UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Mineral resource potential map of the Three Sisters Wilderness, Deschutes, Lane, and Linn Counties, Oregon

By

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STUDIES RELATED TO WILDERNESS

Under the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and related acts, the U.S. Geological Survey and the U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System, and some of them are presently being studied. The act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. The act directs that the results of such surveys are to be made available to the public and be submitted to the President and the Congress. This report discusses the results of a mineral survey of the Three Sisters Wilderness (NF083), Deschutes and Willamette National Forests, Deschutes, Lane, and Linn Counties, Oregon. The Three Sisters Wilderness was established by Public Law 88-577, September 3, 1964, and the Endangered American Wilderness Act (PL95-237), March 1, 1979.

SUMMARY STATEMENT

The Three Sisters Wilderness contains pumice deposits and may have geothermal resources; it has no known metallic-mineral or hydrocarbon deposits. Investigations indicate 900,000 tons of block pumice suitable for decorative stone and other commercial uses occur at Rock Mesa in the wilderness. A broad area centered around South Sister volcano is among the most geologically favorable localities for geothermal resources in the Oregon Cascade Range, based on the large volume of silicic volcanic rocks that occur in this area and the very young age of some of these rocks. However, no drill hole information is available with which to evaluate the existence or magnitude of the geothermal resource. The rare mineral osumilite, which occurs at a mining claim in the wilderness, is of interest to some mineral collectors.

INTRODUCTION

The Three Sisters Wilderness straddles the crest of the Cascade Range in Deschutes, Lane, and Linn Counties of central Oregon (fig. 1). It includes 245,302 acres in the Willamette and Deschutes National Forests. Established as a primitive area of 196,708 acres in 1937, it was classified as wilderness in 1957 and included in the National Wilderness Preservation System in 1964 (Public Law 88-577). Subsequently, the Endangered American Wilderness Act (Public Law 95-237) added another 48,594 acres, most of which was part of the French Pete Proposed Addition.

The U.S. Bureau of Mines spent 80 days in 1980 examining prospects and obtaining pan-concentrates of sediments from streams draining the Three Sisters Wilderness. The only previous detailed studies of the mineral resources dealt solely with the pumice deposits at the Hermana Group claims (fig. 2) and are described in U.S. Forest Service internal reports by Suchy (1963) and Ball (1972) and contracted reports by Richards (1972), Stoeser and Swanson (1972), Grant (1976), Magill (1976), and Kolberg (1976).

The U.S. Geological Survey mapped the geology of the wilderness in the summer and fall of 1978 and 1979 (Taylor and others, 1983) and conducted geophysical surveys in 1980 and 1981. There are no prior detailed geologic maps of the entire wilderness, although all of it has been studied in reconnaissance and some of it in detail. Prior studies of the wilderness and adjacent areas include: Williams (1944, 1957); Peck and others (1964); Taylor (1965, 1967, 1968, 1978, 1981); Anttonen (1972); Peterson and others (1976); Brown and others (1980); and Flaherty (1981). Gravity and aeromagnetic maps by Pitts and Couch (1978) and Couch and others (1978) include the wilderness area.

LOCATION AND GEOGRAPHY

The Three Sisters Wilderness is the southernmost of three nearly contiguous wilderness areas that occupy most of a 65-mile-long north-south stretch of the High Cascade physiographic province in central Oregon (fig. 1). A narrow corridor occupied by Oregon State Highway 242 separates the Three Sisters Wilderness from the Mount Washington Wilderness; the Mount Jefferson Wilderness is only a short distance farther north.

The Three Sisters Wilderness is approximately 45 mi east of Eugene and 30 mi west of Bend, Oregon (fig. 1). Access from Eugene is by Oregon State Highway 126 and Forest Service roads branching from it; access from Bend is by U.S. 20 and Oregon State Highways 46, 126, and 242 and by Forest Service roads branching from these highways. A 50-mile-long segment of the Pacific Crest National Scenic Trail extends north-south through the wilderness.

The wilderness is mostly in the High Cascade physiographic province of the Cascade Range (fig. 2). This section of the High Cascades consists of a volcanic highland that slopes gently east and west from the Cascade crest, typically at an elevation of about 6,000 ft; the western slopes are dissected by deep canyons. The Three Sisters (South Sister, 10,358 ft; Middle Sister, 10,047 ft; North Sister, 10,085 ft) and Broken Top (9,175 ft) are four large contiguous stratovolcanoes on this highland. No other part of the High Cascades contains such a cluster of stratovolcanoes, and the range is especially wide in this area. The western part of the wilderness (French Pete Addition) is in the Western Cascade physiographic province and is a mountainous terrain cut by deep canyons. Total relief in the wilderness is about 8,300 ft.

Higher areas of the wilderness around the four stratovolcanoes are above timberline, but the western areas are brushy and thickly forested, and the remainder is mostly open forest. Numerous lakes occur in the wilderness, especially in the southern half.

GEOLOGY

The Three Sisters Wilderness is underlain entirely by volcanic rocks of late Cenozoic age and sediments derived from them (Taylor and others, 1983). Gently dipping flows and pyroclastic rocks that crop out in the western part of the wilderness in the Western Cascade province are the oldest rocks. They have yielded K/Ar ages mostly between 10 and 16 m.y. (Flaherty, 1981; Priest and Vogt, 1982, Appendix A; R. A. Duncan, 1982, written communication); a few ages as young as 8 m.y. are probably a consequence of rock alteration. They are overlain by a discontinuous sequence of epiclastic sediments capped by flat-lying basalt and andesite flows. These flows, which form the tops of most ridges in the French Pete Addition, have yielded K/Ar ages of 6 to 10 m.y. (Flaherty, 1981; Priest and Vogt, 1982).

The High Cascade part of the Three Sisters Wilderness is formed of upper Pliocene, Pleistocene, and Holocene volcanic rocks, glacial deposits, and alluvium. The oldest rocks in this part of the wilderness are basalt and basaltic andesite flows exposed in deep canyons, such as along Separation Creek, that dissect the western side of the High Cascades (fig. 2). K/Ar ages of these flows range widely. Most of them are probably 1 to 3 m.y. old, but ages of as much as 8 m.y. have been obtained on some of them (Priest and Vogt, 1982, Appendix A). If the older determined ages are not due to contamination or initial inclusion of radiogenic argon, then some of these flows may correlate with the ridge-capping flows in the Western Cascade part of the wilderness. Pleistocene basalt and basaltic andesite flows younger than 2 m.y. are the dominant rock type in the wilderness. Basaltic andesite (53 to 58 percent SiO_2) is generally more abundant than basalt (less than 53 percent SiO_2) except in the lower parts of the pile. The flows are glaciated and commonly covered by a discontinuous veneer of glacial outwash and till. Vents, including cinder cones, small to large stratovolcanoes, and lava shields are abundant, especially near the axis of the range. The vents are variably glaciated. Some retain most of their original form, others are so deeply glaciated that little remains to indicate their location except for remnants of the core plugs and dikes that once laced them.

Intermediate and silicic volcanic rocks of Pleistocene age are interlayered with and overlie the more widespread flows of basaltic andesite and basalt in a broad region extending from Obsidian Cliffs (west of North Sister) southward to Kokostick Butte (south of South Sister) and eastward to the area surrounding Broken Top (fig. 2). They consist of andesite, dacite, and rhyodacite flows, domes, and pyroclastic rocks.

North Sister, Middle Sister, South Sister, and Broken Top stratovolcanoes are formed of interlayered thin flows and pyroclastic deposits and of dikes and plugs. They formed during the Pleistocene, probably during the last several hundred thousand years. Andesite flows and pyroclastic rocks, however, were erupted from the summit of South Sister during the Holocene. Active glaciers and large areas of permanent snowfield are present on the stratovolcanoes.

Holocene mafic and intermediate flows and related cinder cones and fissure vents are widespread in a broad area generally west of North Sister and south of South Sister and Broken Top. Some of these flows were erupted less than 2,600 years ago (Taylor, 1981).

Holocene silicic flows, domes, and pyroclastic rocks occur around the southern and eastern sides of South Sister. Rock Mesa is a thick stubby rhyodacite flow south of South Sister (fig. 2), and small domes and pyroclastic vent deposits occur less than one mile northeast. A belt of rhyodacite flows, domes, and pyroclastic deposits extends northward from State Highway 46 near Devils Hill up and across the east flank of South Sister. Pumiceous pyroclastic deposits related to the rhyodacite flows and domes are thick near the vents, but also occur as air-fall deposits that discontinuously veneer most of the southern and eastern parts of the wilderness. Carbon derived from peat deposits interlayered between these air-fall deposits have yielded ^{14}C ages of 2,000 to 2,900 years (Taylor, 1978; D. R. Mullineaux, 1979, written communication).

Considering the youthfulness of volcanic activity, the highlands around the four major stratovolcanoes likely will continue to have eruptions in the future. Three of the stratovolcanoes have not erupted during the Holocene and may have no future activity. South Sister has been active during the Holocene and is capable of future eruptions. The area around the Three Sisters and Broken Top is geologically similar to that of Mount Mazama before the climactic eruptions that produced Crater Lake (see Bacon, 1983).

Most rocks in the Three Sisters Wilderness are not tectonically deformed. The older volcanic rocks of the French Pete Addition are locally faulted, but the displacement is not large. A large north-south-trending east-dipping normal fault has been mapped adjacent to the wilderness in the vicinity of Horse Creek (fig. 2) near the boundary between the Western Cascade and High Cascade provinces (Flaherty, 1981). The Pliocene and Pleistocene basalt and basaltic andesite flows of the High Cascades province in the wilderness may bank against a fault line scarp, with the actual fault trace buried by flows younger than the fault. Faults were not observed in the High Cascades part of the wilderness. Alignments of vents may define the location of buried inactive faults, but are more likely a response to the regional stress field (Nakamura, 1977).

Younger rocks in the wilderness are mostly fresh; older rocks show variable alteration (clay minerals and zeolites) similar to that found in many other areas of the Western Cascade province. Hematite and limonite, and very rare pyrite, chalcopyrite, and malachite were noted along fractures in the volcanic rocks in vent deposits at scattered localities in the High Cascades. Similar alteration occurs at many other vents in the High Cascades and is interpreted to result from volcanic exhalative processes.

MINERAL RESOURCES

No resources of base or precious metals were identified in the Three Sisters Wilderness. The area contains no base- or precious-metal mines; the nearest mines, in the Blue River and Fall Creek districts 10 miles west of the wilderness, contain vein deposits of gold with some silver, copper, and lead (Brooks and Ramp, 1968). Thirteen base- or precious-metal claims have been staked within the wilderness; 12 of these are placer claims. The Pat Creek claim (fig. 3), located in 1969 by Marcus Jones and Joe Reynolds, is in a poorly exposed shear zone and contains trace gold and 0.4 oz silver/ton. The claim is apparently abandoned. The placer claims are located along streams in the wilderness.

As part of this mineral investigation, stream-sediment samples were collected from streams near the border of the wilderness and analyzed for their content of trace elements. Locations of the samples are shown on Figure 2 and the analyses are listed in Table 1; sample locations are unevenly distributed because of the paucity of streams in some areas. At each location two samples of fine sediment were collected, one of bulk sediment, the other a pan concentrate of the heavy-mineral fraction of the sediment. In the laboratory each sample was dried, sieved to minus-80 mesh, and split. The heavy minerals in the pan-concentrate samples were further concentrated by settling in bromoform (specific gravity, 2.8) and separated into magnetic and non-magnetic fractions.

Samples of stream sediments and non-magnetic heavy mineral concentrates were then pulverized before analysis by standard semiquantitative emission spectrography and by fluorimeter (U), Hg detector (Hg), and atomic absorption (Zn, Au). The analyzed sediments from steams draining the wilderness show concentrations of metallic elements similar to those commonly found in volcanic rocks. No anomalous concentrations of any elements were found. Gold was observed in trace amounts in pan concentrates from many streams, but it constitutes only a few parts per billion of the alluvium. Similar traces of gold were found in many streams in other parts of the High Cascades province which suggests the gold is derived from dispersed sources in the volcanic rocks rather than being related to surficial or buried mineral deposits.

Pumice deposits at the Hermana Group claims on Rock Mesa (fig. 3) are the only industrial mineral resource identified in the wilderness. The pumice occurs as an irregular blocky capping of the glassy rhyodacite flow that forms Rock Mesa. This deposit has never been mined, but has been studied in detail. The deposit contains 900,000 tons of commercial grade pumice, 50 percent of which is estimated to be recoverable (Richards, 1972; Grant, 1976). Pumice samples totaling 0.75 tons from the Hermana Group claims were examined during patent investigation. The pumice would be used primarily for decorative stone.

Magill (1976) recommended that mining be done at the Hermana Group claims with crane and bucket. He assumed a yearly production rate of 12,000 tons, equal to that at U.S. Pumice Company's Mono Craters, California deposit. Because of snowfall on Rock Mesa, mining would be done only during the summer. According to the company, the deposit would not be worked until after the deposit at Mono Craters is exhausted. The sale of 12,000 tons of pumice would be worth $1,155,960 at 1981 prices; operating costs would be $823,962 per year according to Magill (1976).

Other pumice deposits located between Devils Lake and Green Lakes (fig. 2) were examined, but the amount of block pumice at rhyodacite domes and flows there is small.

Specimens of the rare mineral osumilite from the Betsy Girl claim at Obsidian Cliffs (fig. 3) have been sold to Ward's Natural Science Establishment, Inc., Rochester, N.Y. The claim, located by M. M. Groben in 1977 and currently held by assessment work, is on a thick rhyodacite flow that contains black euhedral crystals of osumilite $[K(MgFe,Mn)_2(Al,Fe)_3(Si,Al)_{12}O_{31}]$ in vesicles. The crystals, mostly less than 0.1 inches in diameter, are of interest to some mineral collectors, but are not a major economic commodity.

Large amounts of cinders and stone occur in the wilderness, but numerous other deposits are closer to markets.

Hydrocarbon deposits (oil, gas and coal) do not occur within the Three Sisters Wilderness. Cenozoic volcanic rocks many thousands of feet thick underlie the wilderness and have no hydrocarbon potential.

The High Cascades physiographic province is an area of interest for geothermal exploration, but the magnitude of the geothermal resource is not known. Possible geothermal resources are suggested by the abundance of Quaternary volcanic rocks, relatively high heat flow, and hot springs.

The Belknap-Foley Known Geothermal Resource Area (KGRA) is just northwest of the Three Sisters Wilderness. Belknap Hot Springs and Foley Hot Springs (fig. 2) are about 5 mi from the wilderness and yield 25 to 75 gallons of water per minute with a temperature of 147^{o} to 180^{o}F

(Waring, 1965); other hot springs are a few miles farther west. Hot springs near the western edge of the High Cascade province are interpreted to be the result of lateral flow of warm or hot water from heat sources beneath the High Cascades (Blackwell and others, 1978; Black and others, 1982).

Several heat-flow holes have been drilled near the western border of the Three Sisters Wilderness. These have yielded temperature gradients of 147 to 332 °F/mi (Brown and others, 1980; Priest and Vogt, 1982, appendix D). No heat-flow holes have been drilled in the wilderness itself.

The geology of the Three Sisters Wilderness suggests that parts of it have a higher geothermal resource potential than most other areas in the Cascade Range. Geothermal resources in the range are likely to be of two general types. The first is a possible regionally extensive deep resource related to influx of mafic magma into the upper crust during the development of the young mafic volcanic pile that forms the range. This resource may be too deep for development using current technology. Also, even if hot rocks are present at exploitable depths, permeability and porosity may be too low to yield adequate hydrothermal fluids for conventional methods of electric power generation. This type of deep resource may occur along the axial part of the High Cascades province in the Three Sisters Wilderness, but may also be present in many other areas of the range outside the wilderness.

The second, and probably more important, geothermal resource type is related to large silicic magma bodies or still hot, but solidified, silicic intrusions. Silicic intrusive bodies commonly are larger in the shallow crust than are mafic bodies, and commonly are associated with developed geothermal resources in other areas in the world. Smith and Shaw (1975) consider areas of young silicic volcanic rocks to be the most favorable for geothermal resources. The Three Sisters Wilderness contains relatively abundant silicic volcanic rocks. Dacite and rhyodacite domes and flows are more common in a broad area centered around South Sister volcano than in any other part of the Oregon Cascade Range, with the possible exception of the Crater Lake area. Furthermore, the Holocene rhyodacite flows and domes on the south to east sides of South Sister volcano are the youngest rhyodacites known in the Oregon Cascades.

On the basis of the distribution of silicic volcanic rocks, a broad area around South Sister (fig. 3) is one of the most favorable targets for geothermal resources in the Cascade Range of Oregon. Without drill-hole data, the area of geothermal interest can only be rudely defined, and it is here delineated on the basis of distribution of silicic vents around North Sister, Middle Sister, South Sister, and Broken Top stratovolcanoes. The most geologically favorable site for geothermal resources in this area is on the south and east sides of South Sister where Holocene rhyodacite vents are located.

The Three Sisters area is one of three in Oregon estimated by Smith and Shaw (1979, Table 3) to have large amounts of available thermal energy and is among the most geologically favorable sites for geothermal resources in Oregon according to Priest and Vogt (1982). However, no holes have been drilled to determine temperature gradients in this area, nor is there other surface evidence, such as hot springs or extensive areas of hydrothermal alteration, that might indicate a potential resource.

If high temperatures are present in this area at exploitable depths, development could be hampered by two factors. First, the porosity and permeability of the rocks at depth may be so low that fluids may be insufficient for direct hydrothermal power production. If so, techniques for transport of heat at depth to surface generating facilities would have to be different than in existing geothermal fields where electric power is generated by direct or indirect use of geothermal fluids. Second, this area has had numerous Holocene eruptions and future eruptions can be expected. Eruption of silicic magma is commonly explosive and capable of destroying nearby structures, such as power generation plants.

In summary, geothermal resources may occur in the Three Sisters Wilderness, but available information confirms neither their existence nor magnitude. Nevertheless, a broad area centered around South Sister volcano is among the most geologically favorable targets for geothermal resources in Oregon.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

The principal known mineral resource in the Three Sisters Wilderness is pumice. The pumice deposits occur at Rock Mesa on the south side of South Sister. Availability of other sources of similar pumice and environmental concerns have inhibited their development.

On the basis of the abundance of young silicic volcanic rocks, a broad area around South Sister volcano is among the most geologically favorable areas for geothermal resources in Oregon. However, no drill data exists with which to evaluate this resource, if present.

The rare mineral osumilite, which occurs at Obsidian Cliffs, is of interest only to mineral collectors, is not a major commodity, and has low mining potential. There are no known precious- or base-metal deposits or hydrocarbon deposits in the Three Sisters Wilderness.

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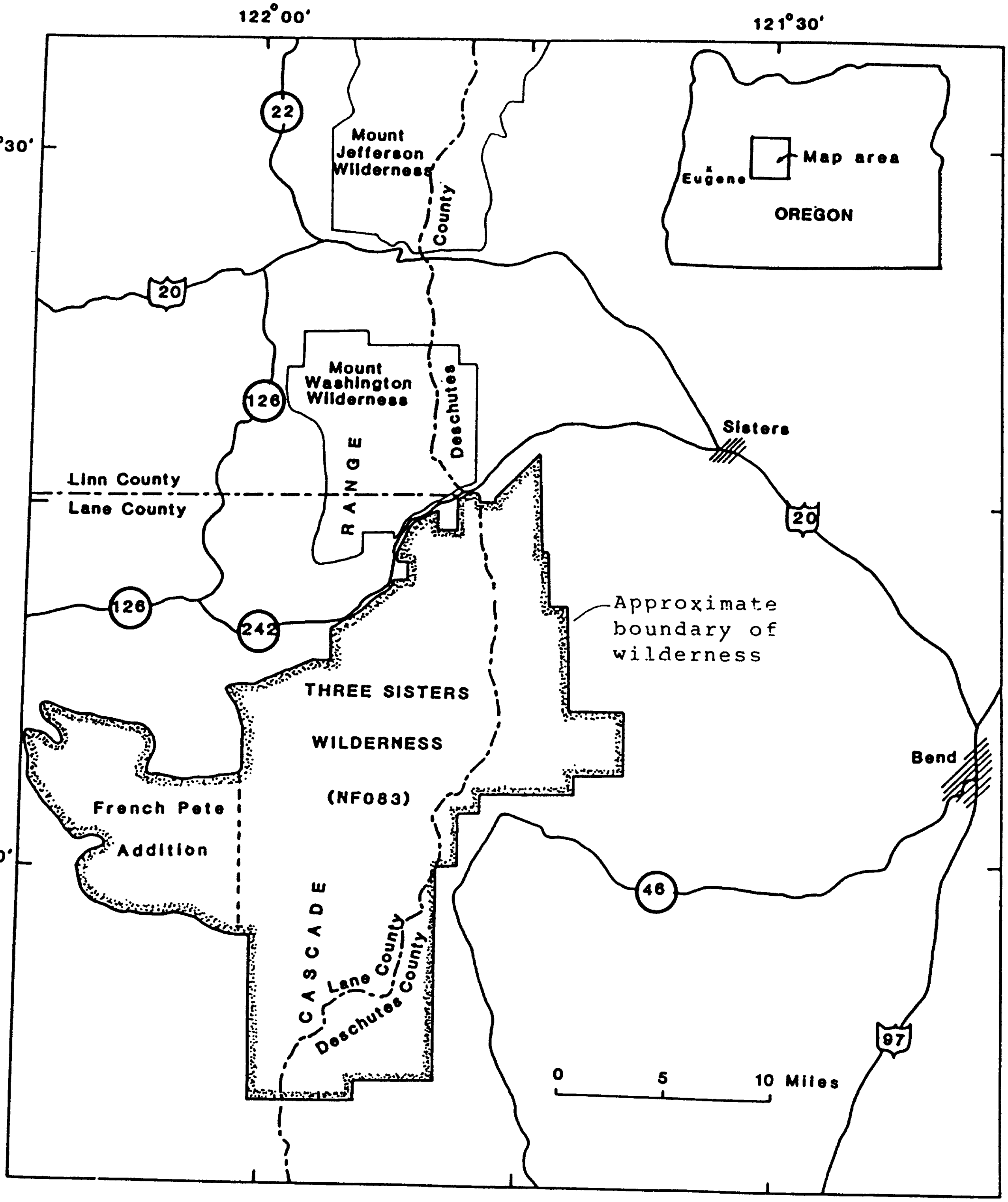

Figure 1. Map showing the location of the Three Sisters Wilderness, Deschutes, Lane, and Linn Counties, Oregon.

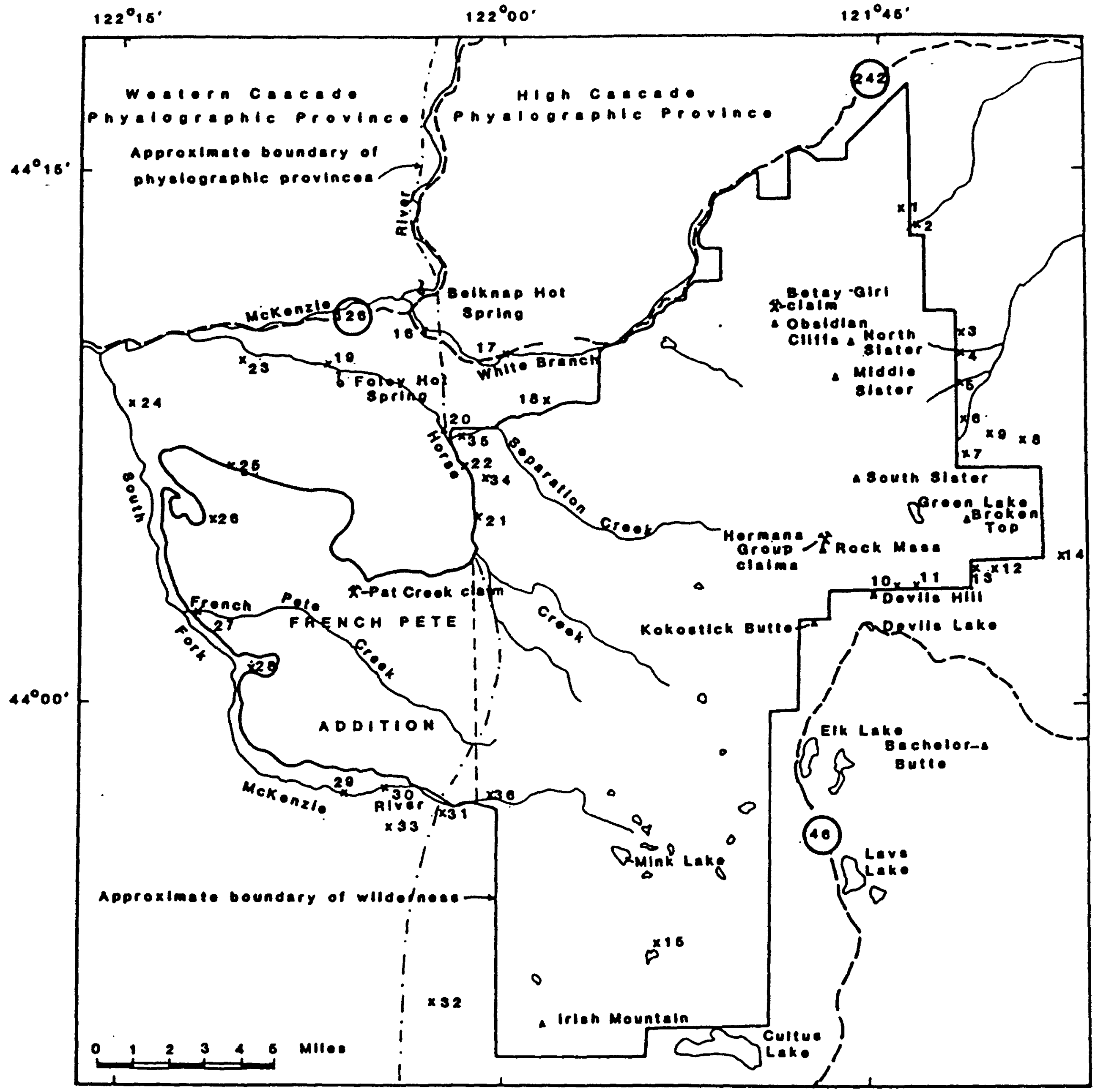

Figure 2. Map showing locations of geographic features in the Three Sisters Wilderness, Oregon, and locations (X) of analyzed stream-sediment samples for which analyses are listed in Table 1.

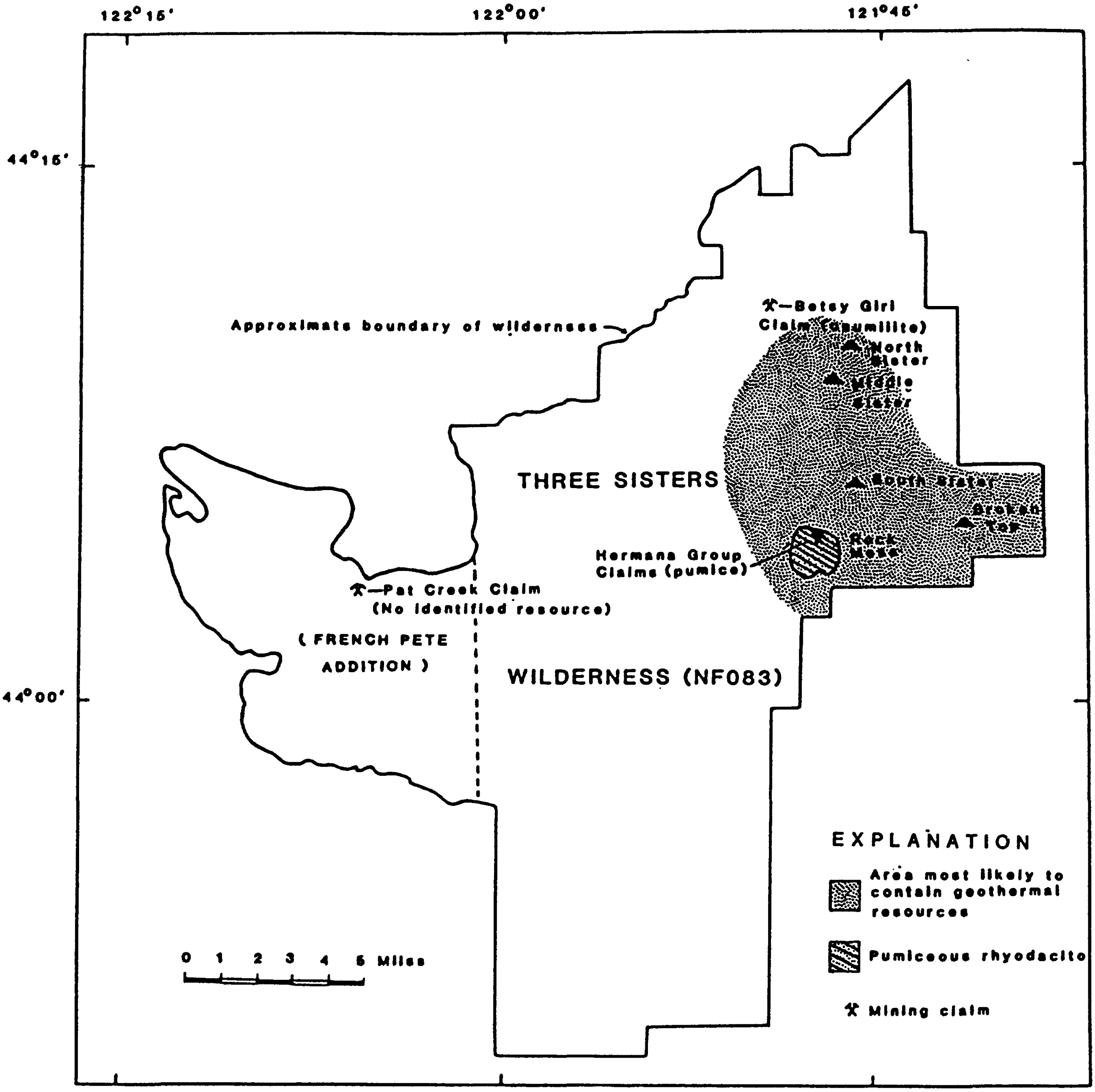

Figure 3. Mineral resource potential map of the Three Sisters Wilderness, Deschutes, Lane, and Linn Counties, Oregon.

Table 1. Analytical data for stream-sediment samples from Three Sisters Wilderness, Oregon. Sample locations are shown on Figure 2. Analyses are by C. Forn, B. Arbogast, and J. Viets, U.S. Geological Survey, Denver, Colorado. (Fe, Mg, Ca, and Ti in percent; all other elements in parts per million; N, not detected; L, detected, but below limit of determination; * identifies non-magnetic heavy-mineral concentrate)

Field No.	Map No.	Fe	Mg	Ca	Ti	Mn	B	Ba	Co	Cr	Cu	La	Ni	Pb	Sc	Sr	V	Y	Zr	Zn	U	Hg
MTS8- 1	1	5	1.5	2	0.3	1000	15	300	20	500	100	20	30	L	20	500	300	20	50	45	-	-
MTS8- 2*	1	7	10	2	.3	2000	L	150	200	700	15	L	1000	20	20	N	100	L	20	65	0.24	0.04
MTS8- 3	2	7	2	3	.3	1000	10	700	30	500	100	20	100	10	20	500	300	20	50	35	-	-
MTS8- 4*	2	7	10	1.5	.2	2000	L	100	150	700	15	L	700	L	15	N	50	L	L	60	.23	.02
MTS8- 5	3	5	2	5	.3	1000	10	700	20	500	100	20	70	L	20	500	200	15	50	20	-	-
MTS8- 6*	3	7	10	0.2	.05	1500	L	100	100	500	10	L	700	L	L	N	20	L	L	80	.28	N
MTS8- 7	4	7	2	7	.5	1000	10	1000	30	150	150	20	30	L	30	700	300	30	70	15	-	-
MTS8- 8*	4	7	10	3	.2	3000	L	200	100	500	70	L	300	20	30	N	100	L	100	75	-	-
MTS8- 9	5	7	2	2	.5	1000	10	1000	20	100	30	20	20	L	20	300	300	20	50	15	-	-
MTS8-10*	5	10	7	5	1	3000	L	150	50	500	30	L	70	20	50	N	200	L	20	15	.42	N
MTS8-11	6	10	2	2	.7	1500	L	700	70	150	100	L	30	L	30	300	1000	20	30	30	-	-
MTS8-12*	6	7	7	5	.7	3000	L	150	50	200	20	L	100	L	50	N	200	L	L	10	.27	N
MTS8-13	7	5	2	5	.5	1000	20	1000	20	500	70	20	70	L	20	500	200	20	50	20	-	-
MTS8-14*	7	5	7	3	.2	3000	L	300	70	1000	15	L	300	L	30	N	100	L	L	30	.33	.04
MTS8-22	8	7	3	3	.5	1000	10	1000	50	500	100	L	150	10	20	500	300	20	50	30	-	-
MTS8-23*	8	10	10	1.5	.2	3000	L	150	150	1000	15	L	700	20	20	N	50	L	20	55	.33	.02
MTS8-24	9	5	2	5	.5	1000	15	700	20	200	100	20	70	L	20	500	200	30	50	30	-	-
MTS8-25*	9	7	10	2	.2	5000	L	700	70	700	50	L	300	20	20	N	100	L	L	40	.24	.26
MTS8-26	10	5	1.5	1	.3	1000	10	1000	15	150	10	20	20	L	10	300	200	15	50	20	-	-
MTS8-27*	10	7	7	3	.5	5000	L	200	50	500	15	L	150	50	50	N	150	L	50	15	.34	.02
MTS8-28	11	7	2	3	.5	1500	20	1000	20	200	50	20	50	15	20	500	300	20	70	30	-	-
MTS8-29*	11	7	10	5	.5	3000	L	150	50	700	20	L	500	20	30	N	150	L	20	30	.35	L
MTS8-30	12	5	2	5	.3	1500	L	700	30	700	100	20	100	10	15	500	200	20	30	25	-	-
MTS8-32	13	5	2	7	.5	1000	15	1000	30	300	100	20	70	10	20	700	200	20	50	20	-	-
MTS8-33*	13	7	7	2	.3	3000	L	300	50	1000	50	L	200	20	30	N	150	L	L	30	.25	.35

Table 1. Continued

Field No.	Map No.	Fe	Mg	Ca	Ti	Mn	B	Ba	Co	Cr	Cu	La	Ni	Pb	Sc	Sr	V	Y	Zr	Zn	U	Hg
3S-013A	28	15	5	1.5	.7	2000	10	100	30	500	70	N	150	L	30	100	300	15	30	70	-	-
3S-013B*	28	5	7	1.5	.2	1000	L	50	50	700	15	N	700	N	30	L	100	15	30	40	.3	N
3S-014A	29	5	3	1.5	.3	1500	10	100	30	700	70	N	100	15	30	150	150	15	30	75	-	-
3S-014B*	29	3	5	7	.3	1000	L	50	20	1500	30	N	150	50	70	70	150	15	15	15	.1	N
3S-015A	30	7	3	1.5	.7	2000	L	100	30	500	70	N	150	L	20	200	200	15	30	90	-	-
3S-015B*	30	5	7	1.5	.2	1000	L	50	50	700	15	N	700	N	15	L	50	10	10	70	.2	L
3S-016A	31	5	5	2	.5	1500	10	200	30	500	70	N	150	L	30	300	150	15	30	85	-	-
3S-016B*	31	7	7	2	.3	1500	L	70	30	1000	20	N	700	L	20	100	100	10	15	55	.2	L
3S-017A	32	7	5	1	.3	1500	L	50	30	300	20	N	100	L	20	L	70	15	30	85	-	-
3S-017B*	32	7	7	2	.5	1500	L	70	50	1000	30	N	700	20	30	150	100	15	20	60	.5	.02
3S-018A	33	7	5	3	.5	1500	10	150	30	500	70	N	100	L	20	300	200	15	30	60	-	-
3S-018B*	33	5	7	5	.3	1500	L	50	30	1000	20	N	150	N	50	150	100	15	30	35	.2	L
3S-019A	34	7	5	1.5	.7	1500	10	150	30	500	70	N	150	L	20	200	200	20	50	75	-	-
3S-019B*	34	7	7	3	.3	1500	L	50	50	1000	30	N	500	N	30	L	150	15	30	80	-	.04
3S-020A	35	10	5	1.5	.7	2000	10	70	30	300	70	N	100	L	30	100	300	15	30	70	-	-
3S-020B*	35	5	3	1.5	.5	700	L	300	30	500	70	N	200	N	30	L	70	10	50	60	.4	.10
3S-021A	36	7	5	1.5	.3	1000	10	100	30	500	70	N	200	L	15	300	100	15	30	65	-	-
3S-021B*	36	7	5	1	.3	700	L	50	50	700	30	N	700	N	20	L	70	10	20	65	.3	L
Lower limit of detection:		.05	.02	.05	.002	10	10	20	5	10	5	20	5	10	5	100	10	10	10	10	.1	.02

Analyzed for but below limit of detection (indicated as ppm in parentheses): antimony (100), arsenic (200), beryllium (1), bismuth (10), cadmium (20), gold (0.1), molybdenum (5), silver (0.5), thorium (100), tin (10), and tungsten (1).

Table 1. Continued

Field No.	Map No.	Fe	Mg	Ca	Ti	Mn	B	Ba	Co	Cr	Cu	La	Ni	Pb	Sc	Sr	V	Y	Zr	Zn	U	Hg
MTS8-34	14	5	1.5	2	.3	1000	L	1000	20	200	70	20	50	10	20	500	200	30	50	40	-	-
MTS8-35*	14	5	10	1	.2	2000	L	300	50	700	20	L	300	20	15	N	50	L	20	60	.35	.45
MTS8-40*	15	7	2	5	.7	1000	L	700	30	500	70	L	70	10	20	700	300	15	30	25	-	-
MTS8-41	15	5	2	3	.5	1000	20	700	20	700	50	20	50	10	15	500	200	15	30	35	-	-
3S-001A	16	7	5	1.5	.7	2000	L	100	30	200	50	N	100	L	15	200	100	15	30	45	-	-
3S-001B*	16	7	7	1.5	.3	1500	L	70	30	700	50	50	300	10	15	150	70	15	30	100	1.4	.02
3S-002A	17	7	7	1.5	.5	1500	L	150	30	150	50	N	150	L	15	300	100	15	30	55	-	-
3S-002B*	17	7	7	1	.2	1500	L	50	50	500	20	N	700	50	15	100	50	10	20	90	.4	.02
3S-003A	18	7	5	1.5	.7	1500	L	70	30	200	30	N	70	L	20	150	150	15	30	70	-	-
3S-003B*	18	5	5	3	.3	1500	L	50	30	700	50	N	200	N	30	200	100	15	30	50	.6	L
3S-004A	19	10	5	1.5	.7	2000	10	70	30	300	50	N	70	L	30	L	300	15	30	50	-	-
3S-004B*	19	7	5	3	.3	1500	L	70	30	500	20	N	150	N	50	100	100	15	30	25	.3	N
3S-005A	20	10	5	1.5	.5	2000	10	70	30	150	30	N	70	L	30	L	200	15	30	35	-	-
3S-005B*	20	7	5	3	.5	2000	L	100	30	700	20	N	150	N	30	100	100	15	30	50	-	L
3S-006A	21	10	5	2	.7	3000	10	100	30	300	70	N	70	L	30	100	300	15	30	45	-	-
3S-006B*	21	5	5	3	.3	2000	L	70	30	500	30	N	150	N	30	150	100	15	30	35	-	N
3S-007A	22	10	5	1.5	.7	2000	10	100	30	500	70	N	100	L	30	100	300	15	30	90	-	-
3S-007B*	22	7	7	3	.3	1500	L	70	30	700	30	N	300	N	30	100	150	15	50	60	.2	.02
3S-008A	23	10	3	1.5	.7	2000	10	50	30	300	70	N	70	L	30	N	300	15	30	35	-	-
3S-008B*	23	5	5	2	.5	2000	L	50	30	150	30	N	70	N	30	L	100	15	30	15	.1	N
3S-009A	24	15	5	1.5	.7	2000	10	70	30	500	70	N	70	L	30	N	500	15	30	60	-	-
3S-009B*	24	7	5	2	.3	2000	L	50	30	200	30	N	100	15	30	L	150	15	30	15	.2	.04
3S-010A	25	10	5	1.5	.7	2000	10	70	30	300	70	N	70	L	50	N	300	15	30	50	-	-
3S-010B*	25	5	5	3	.5	1500	L	70	30	150	30	N	150	N	30	L	70	15	30	25	.1	N
3S-011A	26	10	5	1.5	.5	1500	10	100	30	500	70	N	150	L	30	150	150	15	30	95	-	-
3S-011B*	26	7	7	2	.3	1500	L	70	50	700	30	N	500	N	30	L	150	15	20	75	.4	.02
3S-012A	27	10	5	1.5	.5	1500	10	70	30	300	50	N	100	L	20	L	300	15	30	85	-	-
3S-012B*	27	5	5	2	.2	1500	L	70	30	700	30	N	500	N	30	L	70	15	20	45	.2	N