding mountains were collapsing.

Indeed, that was exactly what was happening. The mountain just north of the family's cabin, composed of granite interlaced with layers of volcanic ash, had split in half, and millions of tons of rocks and earth crashed thousands of feet below into the mighty Columbia River — to become an earth dam blocking its flow!

Because there were few residents in the area and because those who had settled there lived in small frame wooden buildings, no casualties were recorded the night of the big quake, but many strange things were reported.

When Indian women went to the river to get water the next morning from their camp near Wenatchee, they found the river had dried up and vanished.

A Yakima pioneer said two large cracks had opened up along a ridge east of the Columbia River, and oil was pouring out of the cracks and running down the mountain.

At Lake Wenatchee, where a pack train carrying supplies to a railroad survey party was camped, the packers reported huge boulders rumbled down Dirty Face Mountain and plunged into the lake.

At another spot, this near Chelan Landing, a huge geyser shot high into the air and continued to flow for months before its pressure was reduced and it became a mere spring. The Columbia River's flow continued to be dammed for several days, and everyone within traveling distance came to see the phenomenon. Fortunately, when the dam finally began to weaken and burst, those ahead of the wall of water that rushed down the valley were able to scurry to safety.

No effect at Portland?

At Portland, there is no recorded effect of the damming of the Columbia, although when the dam burst, it must have had some influence on the water level downstream. However, persons living along the river at that time built well back from the shores because of frequent flooding, and even a significant difference in water levels probably was not unusual.

Besides, the Snake, Yakima, John Day, Deschutes, and other large rivers join the Columbia before it reaches Portland, so the river probably just dropped slowly for several days and then surged as if from snow melt or cloudburst when the dam water was released.

Severe earthquakes were evidently more frequent in the Northwest in the 1800s, but because there were no recording instruments, because population was sparse, and communication was mostly by word of mouth, reports are vague as to their exact intensity. The next year after the North Cascades quake that dammed the Columbia River, a severe quake was reported at Fort Klamath to the south. This quake hit in the early morning and knocked people and animals to the ground.

An officer at the Fort, writing about the quake, said there were two hard shocks lasting about five to ten seconds each. Every pane of glass in windows at the Fort was broken, he said, but the frame wooden buildings did not suffer much damage. ☐

(DOGAMI PUBLICATIONS *continued from page 50)*

This database is provided in dBase III format (.DBF file) on one 3½-inch diskette. Introductory and explanatory discussions are contained in a text file.

This catalog is the first publicly available digital earthquake catalog for Oregon and presents Oregon's recorded earthquake history up to the most recent events. Over 15,000 earthquakes are included in the database, which was compiled from a variety of databases and catalogs covering the Pacific Northwest. Depending on the completeness of the source information, each earthquake record includes data on date and time of the event, location and depth of the epicenter, and magnitude and intensity of the shaking. Each record also contains information on the source of the data and, for many modern sources, on the quality of the determinations regarding location and magnitude of the earthquake.

When it is used in a database software program, this catalog can be searched to find earthquakes by size, time, geographic area, or any of the other details contained in each record.

Released April 1, 1994:

Mist Gas Field map, 1994 edition. Released as Open-File Report O-94-1. Price $8.

(Continued on page 70, DOGAMI PUBLICATIONS)

Geologic field work in Oregon and other parts of the the West since the 1930s

by John Eliot Allen, Emeritus Professor of Geology, Portland State University, P.O. Box 751, Portland, OR 97207-0751

ABSTRACT

The author, during 20 years as a field geologist, examined nearly 200 chromite deposits, at least 350 other prospects and mines containing (or not containing) 14 different economic minerals and rocks, and mapped or assisted in mapping all or parts of 17 topographic quadrangles. Of the 14 in Oregon, seven were DOGAMI projects. One was in California and two in New Mexico.

For a young geologist with outdoor skills in the 1930s, field geology was rewarding professionally, personally, and even financially. This geologist now regrets the lowering prestige of this necessary and rewarding investigation of ground truth; he is glad he spent his most productive years in this stimulating and gratifying activity.

INTRODUCTION

This contribution to the history of West Coast geology, especially that in Oregon, summarizes recollections of some of my experiences in examining mineral prospects and mines and in mapping or assisting in the mapping of 17 quadrangles during 20 years as a field geologist from 1931 to 1951. These musings are more elaborately told in my autobiography *Bin Rock and Dump Rock* (1986)[1]. Fourteen of the 17 maps are in Oregon, seven were DOGAMI projects. One was in California, and two were in New Mexico.

I mapped the geology of all or substantial parts of these quadrangles during periods ranging from 30 days to more than two years; I also did several stints of less than 30 days of mapping in other quadrangles. I also examined and reported on hundreds of mineral deposits in Oregon, as well as on many in Washington, California, Nevada, New Mexico, Arizona, and Pennsylvania.

Besides mapping, I had duties (and opportunities) to examine in these states prospects and mines that contained 14 different commodities: chromite (1938), tungsten, nickel, quicksilver, gold and silver (1939, 1941), tin (1942), manganese (1942), coal (1944, 1954), vanadium (1945), limestone (1946), perlite (1946), clay (1949), titanium (1956), and iron.


The author as "field geologist" in 1931.

Some mapping in several other quadrangles generated no publications. These included mapping projects where I spent less than 30 days or occasions when I attended or supervised summer field camps in central Oregon, California, Pennsylvania, and New Mexico.

QUADRANGLES MAPPED

Quadrangles 1–4, during 1931: Parts of Camas, Bridal Veil, Bonneville Dam, and Hood River (1931, 1979, 1986, 1991).

A party of 11 graduate and undergraduate student geologists under the leadership of Dr. E.T. Hodge camped out in the Columbia River Gorge and in the northern Cascades of Oregon from early in June to late in September. Besides Hodge and Allen, other members of the party were Martin Meredith Sheets, Richard Bogue, Allen Griggs, Lloyd Ruff, Ernest McKitrick, Harold Fisk, Ed Thurston, Howard Handley, and (?) Derby.

The summer objective was to make a geologic reconnaissance of nearly 2,000 square miles in the Gorge and for 10 miles to the north and 30 miles to the south, including Mount Hood. The only day off was the Fourth of July, although each of us spent one day every week as camp tender and cook. The camp stove was a 1- by 3- by 5-foot ice freezing can, supported by rocks around the wood fire. We took down the tents and tables and changed camp every two or three weeks, occupying sites within the Gorge, near Government Camp, and farther south.

Each morning, Hodge would drop us off to follow a traverse from 5 to 15 miles long. Each evening, he expected us to be at a given pickup point by 5:00 p.m. Since completion of many traverses in nine hours was not always accomplished, all of the party except Allen Griggs and myself joined the OAN (out all night) Club.

I mapped in several parts of the area, with traverses around and across Mount Hood and as far south as Fish Creek Divide and Roaring River on the Clackamas. But most of my traverses consisted of climbing the Gorge walls at mile intervals to determine the elevation of the contact of the Columbia River basalt with the Troutdale gravels on the south side, and the basal contacts of the Columbia River basalt and the Eagle Creek Formation on the north side.

My most memorable traverse, however, was from Timberline on Mount Hood over the col above Illumination Rock, down Reid Glacier as far as the seracs of the icefall, over Yokum Ridge onto Sandy Glacier, then down Yokum Ridge to the road 10 miles to the west. It was long past the five o'clock deadline when I got to the meeting place, but Allen Griggs made a clandestine trip to pick me up and bring me back to camp. As a result of this traumatic experience I have never, during my entire professional career, sent a geologist out alone in rough country.

Each of us contributed to the others' maps, and three master's theses resulted from this work by the end of the next year. I compiled the geologic maps of the Gorge (1932); Martin Sheets described the petrology of the High Cascade andesites and Dick Bogue the petrology of the Columbia River basalts.

Twenty-five years later when I returned to Oregon to teach at Portland State College, the first thing I did was write a Gorge field trip guide for use by the class in physical geology during its fall term trip (up to 11 bus loads), a field trip that has taken place every year since 1955. After retirement, I enlarged this to the book *The Magnificent Gateway* (1979), the second edition of which (1984) is still in print in 1994.

Quadrangle 5, during 1933–4 and 1938: San Juan Bautista, California (1946).

When I went to Berkeley to work towards a Ph.D., it was suggested that I map the geology of the San Juan Bautista quadrangle, just east of Monterey Bay. I spent two full field seasons mapping this quadrangle, which is bisected by the San Andreas Fault and thus presents an entirely different stratigraphy on opposite sides of the rift. Since the map is about an area in California, this is not the place to describe the fascinating geology.

I was unable to complete this complicated map during my three years as a teaching assistant at Berkeley. So, in the spring of 1935,

[1] *All dates in parentheses refer to the primary publications listed at the end of this paper. Perhaps twice as many secondary publications resulting from these years of work are not cited.*

Field camp near Troutdale in the Columbia River Gorge during the summer of 1931.

I took a summer job at Crater Lake and then worked for two years prospecting for chromite before joining the Oregon Department of Geology and Mineral Industries (DOGAMI) in 1937. In 1944, I took leave to complete the San Juan Bautista map and write the Ph.D. dissertation (1946).

The start of the memorable Mount Hood traverse of 1931. The "X" marks the gap the author was to cross.

Quadrangle 6, during 1935: Small parts of Crater Lake (1936).

My former professor, Dr. Warren D. Smith, always meticulous in caring for his Oregon graduates, got me this first professional job at Crater Lake. Early in June, when we arrived at the Rim Village, the last mile of road was being cut through ten-foot snow drifts. Our quarters consisted of a platform with two facing tents, one to live in and one to sleep in, located about 300 yards southwest of the lodge. A faucet tap, an outdoor toilet, and a nearby washroom served as the naturalists' "Tent City."

The Ranger Naturalist staff consisted of four geologists, Carl R. Swartlow, Dr. Smith, myself, and Carl Dutton; botanist Elmer Applegate; biologist Ray Coopey; poet Ernest G. Moll; and photographer and artist L.H. Crawford. Our delegated and rotated duties consisted of (1) answering questions at the head of the Lake Trail and in the Sinnott Memorial, (2) conducting boat trips to Wizard Island and around the Lake, (3) conducting car caravan trips around the Lake, and (4) giving lectures after dinner in the lodge.

We each had one day of the week off; during those days I was able to map the location of 35 caves in and around the lake, describe the origin of numerous waterfalls, and map the geology of the domes exposed on the western and northern walls. Publication of a paper on the domes (1935) gave me full membership in Sigma Xi, and a diagram from that paper was used in Cotton's *Volcanic Landforms*. It was my first (and only) inclusion in a textbook.

Quadrangles 7–8, during 1935–6: Collier Butte and parts of Agness—Only Forest Service planimetrics available (1938).

At the end of the Crater Lake season, again through Dr. Smith's contacts, I was hired as field geologist for $150 per month and **all** expenses by C.E. Tuttle, CEO of Rustless Iron and Steel Corporation, to prospect for chromite on the West Coast, beginning in Curry County. Our base camp at Agness in 1935 was for nine months of the year accessible only by a 35-mile boat trip from Gold Beach.

We rented a log cabin on the south side of the Illinois River for $40 a month. It had two wood stoves, so we sawed and split several cords of wood to last us through the winter. Our water supply was through a pipe from a box 400 feet up the stream that ran alongside the house. A winter flood once tied the pipe in knots, while the roar on the "stream" kept us awake all night. We trapped numerous mice, and a polecat (spotted skunk) got into the cabin and had to be "coaxed" out.

To get our mail, we rowed across the Illinois River and then hiked for a mile, across the Rogue River suspension bridge (since then taken out by another flood), to the post office at Agness. We could order groceries from Gold Beach, which would be dumped on the river bar for us to pick up, half a mile downstream at the junction of the two rivers.

Since Oregon chromite is found in serpentine, peridotite, and dunite, for a year I mapped these rock bands while directing an eight-man prospecting crew, mostly from a tribe of Rogue River Indians headed by Walter Fry, who knew the country like the palm of his hand. I supplied the crew weekly from Agness by pack train, and reported on the claims they located. The crew took a day or so to construct each of three spike camps by cutting down a Port Orford cedar, splitting it into shakes, and building a small cabin.

Early in June of 1936, I sent a 30-page report to Tuttle, detailing the location, tonnage and grade of 67 small (less than 150 tons) chromite deposits in 92 claims. A week later a telegram from Tuttle said, "Fine work, but what shall I do?" I learned the hard way to put conclusions and recommendations **first** in all my reports.

As it turned out, all but one or two of the claims were too small and "too far from the railroad," so we moved our base to Grants Pass, where we set up a chemical laboratory to assay chromite samples, with Howard Stafford as chemist, and broadened the exploration to eventually report on more than 100 other chromite deposits in southern and central Oregon (1939), northern Washington (Twin Sisters), and in California as far south as San Luis Obispo (1941).

During this period, Tuttle asked me to report on several tungsten deposits in Nevada and an interesting large "low-grade" nickel deposit near Sedro Wooley, Washington. Many years later I spent several weeks examining the iron deposits of Nevada.

Conducting boat trips around Crater Lake was one of the author's responsibilities in 1935.

Quadrangle 9, during 1937: Parts of Round Mountain (now Ochoco Reservoir)—On planimetric Forest Service maps (1940); and

Quadrangle 10, during 1938: Parts of Butte Falls—Map published by DOGAMI without text (1941):

During the first two years with DOGAMI, I spent most of my time examining more than 200 prospects and mines in Baker County for DOGAMI Bulletin 14-A, the first of the Metal Mines Handbook series (1939). I was borrowed several times, however, to help with mapping in progress in other parts of the state. Wayne Lowell and I mapped for several weeks in the area northeast of Ochoco Reservoir (1940). The area was nearly all Clarno Formation and could be mapped only by locating widely scattered outcrops by traverses through the forest with Brunton compass and a 200-foot chain.

I also mapped for several weeks under W.D. Wilkinson in the Butte Falls quadrangle (1941) northeast of Medford. The rocks of this area were mostly composed of Western Cascades volcanics (we called the volcanic breccias the "Crud Formation"). It was another difficult area to delineate at that time.

The road to the lodge at Crater Lake in June 1935.

Quadrangles 11–14, during 1938–39: Substantial parts of Enterprise, Eagle Cap, Joseph, Cornucopia—Only forest service maps with a 500-foot contour interval were available at that time (1941, 1975).

My first important mapping project for DOGAMI was reconnaissance of the Northern Wallowa Mountains, under Dr. Warren D. Smith. The crew of nine consisted of Dr. Smith, Ray Treasher, myself, Lloyd Ruff, Wayne Lowell, Herb Harper, Wilbur Greenup, Jim Weber, and Ray Huffaker.

"Spike cabin" as used for spike camps by the author in 1936 in southwestern Oregon.

The Wallowa Mountains have a relief of nearly a mile and a half, with elevations from less than 4,000 to more than 11,000 feet. To reach areas far from the roads, two of us would hike in with a pack horse and set up a spike camp. It usually took until noon to climb from camp to the top of the ridges.

The area includes most of the Cretaceous Wallowa Batholith, which intrudes Permian to Upper Triassic greenstone, siltstone, and limestone that have been folded into tight northeast-trending folds. The older rocks, now considered to be part of the Wrangellia Terrane, are overlapped on all sides by Columbia River basalt. Twenty-four glaciers, several of them more than 20 miles long, once cut the deep valleys that radiate out from the high peaks in the center of the range (1975).

Upon return to Portland late in August, we were able to patch together and publish within 90 days a preliminary colored map (1938) with a 16-page description. A few of us did further field work next summer, and the completed study was published as Bulletin 12 (1941).

Picture postcard scene of 1935, near Agness in Curry County, where the Illinois and Rogue Rivers join.

During the early 1940s, I examined quicksilver deposits in the Ochoco and Maury Mountains and helped complete the second part of the Metal Mines Handbook, Bulletin 14-B (1941). I contributed to a bulletin on manganese in Oregon (1942) and sampled and mapped the geology of a reported tin deposit at Glass Buttes (1942), which turned out to be an elaborate hoax.

Quadrangle 15, during 1942–3: Substantial parts of Coos Bay (1944).

Ewart Baldwin, Ralph Mason, and I started remapping the Coos Bay quadrangle early in 1942. Besides measuring and subdividing the geologic formations and making large-scale topographic maps of several mine areas, we cleaned outcrops and measured thicknesses of numerous coal prospects and old mines. Ralph Mason, as engineer, supervised the hand-drilling of several of the shallower deposits and estimated coal reserves. The result was the publication of DOGAMI Bulletin 27 (1944).

Since we worked through a normal wet winter, we wore loggers' "tin" pants and heavy canvas jackets in an attempt to keep dry. While making large-scale topographic maps of deposits with a planetable, we used machetes to slash our way through the brush to give us a view of the stadia rod. For planetable "paper," we used aluminum sheets from a multigraph machine.

During the late 1940s I worked out of the Portland office on several economic deposits in western Oregon, such as limestone (1946) and brick and tile (1949). However, a most interesting commodity at that time was perlite, which is a high-water-content obsidian that expands like popcorn in a rotary furnace to form a very lightweight and fluffy aggregate that can be used in plaster and cement blocks.

I mapped a perlite deposit (1946) that lay on the steep east slope of the Mutton Mountains above the west bank of the Deschutes River at Dant. Before doing the geology, I made a one-square-mile, large-scale topographic map by planetable, using the railroad as a baseline and numerous laths set up around the property for triangulation to give elevations. The deposit was later extensively mined, the "ore" being shipped to Portland for furnacing.

Quadrangle 16, during 1950: Capitan, New Mexico (1981).

In 1947, I went to Pennsylvania State College as associate professor and head of the summer field camp. During two years there, I was unable to do any significant field mapping, although the 60 students in my camp mapped and measured sections in the mountains south of State College. An attempt to spend the latter part of the summer in quadrangle mapping was stymied when the head of my geology department heard that I was trying to map and assigned two graduate students to map my quadrangle.

When I went in 1949 to the New Mexico Institute of Mines and Technology as professor and head of the geology department, I began mapping the Capitan quadrangle, located east of Carrizozo, New Mexico. During my seven-year stay at Socorro, I mapped there for parts of three summers but was unable to finish the project. I did write a guidebook (1981) of the Capitan area, which went through three editions.

Quadrangle 17, during 1953–4: Substantial parts of Tohatchi, New Mexico, and east edge of Fort Defiance, Arizona (1954, 1955).

In 1952, I transferred from the Institute to the Bureau of Mines, and one of my first projects was to help Robert Balk map for the Navajo Tribal Council the Fort Defiance and Tohatchi quadrangles on the reservation 40 miles northwest of Gallup, New Mexico. As it turned out, Balk mapped the Fort Defiance, and I did the Tohatchi quadrangle.

Since no planimetry or topography existed, we mapped and published the geology in color on air-photo mosaics, perhaps the first time they had been used that way, but well adapted for use by the tribes. You could spot your location to the nearest pine tree or juniper bush!

Besides mapping this area, John Schilling and I measured with planetable more than 20,000 feet in eight different stratigraphic sections of Cretaceous Mesa Verde intertonguing sandstones and shales. The result (1954) was my last significant publication of geologic quadrangle maps.

CONCLUSION

Field geology during the 1930s may well have required more outdoor skills and adaptability than it does today, when 7½-minute topography, helicopter transportation, radio and satellite communication and location, and portable PC notebooks with modems are available.

Since geologic maps furnish basic information used in nearly all fields of geology, their construction and constant refinement by remapping (on larger scales and with newer hypotheses) should have higher priority than is frequently shown. There are still dozens of quadrangles that have never been mapped at all.

Author carrying planetable equipment for mapping on the Deschutes River in 1928.

When I began field work, I discovered at once that I had use for skills I learned in winning 36 Merit Badges in Scouting (1990), such as hiking, cooking, camping, pioneering, surveying, first aid, canoeing, swimming, etc. My first professional job at Agness required each week that I make up and load (diamond hitch) two mules for a pack train.

I was constantly challenged and stimulated by the need for problem solving, strategy, and logistics of field work, as well as by the actual deciphering of the intricacies of geology to make the geologic map. I found that my traverses were actually guided by the "multiple hypotheses" I generated. Field work gave me travel (and sight-seeing), hiking gave me exercise (and good health maintenance), and the many hours outdoors introduced me to flora and fauna I would never have seen or learned about otherwise.

At Crater Lake I learned to memorize Latin names of most of the plants and animals of the area. I had adventures with both bears and golden-mantled ground squirrels, there and elsewhere. I was once dive-bombed by a hummingbird (I must have sat down for lunch too near her nest?). I learned how to avoid rattlesnakes, wood ticks, mosquitoes, horseflies, and yellow-jacket nests (imagine what one could do to my pack train!). I learned how to work, talk, and deal with Indians, both in Curry County and in New Mexico. And perhaps best of all, I met all those other enthusiastic and interesting geologists!

All teachers should have a few years of field work before they meet their first classes. Such experiences gave me dozens of stories that I used for 28 years to perk up the students in my classes in general, economic, and regional geology. Such anecdotes, told with enthusiasm to illustrate a point, can make an ordinary teacher into an excellent teacher.

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Reclamation, regulation, and you — some basic questions and answers

The following text is from a recently published booklet by the Mined Land Reclamation Program, Oregon Department of Geology and Mineral Industries (MLR/DOGAMI), Albany, Oregon. The booklet is being distributed on request to all those interested in surface mine reclamation or in developing a mining operation. Anyone interested should contact MLR/DOGAMI at its Albany office, 1536 Queen Ave. SE, Albany, OR 97321, phone (503) 967-2039.

—ed.

Just what is reclamation?

Reclamation is a multidisciplinary process of land treatment that minimizes adverse effects, such as water degradation, damage to aquatic or wildlife habitat, and flooding and erosion potential, that can result from mining operations.

Reclamation is not an activity that starts the day the mining ends. Instead, when done correctly it is a plan that is used throughout the entire mining operation. Then, when mining ends, the site is ready for completion of effective and acceptable reclamation.

Reclamation in Oregon means that after mining operations are over, a mine site must be made fit for other beneficial uses ("second uses") that are compatible with local zoning and surrounding land use activities and meet prevailing environmental and aesthetic standards as required in the mining permit.

Reclamation is a complex technical process. It involves ongoing attention and creative insight into engineering properties of material, mine configuration and development, the environment, economics, physical constraints of production, and sequence of mining activities.

The role of the Oregon Department of Geology and Mineral Industries (DOGAMI) is to oversee the sequencing and coordinating of this process to minimize the impacts to natural resources. The DOGAMI Mined Land Reclamation program is funded by the permit fees paid by mine operators.

Who must reclaim?

In Oregon, all mine sites that have greater than 5,000 cubic yards of production per year or that disturb more than one acre of land per year are subject to the reclamation requirements of DOGAMI. Also, if a mining operation disturbs a total of five acres over time, then reclamation is required. These regulations apply, in general, to commercial operations. Exemptions are made for on-site construction activities such as timber production and agriculture.

What about people?

Simply stated, those impacts of mining that affect people more than the engineering properties of the land or the environment are subject to considerations of land use. The land use category includes such factors as hours of operation, off-site noise, related road traffic, and impact on neighboring areas. These types of impact on people are not regulated by DOGAMI. Instead, they are regulated by local government through land use permitting processes.

What is the difference between reclamation and land use?

The simplest way to visualize the distinction between permitting for reclamation and permitting for land use is to picture yourself standing at the edge of a permit boundary. If you are looking at the mine site and thinking in terms of engineering properties, landslides, water, and other aspects of the natural environment, then you are thinking about aspects of reclamation. Those are the aspects of mining that are regulated by DOGAMI.

In deciding whether or not to issue a permit, DOGAMI works with other agencies and simply tells you, "If you are permitted to mine by local government, then your mine must meet these requirements."

On the other hand, the fundamental question asked by local government in considering an application to mine is simply, "Are you going to be allowed to mine, or aren't you?" Local government then makes a land use decision, as opposed to designing or approving a reclamation plan, as DOGAMI does.

How do state and local government agencies coordinate?

As the public and the prospective operator approach questions of whether to mine or not and how mining, if approved, is to proceed from a reclamation standpoint, the concerns of local government and DOGAMI are often interrelated. For example, if the public responds to local government hearings about a potential mine site by expressing concern about landslide potential, this concern must be communicated to DOGAMI. Likewise, when DOGAMI is considering the environmental and engineering aspects of a reclamation permit, it needs to know what is the second use that is being considered, how does this second use relate to local plans, and how does the public feel about such a second use.

Since 1991, the permit processes of DOGAMI and of local government have been properly constructed by law to allow the necessary coordination between the two types of permits. Before that time, coordination had been much more difficult.

When DOGAMI considers an application, it sends a copy to local government. Most commonly, local government asks for up to 165 days to work with DOGAMI and asks that DOGAMI not issue a permit until after local government has acted. Other coordination options are available, too, and local government has the opportunity to request them.

During this period of mutual consideration of applications, one for reclamation at the state level and the other for land use permit at the local level, several other natural-resource agencies are also routinely consulted before any permit is issued.

How much mining is there in Oregon?

Currently, DOGAMI has permits for approximately 800 active mine sites throughout the state. These include such operations as quarries, gravel pits, sand pits, mines for various types of industrial minerals, metal mines, and exploration sites. The sites range in size from one acre to tens or even hundreds of acres. Since 1972, approximately 3,000 acres have been reclaimed. Currently, 4,000 acres are under bond. Mining now covers less than one hundredth of one percent of the land in Oregon.

What does the future look like?

Mineral deposits do not occur everywhere. The choices of locations for possible mine sites to meet the needs of Oregon's growing population are dictated largely by nature. Challenges and potential conflicts related to mining will continue to need increased attention.

A trend that DOGAMI has noticed in recent years is toward increased complexity of permitting, particularly in areas affected by urban growth. As more and more of Oregon is urbanized, larger and larger mine sites are being contemplated in certain areas. At the same time, market areas and construction demands for materials from these sites are also expanding. Thus, we are going to see more complex regional sites in addition to the smaller, more local sites of the past.

Although planning and permitting of mining is done at the local level, the demand areas for some sites are expanding beyond the county boundaries in which the sites occur. This is placing a new challenge on the planning process in Oregon, particularly in the northern Willamette Valley. Dealing with these types of applications is going to be a growing challenge, both to government and to the public. New methods of decision-making may be required.

From a technical standpoint, the larger sizes of these new types of sites will require that DOGAMI give increasing attention to physical impacts on the environment, such as possible landslides and effects on ground water. More initial data will be required from the applicant. Monitoring and increased site visits may be required to assure that mining is proceeding as planned where it is permitted.

How does reclamation make sense?

It is important that, at a minimum, various laws, regulations, and requirements placed on mining be followed. In this way, the environment, safety, second beneficial use, and other concerns will be protected.

Reclamation securities or performance bonds are required to ensure performance of the reclamation plan requirements. Beyond this minimum level of reclamation and management, however, it is desirable to do more. We should cultivate a reclamation ethic. Where possible, creative use of the land should provide benefits above and beyond the requirements of the law.

For this reason, DOGAMI has implemented an awards program to recognize reclamation and mine operations that exceed law requirements. Other procedures are in place to facilitate reclamation "above the law." Visionary cooperation toward long- range goals can turn some mining into public landscape architecture at a profit.

With proper incentives, information, and a constructive working environment with the people and government, many operators can exceed the requirements of the law. Oregon mine operators, too, are concerned about the environment, second land use, and the cost-effective supply of our dwindling mineral resources to society. All Oregonians stand to gain with proper management of mines and their reclamation.

Reclaiming land to a second beneficial use can produce land with a greater value than it had originally. In some cases, productivity of farm land was increased through reclamation where lenses of porous gravels were removed to reduce irrigation demands. In other farm locations, the terrain was leveled to increase irrigation efficiency, or surface gravels were removed and separated from soil materials before the soil was replaced to reconstruct farmland.

Wetland protection is a concern to all Oregonians. The state has numerous operations where upland areas with shallow ground water have been converted to wetlands and lakes. This type of reclamation can actually begin while the sites are actively being mined. Increasing numbers of wildlife, particularly migratory waterfowl, use lakes and wetlands that have been created on mine sites because these sites provide excellent resting and foraging opportunities for wildlife. This type of reclamation helps create more diversified habitat than existed prior to mining. □

(DOGAMI PUBLICATIONS, *continued from page 64*)

The map of the Mist Gas Field in Columbia and Clatsop Counties has been updated and is accompanied by a production summary for 1993.

For the first time, the *Mist Gas Field Map* is available both as the usual paper copy and, on request, in digital form (price $25). It is offered in three different CAD formats (.DGN, .DWG, and .DXF), all on one 3½-inch high-density diskette formatted for DOS, for use by different software systems. Using a digitized version allows, for instance, add additional information or work with various scales and sections of the map.

Mist Gas Field production figures. Released as Open-File Report O–94–6. Price $5.

The cumulative report of past production at the Mist Gas Field during 1979–1992 is now available in a separate 40-page release.

Both the *Mist Gas Field Map* and the *Production Figures* are useful tools for administrators and planners as well as explorers and producers of natural gas.

Released April 6, 1994:

Preliminary geologic map of the Medford East, Medford West, Eagle Point, and Sams Valley quadrangles, Jackson County, Oregon, by Tom J. Wiley and James G. Smith. Released as Open-File Report O-93-13. Price $8.

The two-color map is printed on two sheets. An eight-page text contains a description of the rock units of the area, a geologic summary, a discussion of ground-water resources, mineral resources, and data tables with geochemical analyses and descriptions of mines and prospects.

The rocks in the Medford area record the 200-million-year geologic history of the region. Most of the rocks found in the region are either sedimentary rocks that were originally deposited as sediments in ancient oceans and rivers or volcanic rocks. Some have been metamorphosed; others have been mineralized to form precious-metal deposits. The region has been affected by landslides and faults, which are also shown on the map.

These maps continue the series of maps planned to aid regional planning in the Medford-Ashland area, which is experiencing rapid population growth. In addition to providing bedrock geology and mineral-resource data, landslides and faults are depicted in greater detail in this series than on previous maps. Earlier maps of this series are DOGAMI maps GMS–70 (1991) of the Boswell Mountain quadrangle and GMS–52 (1992) of the Shady Cove quadrangle.

The new publications are available over the counter, by mail, FAX, or phone from the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444, FAX (503) 731-4066; and the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment except for credit-card orders. □

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