MASTER

Reference Waste Form, Basalts, and Ground Water Systems for Waste Interaction Studies

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September 1978

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PRELIMINARY REPORT

NOTICE

REFERENCE WASTE FORM, BASALTS,
AND GROUND WATER SYSTEMS FOR
WASTE INTERACTION STUDIES

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for

Basalt Waste Isolation Program

September 1978

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SUMMARY

This report summarizes the type of waste form, basalt, and ground water compositions to be used in theoretical and experimental models of the geochemical environment to be simulated in studying a typical basalt repository.

Waste forms to be used in the experiments include, and are limited to, glass, supercalcine, and spent unreprocessed fuel. Reference basalts selected for study include the Pomona member and the Umtanum Unit, Shwana Member, of the Columbia River Basalt Group. In addition, a sample of the Basalt International Geochemical Standard (BCR-1) will be used for cross-comparison purposes. The representative water to be used is of a sodium bicarbonate composition as determined from results of analyses of deep ground waters underlying the Hanford Site.

At present, the experiments do not include an analysis of overpack material and/or container materials, inasmuch as the nature of these materials will be determined as a result of the experiments on the interactions in the absence of these materials.

WASTE FORM

The present emphasis in the United States' Terminal Storage Program is not to reprocess spent fuel elements. Due to this directive, we are considering spent unreprocessed fuel to be our prime radioactive waste form to be stored in a potential basalt cavern.

If the decision were made to reprocess spent fuel with its resultant high-level waste stream, a vitrification process yielding a glass product would probably be the leading contender for the solid waste form, since it has, to date, received the majority of research and development funding.

In order to ensure the comprehensiveness of our current waste/basalt interaction studies, we have chosen to include the following waste forms in our experiments: spent unreprocessed fuel; glass; and supercalcine.

As a first step in analyzing the physical and chemical effects of storing nuclear waste in an underground basalt repository, one must first deal with the waste forms themselves. Needless to say, each waste form has its own set of unique characteristics (chemical and radiological composition, mineralogy, structure, thermal energy, physical properties, etc.) which will have a direct bearing upon the storage concept. Table I summarizes many of these properties for the above waste forms.[1]

GLASS

The composition of glass chosen for study will be the same specimen being used in the source term characterization task of the Office of Nuclear Waste Isolation/Battelle-Northwest/Waste Isolation Safety Assessment Program. Its code is 76-68 and its composition is given in Table II. The waste composition (PW-8a) used to prepare glass 76-68 is given in Table III.

TABLE I

WASTE FORM PROPERTIES

PROPERTY	UNITS	SUPER CALCINE POWDER	SUPER CALCINE CERAMIC	PHOSPHATE GLASS	BORO-SILICATE GLASS	SPENT FUEL PELLETS
SOLUTION RATE	$\frac{mg}{m^2 sec}$	10^{-6} to 10^{-4}	10^{-7} to 10^{-5}	10^{-5} to 0.7	10^{-5} to 0.01	10^{-2} to 10^5
CORROSION TO CLAD MATERIAL	nm/sec	0 to 10	0 to 10	0 to 10	0 to 10	*
RESIDUAL NITRATE AND/OR WATER	%	0.005 to 0.05	0.005 to 0.01	0.005 to 0.05	0.005 to 0.05	<.005
MAXIMUM PROCESSING TEMPERATURE	°K	1,370 to 1,570	1,370 to 1,570	1,170	1,270 to 1,670	NA
RUTHENIUM VOLATILIZED AT PROCESSING	%	≤7.0	≤5.0	3 to 15	≤2.0	NA
VOLATILITY	NA	1,570°K some Ru & Cs	1,670°K much Ru & Cs	<1,500°K all Ru & Cs	<1,500°K all Ru & Cs	NA
SPECIFIC VOLUME	$\frac{m^3}{MgU}$	0.070	0.070	0.036 to 0.078	0.04 to 0.1	——
WEIGHT PERCENT WASTE PRODUCT OXIDES — MAXIMUM	MAXIMUM	≤75%	≤75%	≤25%	≤50%	5%
WEIGHT PERCENT WASTE PRODUCT OXIDES — TYPICAL	TYPICAL	45%	45%	20%	20-35%	4%
SPECIFIC AREA	$\frac{m^2}{Kg}$	10,000 to 20,000	0.005 to 0.05	0.005 to 0.05	0.005 to 0.05	——
FORM	NA	Powder	Monolithic	Fractured Monolith	Fractured Monolith	Fractured Pellets
STRUCTURAL QUALITY	NA	Soft & Crumbly	Very Hard & Brittle	Very Hard & Brittle	Very Hard & Brittle	Very Hard & Brittle
POROSITY	%	40 to 80	2 to 20	≤5.0	≤1.0	2 to 10
DENSITY	$\frac{Kg}{m^3}$	4,000	3,500 to 4,000	2,700 to 3,000	3,000 to 3,600	10,000 to 10,500**
COEFFICIENT OF LINEAR EXPANSION	$\times 10^{-6}$/°K	~8.3	8 to 10	8 to 10	8 to 10	~10**
THERMAL CONDUCTIVITY	$\frac{W}{m°K}$	0.6	0.8 to 2	0.8 to 1.3	0.9 to 1.3	2** to 6
HEAT CAPACITY	$\frac{J}{Kg°K}$	470	1,100 to 1,200	1,100 to 1,200	750	238** to 330
LIQUIDUS TEMPERATURE	°K	1,670 to 1,870	1,670 to 1,870	820 to 1,020	800 to 1,500	~3,138**
TRANSITION TEMPERATURE	°K	NA	NA	770	870 to 970	NA

KEY TO SYMBOLS

___ = Not Available.

NA = Not Applicable.

* = Mostly stress corrosion cracking which is localized, variable, and dependent upon the chemical species.

** = Based on UO_2 with approximately 2-10 percent porosity.

*** = Alloy has a transition temperature.

TABLE II

COMPOSITON OF BATTELLE-NORTHWEST
WASTE GLASS 76-68*

Oxide	Wt.%	Oxide	Wt.%	Oxide	Wt.%
SiO_2	39.8	MoO_3	2.3	P_2O_5	0.5
Na_2O	12.5	CaO	2.0	Cr_2O_3	0.4
Fe_2O_3	9.8	ZrO_2	1.8	SrO	0.4
B_2O_3	9.5	CeO_2	1.2	TeO_2	0.3
ZnO	5.0	RuO_2	1.1	NiO	0.2
U_3O_8	4.6	Cs_2O	1.0	Rh_2O_3	0.2
RE_2O_3**	3.4	BaO	0.6	Rb_2O	0.1
TiO_2	3.0	PdO	0.5	Others	0.1

*Modified from a table provided by D. J. Bradley, Battelle-Northwest.

**RE = La, Pr, Nd, Sm, Eu, Gd, Y.

TABLE III

PW-8A WASTE COMPOSITION*

(Kgs Oxide/MTU)

Inerts	Na_2O	14.057
	Fe_2O_3	27.225
	Cr_2O_3	1.151
	NiO	0.566
	P_2O_5	1.342
Fission Products	Rb_2O	0.354
	SrO	1.059
	Y_2O_3	0.598
	ZrO_2	4.944
	MoO_3	5.176
	Tc_2O_7	1.291
	RuO_2	2.972
	Rh_2O_3	0.480
	PdO	1.483
	Ag_2O	0.088
	CdO	0.097
	TeO_2	0.725
	Cs_2O	2.880
	BaO	1.567
	La_2O_3	1.480
	CeO_2	3.323
	Pr_6O_{11}	1.482
	Nd_2O_3	4.522
	Pm_2O_3	0.123
	Sm_2O_3	0.924
	Eu_2O_3	0.200
	Gd_2O_3	0.137
Actinides	U_3O_8	11.689
	NpO_2	0.865
	PuO_2	0.174
	Am_2O_3	0.181
	Cm_2O_3	0.040

*See reference 7.

A great deal of experimentation has taken place using this reference glass and other glasses. Ross[2] has discussed the development of glass formulations containing high-level nuclear wastes. Others at Battelle have detailed numerous studies to characterize high-level waste glasses and examine their volatility and devitrification behavior.[3-6] A recent Battelle report[7] discusses some miscellaneous experiments with 76-68 and other waste glass formulations. An important conclusion from the above experiments is that the 76-68 (low ZnO) waste glass form shows much improved resistance to acid attack with little change over the pH 4-12 range. In glass 76-68 where devitrification rates are very slow, elemental differences between as-formed and thermally treated samples have not been significant. Average leach rates based on cesium from the 76-68 waste glass in an International Atomic Energy Agency type long-term test are about $3.3 \times 10^{-8} g/cm^2/day$.

SUPERCALCINE

The specific formulation of supercalcine to be used for study is SPC-2 prepared as described by McCarthy[8] on the spray calciner at Battelle and crystallized by firing at 1,125° C for two to four hours.

The complete composition of SPC-2 oxides is given in Table IV and a portion of an X-ray diffractogram of crystallized SPC is shown in Figure 1. The crystalline phases and their shorthand notation in SPC-2 are:[1]

$Ca_2RE_8(SiO_4)_6O_2$	[Ass]
$REPO_4$	[Mss]
Tetragonal-ZrO_2	[Tss]
$(Ca, Sr, Ba) MoO_4$	[Sss]
$(Cs, Rb, Na)AlSi_2O_6$	[P]
$(Ce, Zr.,,,)O_2$	[Fss]
$(Fe, Cr)_2O_3$	[$(Fe_2O_3)ss$]
$(Ni,Fe)(Fe, Cr)_2O_4$	[SPss]

TABLE IV

COMPOSITION OF SUPERCALCINE SPC-2

Ion	Molarity	Oxide	Grams Oxide Per Liter of Calcined SPC-2	Weight Percent Oxide	
FROM THE MODIFIED PW-7 WASTE:					
Ce	0.161	CeO_2	27.7	16.3	(12.7)[1]
Zr	0.106	ZrO_2	13.0	7.6	(5.9)
RE [2]	0.102[2]	RE_2O_3	17.0	10.0	(7.8)
Fe	0.100	Fe_2O_3	8.0	4.7	(3.7)
$[PO_4]$	0.100	P_2O_5	7.1	4.2	(3.2)
Mo	0.095	MoO_3	13.7	8.0	(6.3)
La	0.094	La_2O_3	15.3	9.0	(7.0)
Cs	0.054	Cs_2O	7.6	4.5	(3.5)
Sr	0.027	SrO	2.8	1.6	(1.3)
Ba	0.027	BaO	4.1	2.4	(1.9)
Cr	0.012	Cr_2O_3	0.9	0.5	(0.4)
Rb	0.010	Rb_2O	0.9	0.5	(0.4)
Na	0.010	Na_2O	0.3	0.2	(0.1)
Ru [3]	0.006	RuO_2	0.8	0.5	(0.4)
Ni	0.005	NiO	0.4	0.2	(0.2)
Cd	0.002	CdO	0.3	0.2	(0.1)
SUPERCALCINE ADDITIVES:					
Si	0.539	SiO_2	32.4	19.1	(14.8)
Ca	0.150	CaO	8.4	4.9	(3.8)
Al	0.148	Al_2O_3	7.5	4.4	(3.4)
Sr	0.020	SrO	2.1	1.2	(1.0)
			170.4	100.0	

<center>(70.5 percent waste loading)</center>

Ion	Molarity	Oxide	Grams Oxide Per Liter of Calcined SPC-2	Weight Percent Oxide	
OTHER WASTE CONSTITUENTS:[4]					
U(Pu,Np)	0.1195	U_3O_8	33.6		(15.5)
Ru [3]	0.053	RuO_2	7.1		(3.2)
Pd	0.032	PdO	3.9		(1.8)
Te	0.012	TeO_2	1.9		(0.9)
Rh	0.010	Rh_2O_3	1.3		(0.6)
Ag	0.002	AgO	0.3		(0.1)
			218.5		100.0

<center>(76.9 percent waste loading)</center>

---

[1]Value in parentheses is the weight percent of the oxide after addition of the appropriate amounts of U, Ru, Pd, Te, Rh, Ag.

[2]RE $= 0.061$ Nd + 0.019 Pr + 0.011 Sm + 0.007 Gd + 0.003 Y (Note: 0.002 RE is a stand-in for Am+Cm).

[3]Ru concentration in the spray supercalcine SPC was 10 percent of the actual PW-7 value of 0.059 M. The addition of the remaining 0.053 M was made after calculation.

[4]These constituents were not included in the large batch of SPC-2 because of their expense or radioactivity. None require fixation additives. The only PW-7 constituent not included above is Tc.

SPC-2
1125°C 3Hr

Legend:
- A_{ss}
- S_{ss}
- F_{ss}
- M_{ss}
- P
- T_{ss}
- $(Fe_2O_3)_{ss}$

DEGREES TWO THETA (CuKα)

V7804-4.3
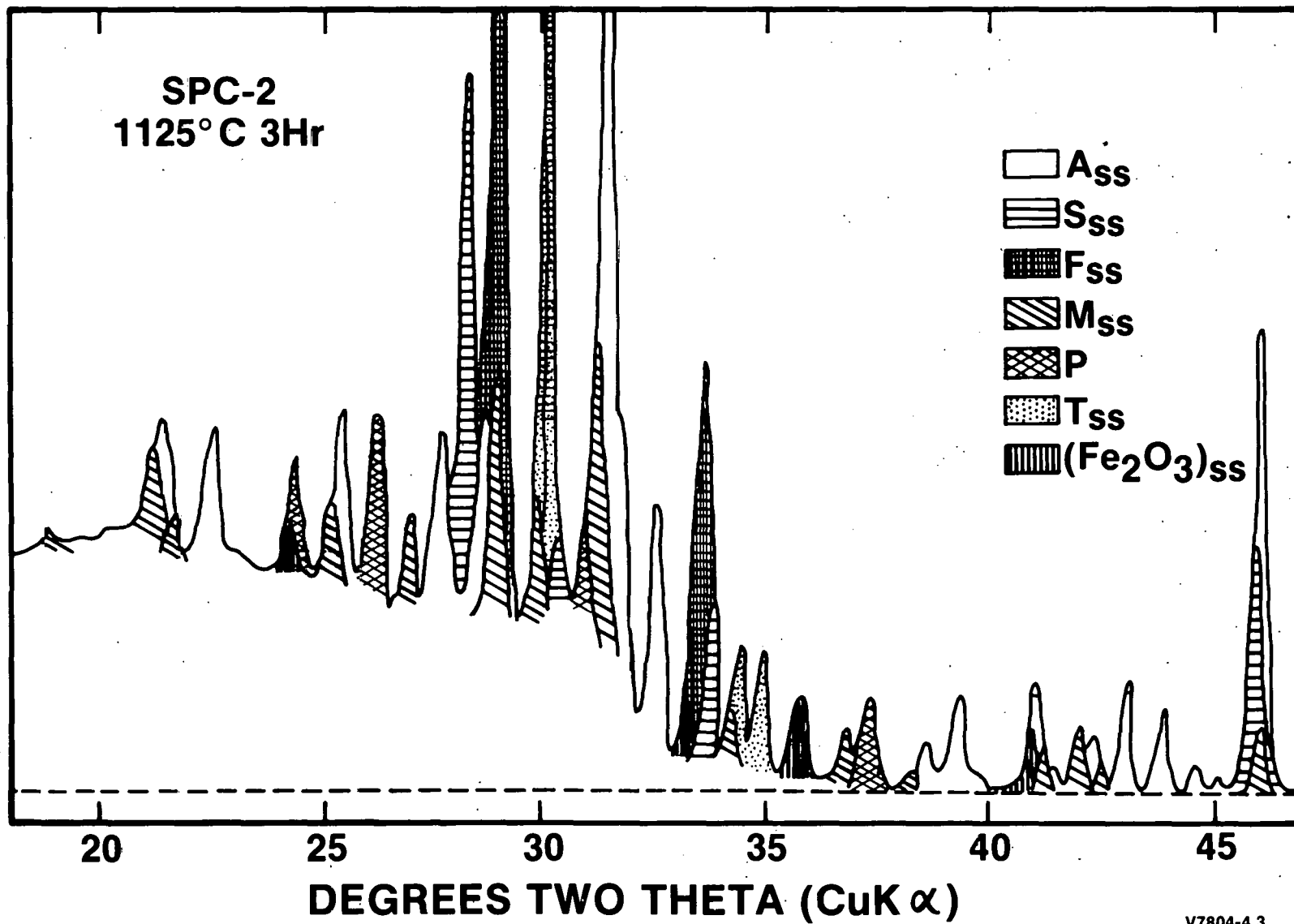
FIGURE 1

PORTION CF AN X-RAY DIFFRACTOGRAM OF CRYSTALLIZED SPC-2

SPENT UNREPROCESSED FUEL

Spent unreprocessed fuel (SURF) from light water reactors (LWR) consist of pellets of UO_2 plus a small amount of fission products clad in high zirconium alloy (zircaloy) tubes. Cohen[9] has shown that nuclear fuel from a LWR having a burn-up of 33,000 MWd/MTU will consist of approximately 3.5 wt.% fission products and 96.5 wt.% UO_2 (+ NpO_2 + PuO_2). In the SURF formulation for this study, UO_2 should be used as a stand-in for NpO_2 + PuO_2.

The number of elements in fission products includes more than 1/3 of the periodic table. Table V lists elements or stand-ins that are present in the fission products at >0.2 wt.%. The actinides Am and Cm are produced by neutron capture rather then fission, but they are included with Gd because of their crystal chemical similarity to this element. Radioactive Tc, gaseous Kr, and Xe and I are not included in this fission product mix.

The atomic concentrations of the elements in Table V come from the ORIGIN code or an LWR fuel having a burnup of 33,000 MWd/MTU. The third column in the table gives the recipe for obtaining these concentrations of a mixture of nitrates and oxides. The nitrates, nitrate solutions, and oxides should be mixed vigorously with a large excess of water to give a homo-geneous solution-suspension and should then be dried as rapidly as possible on a stirrer-hot plate. The residue should further be dried at 90° C and then slowly heated to 400° C in air to decompose most of the nitrate. These conditions are selected to minimize alkali and ruthenium volatilization. The final product should be ground thoroughly.

TABLE V

SIMULATED SPENT UNREPROCESSED FUEL FISSION PRODUCTS[a]
(burn-up of 33,000 MWd/MTU)

Element	Atomic %	Formulation for a 100 Meq[b] Batch	Oxide	Wt.% Oxide
Zr	16.51	4.408g $ZrO(NO_3)_2 \cdot 2H_2O$	ZrO_2	14.3
Mo	14.80	2.131g MoO_3	MoO_3	14.9
Nd(Pm)[c]	11.37	4.980g $Nd(NO_3)_3 \cdot 6H_2O$	$NdO_{1.5}$	13.4
Ru	9.19	27.5 ml 10% Ru nitrate solution	RuO_2	8.5
Cs	8.41	1.640g $CsNO_3$	$CsO_{0.5}$	8.3
Ce	7.94	3.454g $Ce(NO_3)_3 \cdot 6H_2O$	CeO_2	9.5
Pd	4.98	5.3 ml 10% Pd Nitrate solution	PdO	4.2
Sr	4.21	0.893g $Sr(NO_3)_2$	SrO	3.1
Ba	4.21	1.099g $Ba(NO_3)_2$	BaO	4.5
La	3.74	1.619g $La(NO_3)_3 \cdot 6H_2O$	$LaO_{1.5}$	4.3
Pr	3.58	1.564g $Pr(NO_3)_3 \cdot 6H_2O$	$PrO_{1.5}$	4.1
Sm	2.18	0.968g $Sm(NO_3)_3 \cdot 6H_2O$	$SmO_{1.5}$	2.6
Y	2.18	0.835g $Y(NO_3)_3 \cdot 6H_2O$	$YO_{1.5}$	1.7
Te	1.87	0.299g TeO_2	TeO_2	2.1
Rh	1.56	1.61 ml 10% Rh nitrate solution	$RhO_{1.5}$	1.4
Rb	1.56	0.231g $RbNO_3$	$RbO_{0.5}$	1.0
Gd(Eu,Am,Cm)	1.09	0.492g $Gd(NO_3)_3 \cdot 6H_2O$	$GdO_{1.5}$	1.4
Ag	0.31	0.050g $AgNO_3$	$AgO_{0.5}$	0.4
Cd	0.31	0.040g CdO	CdO	0.3
				100.0

[a]Tc, I, Kr, and Xe are not included.

[b]Milliequivalent.

[c]Elements in parentheses indicate that the preceding element is a stand-in.

The conditions in actual spent fuel are highly reducing as controlled by the initial stoichiometry of the uranium dioxide fuel. Thus, some of the fission products in a SURF formulation will be present as metals rather than as dioxides produced in this procedure until this point. Therefore, an additional step should be included in the formulation that would provide reducing conditions where the appropriate oxides are converted to metals. To accomplish this, the oxidized product should be placed on a platinum boat in a Vycor tube and fired at 600° C in flowing hydrogen for four hours. This treatment should be sufficient to reduce the ruthenium, palladium, tellurium, rhodium, and silver oxides to metals and CeO_2 to Ce_2O_3.

The reduced fission product mix should be combined with uranium dioxide to give the 96.5 percent UO_2, 3.5 percent fission product composition. Because the actual phase in which each fission product species is combined can have a major influence on its dissolution behavior or reactivity, it is then necessary to treat the mixture at a high enough temperature to promote phase formation. This firing must be performed in a closed system to prevent this specimen from oxidizing.

The major phase in SURF is a crystalline fluorite structure (UO_2) with fluorite-related structure fission product oxides (RE_2O_2, CeO_2, and some ZrO_2) in solid solution. After a survey of papers on irradiated fuel behavior, it became clear that very little else is actually known about spent unreprocessed fuel crystalline phase behavior. It is widely believed that SrO and BaO react with ZrO_2 to form the perovskite structure [$(Ba,Sr)ZrO_3$]. There also appear to be distinct Cs-Te-rich zones. Cesium is thought to be present as a cesium molybdate and/or a cesium uranate, both of which are quite soluble in water. The bulk of the UO_2-rich spent unreprocessed fuel waste form would remain relatively unreactive under hydrothermal repository ambients, as long as the Eh-pH conditions keep the uranium in the tetravalent state.

BASALTS

The Columbia River Basalt is classed as tholeiitic basalt on the basis of its chemistry and mineralogy. Not all flows within the Pasco Basin fit this classification because of their higher alkali content. The common minerals present in the basalt are plagioclase, clinopyroxene, olivine, opaque minerals (such as magnetite and ilmenite), apatite, and mineraloids (chlorophaeite). Tachylyte, a basalt glass crowded with crystallites, is abundant in most flows. The plagioclase is usually labradorite where it occurs as large phenocrysts, but may range from labradorite to andesine in the groundmass. Olivine is usually altered to clay minerals or Mg-chlorite. The pyroxene present is augite and/or pigeonite. The texture is aphanitic with rare large phenocrysts present in some flows. Although some flows in the Pasco Basin are quite glassy, most exhibit intersertal to intergranular textures. Some show a patchy diktytaxitic ophimottling. The color of the rock is generally gray to black on a fresh surface. Some flows have reddish-orange to reddish-brown weathered surfaces that result from the oxidation of iron in iron-rich clay and mineraloid present in the flow.

The macrostructure of a generalized flow or flow unit is depicted in Figure 2.[10] The stratigraphy of the various flow units in the Pasco Basin is shown in Figure 3.

As part of our waste-basalt interaction studies, three reference samples will be used. Samples of Pomona (high MgO), and Umtanum types (low MgO) and a basalt standard BCR-1 will be used. Data on these samples are given in subsequent sections of this report.

VESICULAR TOP —

HACKLY SLENDER
COLUMNS

NICHE JOINTS —
UNDULATORY
COLUMNS

PLATY JOINTS —

SPIRACLE —

METERS

— 6
— 4
— 2
— 0

— FANNING COLUMNS

— HORIZONAL JOINTS

— RELATIVELY SHARP CONTACT
— DIVIDING COLUMNS

— BLOCKY JOINTS

VESICLE COLUMNS
PIPE VESICLE
VESICULAR BASE
CHILLED BASE & "INCIPIENT PILLOWS"
PILLOW
PALAGONITE

EITHER CHILLED CONTACT
WITH LOWER FLOW
OR PILLOW-PALAGONITE
COMPLEX

V7804-4.7

FIGURE 2

MACROSTRUCTURE OF A GENERALIZED FLOW OR FLOW UNIT

FORMATION	MEMBER	FLOW OR BED	LITHOLOGY

ALLUVIUM, COLLUVIUM, & EOLIAN SEDIMENTS OF HANFORD

C[14] AGE

6,600	MAZAMA ASH	ASH FALL. CRATER LAKE, OREGON
12,500	GLACIER PEAK ASH	ASH FALL. GLACIER PEAK. WASHINGTON
> 12,000	ST. HELENS ASH	ASH FALL. MT. ST. HELENS, WASHINGTON
< 18,000		

GLACIOFLUVIAL SEDIMENTS OF HANFORD

TOUCHET SILTS, SANDS, & PASCO GRAVELS	FINE-GRAINED FACIES OF GLACIOFLUVIAL DEPOSITS, BEDDED. COARSE-TO MEDIUM-GRAINED FACIES OF GLACIOFLUVIAL DEPOSITS, CUT AND FILL STRUCTURE
PALOUSE SOIL	CALCAREOUS SAND, SILT, AND EOLIAN DEPOSITS

RINGOLD FORMATION

(UPPER) RINGOLD	SILT AND SAND, SOME GRAVEL. FLUVIAL. WELL BEDDED. LOCALLY CAPPED BY CALICHE
(MIDDLE) RINGOLD	SAND AND GRAVEL, WELL-SORTED, COMPACT, BUT VARIABLY CEMENTED
(LOWER) RINGOLD	SILT AND CLAY, INTERBEDDED GRAVEL AND SAND. CLAY IS CHARACTERISTICALLY BLUE, BUT MAY BE GREEN, BROWN, OR TAN

COLUMBIA RIVER BASALT GROUP — YAKIMA BASALT SUBGROUP

SADDLE MOUNTAINS BASALT

K–Ar m.y.

	MEMBER	FLOW OR BED	LITHOLOGY	MAGNETIC POLARITY
6.0	LOWER MONUMENTAL MEMBER [1] (GEOLOGIC SYMBOL)	GOOSE ISLAND		N
	ICE HARBOR MEMBER (TI)	MARTINDALE	BASALT, PHYRIC	R
8.5		BASIN CITY		N
		LEVY BED	TUFF AND TUFFACEOUS SANDSTONE	
	BUFORD MEMBER [1]	WARD GAP FLOW		
10.5	ELEPHANT MOUNTAIN MEMBER (Tem)	ELEPHANT MOUNTAIN FLOW	BASALT, APHYRIC	N–T
		RATTLESNAKE RIDGE MEMBER (Ter)	SANDSTONE, TUFFACEOUS	
	(UNNAMED)	MATTAWA FLOW	BASALT, APHYRIC	N
12.0	POMONA MEMBER (Tp)	POMONA FLOW	BASALT, PHYRIC	R
		SELAH MEMBER (Tes)	SANDSTONE, TUFFACEOUS	
	ESQUATZEL MEMBER (Te)	GABLE MOUNTAIN FLOW NO.2	BASALT, LOCALLY PHYRIC	N
		GABLE MOUNTAIN BED	TUFF, DISCONTINUOUS	
		GABLE MOUNTAIN FLOW NO.1	BASALT, LOCALLY PHYRIC	N
		COLD CREEK BED	SANDSTONE, LOCALLY TUFFACEOUS AND CONGLOMERATIC	
	WEISSENFELS RIDGE MEMBER [1] / ASOTIN MEMBER (Ta)	HUNTZINGER FLOW	BASALT, APHYRIC, COARSELY PHANERITIC, AND VERTICALLY DIFFERENTIATED LOCALLY	N
	WILBUR CREEK MEMBER (Tw)	WAHLUKE FLOW	BASALT, APHYRIC	N
	UMATILLA MEMBER (Tu)	SILLUSI FLOW	BASALT, APHYRIC	N
		UMATILLA FLOW	BASALT, APHYRIC	N
		MABTON MEMBER (Tema)	SANDSTONE, LOCALLY CONGLOMERATIC	

N=NORMAL
R=REVERSED
T=TRANSITIONAL

ELLENSBURG FORMATION (NOMENCLATURE NOT FORMALIZED)

< 13.6

WANAPUM BASALT

	MEMBER	FLOW OR BED	LITHOLOGY	MAGNETIC POLARITY
	PRIEST RAPIDS MEMBER (Tpr)	PRIEST RAPIDS FLOW NO.4		R
		PRIEST RAPIDS FLOW NO.3	BASALT, APHYRIC	R
		PRIEST RAPIDS FLOW NO.2		R
		PRIEST RAPIDS FLOW NO.1		R
		QUINCY ?		
	ROZA MEMBER (Tr)	ROZA FLOW NO. 2	BASALT, PHYRIC	T
		ROZA FLOW NO. 1		T
		SQUAW CREEK MEMBER (Tesq)	DIATOMITE	
	FRENCHMAN SPRINGS MEMBER (Tf)	SENTINEL GAP FLOW	OTHERS PROBABLY OCCUR	BASALT, LOCALLY PHYRIC (Tfp) APHYRIC (Tf)	N
		SAND HOLLOW FLOW		N
		GINKGO FLOW		N
		VANTAGE MEMBER (Tev)	SANDSTONE	

(TEPI) ?

~ 14.5 ECKLER MOUNTAIN MEMBER [1]

TiO2 HORIZON
BASE UNDEFINED

GRANDE RONDE BASALT (UNDIFFERENTIATED GRANDE RONDE BASALT=Tgr)

	MEMBER	FLOW OR BED	LITHOLOGY	MAGNETIC POLARITY
	BASALT SEQUENCE OF SENTINEL BLUFFS (Tsb)	MUSEUM FLOW		N
		ROCKY COULEE FLOW		N
		FLOW J		N
		FLOW I	BASALT, APHYRIC	N
		FLOW H		N
		FLOW G		N
		FLOW F		N
		FLOW E		N
	BASALT SEQUENCE OF SCHWANA (Ts)	FLOW D ≈ UMTANUM		N
		1 TO 3 "LOW K2O" GRANDE RONDE BASALT FLOWS	BASALT, APHYRIC	
		FLOW C		N
		FLOW B		N
		FLOW A		R
	UNNAMED	AT LEAST 15 FLOWS (CURRENTLY KNOWN ONLY FROM DEEP BOREHOLES)	BASALT, APHYRIC	UNKNOWN

MgO HORIZON

NORMAL (N2 ?)
REVERSED (R2 ?)
PROBABLE POSITION OF A REGIONALLY RECOGNIZED PALEOMAGNETIC HORIZION (SWANSON AND OTHERS, 1977)

> 15.4

SOURCE: "PASCO BASIN STRATIGRAPHIC NOMENCLATURE," R.K. LEDGERWOOD, C.W. MYERS, R.W. CROSS, RHO-BWI-LD-1, ROCKWELL HANFORD OPERATIONS, RICHLAND, WASHINGTON (MAY 1978).

AGE ? OLDER COLUMBIA RIVER BASALT GROUP ROCKS

AGE ? PRE-COLUMBIA RIVER BASALT GROUP ROCKS INTERPRETED TO EXIST IN LOWER PART OF BOREHOLE RSH-1

[1] MEMBER KNOWN FROM AREAS OUTSIDE THE PASCO BASIN, BUT NOT RECOGNIZED TO DATE WITHIN THE PASCO BASIN.

V7808-6

FIGURE 3

## PASCO BASIN STRATIGRAPHIC NOMENCLATURE

POMONA MEMBER

The Pomona Member is a slightly phyric basalt flow. The
flow is medium to light gray and averages about 33 meters in
thickness. Schmincke[11] has divided this flow into three
zones: (1) a basal zone comprising less than one-third of the
flow; (2) a central zone or entablature comprising the bulk of
the flow; and (3) an upper zone comprising one-fifth of the
flow thickness. The central zone or entablature is conspicuous
for its long, continuous, undulating columns with diameters
of 15-30 cm. Near the top, they cluster into composite
columns, 1-2 meters wide which flare out from the center at
high angles.[11]

The buckled surface of the Pomona flow is broken in many
places into blocks of highly oxidized scoria. About 8 km
west of Benton City, 300 m downstream from a power station[11]
Schmincke has noted that the top of the flow has developed as
a maze of more than six flow units separated by lenses of
scoria and breccia.

Such units are rare and may be the result of extreme
gushing and eddying of the lava due to topographic irregularities.
Spectacular pépérites occur where the flow ploughed into the
vitric tuff near the flow margin such as along Crab Creek in
T.16N., R.28E., and at the Snake River in T.9N., R.32E.

The Pomona Member was defined by Schmincke[11] as the upper
flow in the southern entrance of the Yakima River Canyon 10 km
north of Yakima, Washington, where it is well exposed in a
U. S. Highway 97 road cut and in a nearby quarry (Figure 4).
The Pomona Member was termed the Wenas or one of the Wenas
flows, but incorrect application of this name caused the
designation Wenas to be abandoned.
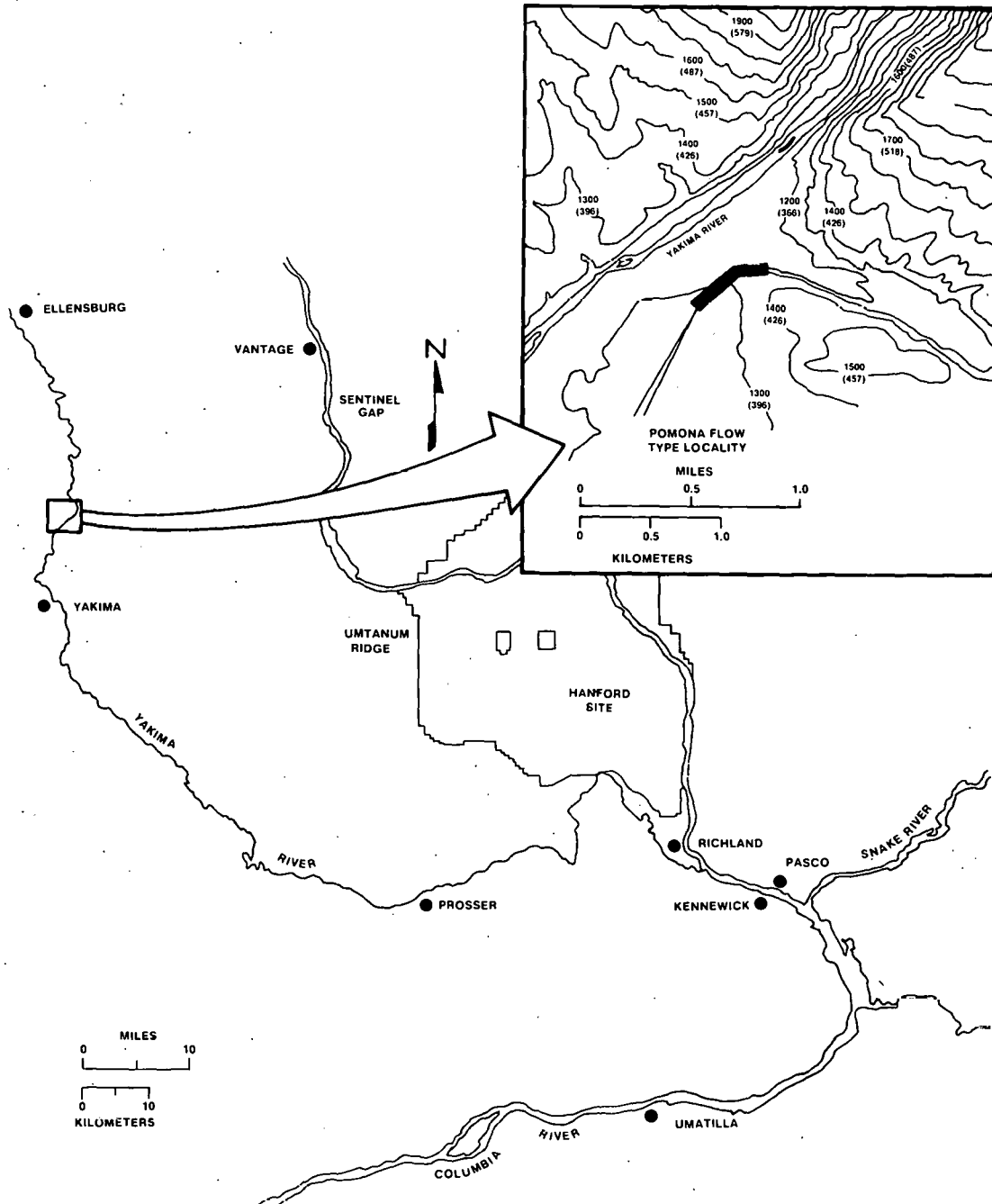
V7804-4.4

FIGURE 4

POMONA TYPE LOCALITY LOCATION MAP

(Contours in feet [meters] above mean sea level.)

Figure 5 depicts an idealized section through the Pomona
Member. The horizontal zones are separated by an abrupt
contact (No. 5). The upper (No. 1) and basal (No. 3) zones
correspond to upper and lower colonnades and the central zone
(No. 2) to the entablature of Tomkeieff.[12] The upper zones
are generally buckled (No. 12) at the top and may contain
vesicles (No. 7) that coalesce into sheets. Undulating
(No. 10) vertical joints divide the zone into thick (No. 4)
prismatic columns. Other features sometimes observable in the
Pomona Member include hackly columns (No. 7) fan jointing
(No. 11) and pipe vesicles (No. 8).

The Pomona Member covers an area of about 18,000 km^2 and
the total volume of lava deposited is estimated as 540 km^3.[11]

The Pomona Member is characterized petrographically by
small phenocrysts of plagioclase (generally less than 5 mm long),
clinopyroxene, and olivine. Modal analyses are distinctive
because of low plagioclase/pyroxene ratios.[11] Plagioclase
phenocrysts commonly have wedge-shaped appearance (Figure 6).
Locally, as in a quarry on the east side of Devils Canyon,
the flow contains large clots (up to 10 cm or more across) of
plagioclase, pyroxene (including very rare hypersthene) and
olivine believed to have formed during crystallization after
eruption. (This information was prepared by D. A. Swanson,
U. S. Geological Survey, Menlo Park, California.) The detailed
petrography of Pomona samples from the type section is given
in Appendix A (prepared by A. C. Waters, Santa Cruz, California).

The Pomona Member has a characteristic intergranular texture
although intersertal and hyalopilitic textures may occur in its
most glassy parts. Most clinopyroxene is colorless, unlike
that in other flows, but where it borders tachylyte, it is a
pale brown, probably due to late enrichment in titanium or iron.

The physical and thermal properties of the Pomona flow
have been reported in other papers.[13] Table VI summarizes
recent results from core analyses of samples from within the
Gable Mountain area, Hanford, Washington.
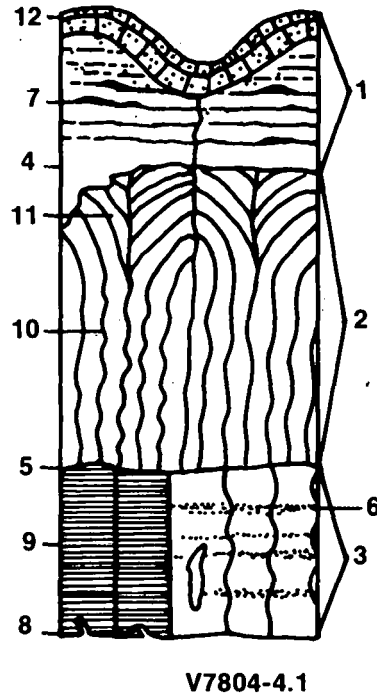
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FIGURE 5

IDEALIZED SECTION THROUGH THE POMONA MEMBER

POMONA
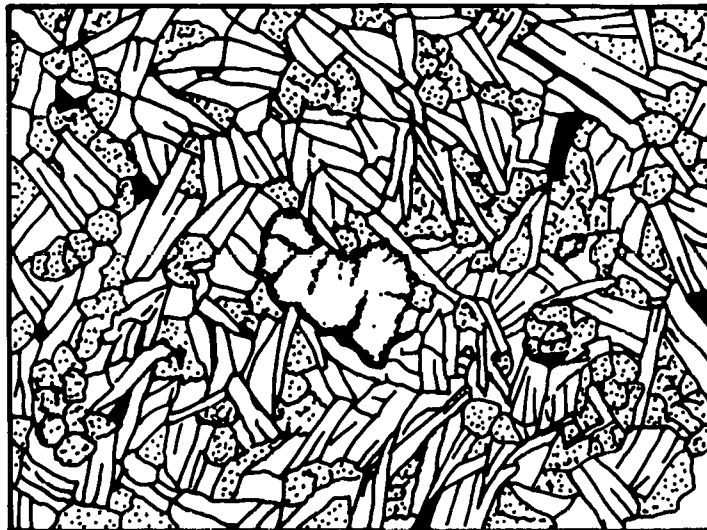
V7804-4.2

PLAGIOCLASE

CLINOPYROXENE

OLIVINE

OPAQUES

200 μ

FIGURE 6

REPRESENTATIVE TEXTURE OF THE POMONA MEMBER

TABLE VI

SUMMARY OF PHYSICAL AND THERMAL
CHARACTERISTICS OF THE POMONA MEMBER

	Average Value	Range Observed	Units
Uniaxial Compressive Strength	284	75-378	MPa
Brazilian Tensile Strength	21.4	15.0-28.5	MPa
Triaxial Compressive Strength	272	141-379	MPa
Modulus of Rupture	23.75	4.03-47.80	MPa
Density	2.84	2.78-2.87	gm/cc
Young's Modulus	76.5×10^3	$63.1\text{-}87.0 \times 10^3$	MPa
Poisson's Ratio	0.25	0.19-0.29	–
Coeff. of Thermal Expansion	6.6×10^{-6}	$6.5\text{-}6.7 \times 10^{-6}$	/$^{\circ}$C
Thermal Conductivity	3.48×10^{-3}	$3.03\text{-}3.84 \times 10^{-3}$	cal/cm sec $^{\circ}$C
Specific Heat:			
at 100° C	0.319	0.288-0.355	cal/gm $^{\circ}$C
at 200° C	0.425	0.394-0.460	cal/gm $^{\circ}$C
at 300° C	0.538	0.474-0.585	cal/gm $^{\circ}$C

Chemically, the Pomona Member is characterized by high
CaO, MgO and chromium, but low FeO, Fe_2O, TiO_2, hafnium, and
barium. Its chemical composition is summarized in Appendix B
using data from existing drill holes (Figure B.1).

UMTANUM UNIT

The Umtanum Unit is an identified flow from the Basalt
sequence of Schwana, Grande Ronde Basalt Formation of the
Columbia River Basalt Group. Unlike the Pomona Member, no
type section has been described for the Umtanum Unit. Exposures
of it are found in Umtanum Ridge due west of the Hanford Site
and at Sentinel Gap (Figure 4). Samples of this flow have also
been obtained from drill holes within the Hanford Site.

The chemistry of the Umtanum Unit is summarized in Appendix B.
The flow shows a very low MgO content. Physically, the Umtanum
Unit possesses excellent platy jointing at several levels. Petro-
graphically, all of the rocks examined are high in glass, have
small microlites, and have almost no microphenocrysts. The flow is
very thick (in excess of 65 meters) and aphanitic. The platy
jointing is probably the result of the stretching and smearing out
of tiny vesicles and diktytaxitic patches, and infilling of the
cavities by chlorophaeite, some of which has altered to clay, opal,
and chalcedony. Petrographic description of drill hole samples
from Wells DDH-3 and DH-5, within the Hanford Site, are given in
Appendix B, Figure B.1, (prepared by A. C. Waters).

BCR-1 STANDARD

The designation of this sample stands for Basalt Columbia
River-1 Standard. The sample was initially collected by
A. C. Waters from a quarry near Hood River, Oregon. This basalt
was used as an international basalt reference sample by the
Standards Committee of the Geochemical Society. Best values
for constituents determined in a rock analysis and for trace
elements were given by Flanagan.[14]

Appendix D depicts the whole rock analyses for BCR-1
using X-ray fluorescence. These results were recently provided
to us by Washington State University. Results on the trace
element composition of BCR-1 are shown in Appendix D from
Flanagan.[14]

WATERS

Generally, waters from basaltic aquifers are characterized
by high ratios of calcium-to-sodium and of magnesium-to-calcium,
a relatively high silica content and a relatively high fluoride
content.

La Sala and Doty[15] have examined numerous water analyses
of Columbia Plateau basaltic aquifers. They concluded that the
waters were typical of those found in sedimentary aquifers.
The silica content of these waters indicates near equilibrium
with a silica phase having properties similar to those of
chalcedony or cristobalite. The silica probably comes into
solution from feldspars and other minerals, but at a concentra-
tion higher than that at which it would be in equilibrium with
quartz.[16,17] The solubility of quartz is particularly low
and would account for only 5 to 15 ppm SiO_2 in the water. Other
silicate minerals, however, have solubilities intermediate
between quartz and amorphous silica (40 ppm).

Waters from deep aquifers underlying the Hanford Site have
recently been analyzed.[18] The location of well samples is
shown in Figure 7. Results of the analysis of Wells DB-1,
DB-2, DB-7, and RSH-1 are summarized in Tables VII and VIII. The
major constituents of these waters are depicted using semi-
logarithmic diagrams in Figures 8-11, respectively. The equili-
brium pH with respect to $CaCO_3$ of all these waters is higher
than the actual pH. The results from the analyses are also
fairly close in the duplicate samples.
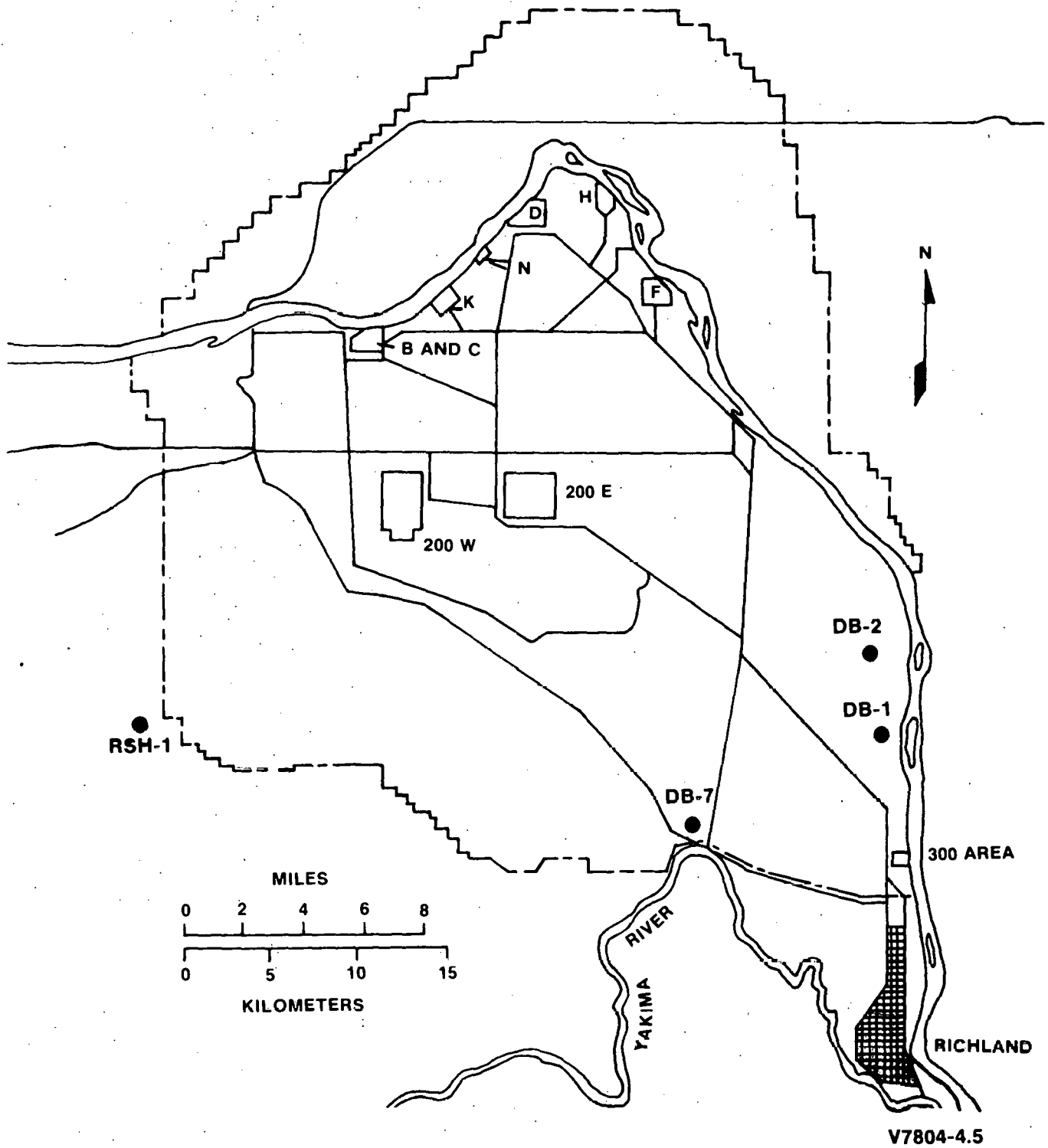
FIGURE 7

HANFORD AREA MAP SHOWING LOCATION OF WELLS SAMPLED

TABLE VII

MAJOR CONSTITUENTS: ANALYTICAL RESULTS

(Sampling Dates are in Parentheses)

Constituent	DB-1 (8/9/76)		DB-2 (8/17/76)		DB-7 (8/11/76)		RSH-1 (5/11/77)		Units
SiO_2	27.8	28.8	31.6	31.8	36.4	36.4	22.5	22.5	ppm
Na	75.0	75.0	150.0	150.0	106.0	117.0	30.0	25.0	ppm
K	14.0	14.0	12.5	12.5	12.5	12.5	9.0	7.7	ppm
Ca	3.5	8.0	4.2	4.5	2.5	2.5	6.5	8.5	ppm
Mg	0.70	0.90	0.18	0.20	0.50	0.50	1.0	2.2	ppm
Fe	.155	.105	0.53	0.63	2.72	3.82	.08	<.02	ppm
HCO_3	208.8	219.6	196.4	192.8	135.7	121.4	42.8	67.3	mg/ℓ $CaCO_3$
CO_3	0	0	21.4	21.4	35.7	50.0	0	0	mg/ℓ $CaCO_3$
SO_4	<.5	<.5	.5	.5	1.0	.5	23.0	15.0	ppm
Cl	12.2	11.8	134.5	117.5	53.0	52.0	16.2	8.8	ppm
F	3.0	3.5	2	<1	7.0	8.7	0.7	0.7	ppm
NO	.5	.5	<.5	<.5	.5	.5	<.05	<.20	ppm
B	.25	.25	.6	.6	.8	.7	<.05	<.05	ppm
T.D.S.	345	307	430	417	531	505	118	112	mg/ℓ
TOC	29	28	14	16	27	28	9	9	mg/ℓ
Cond.	400	430	430	440	450	475	250	250	micromhos/cm
pH	8.2	8.3	8.6	8.6	9.0	9.0	7.3	7.4	
	Water from Mabton interbed sampled with centrifugal pump		Water from Mabton interbed sampled with airlift device and air compressor		Water from Mabton interbed sampled with airlift device and air compressor		Water from Grande Ronde Fm. sampled by swabbing		

TABLE VIII

TRACE CONSTITUENTS: ANALYTICAL RESULTS*

(Sampling Dates are in Parentheses)

Constituent	DB-1 (8/9/76)		DB-2 (8/17/76)		DB-7 (8/11/76)		RSH-1 (5/11/77)	
Zn	24	16	14	15	600	655	2560	39000
Cu	15	15	10	12	15	19	20	50
Hg	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Sb	10	<8	<8	<8	10	15	<3	<3
Ba	22	30	39	35	43	42	140	50
Be	.8	.9	1.3	1.2	.8	1.2	NA	NA
Cd	<.5	<.5	<.5	<.5	1.0	1.5	.2	.6
Cr	2	<1	<1	<1	14	33	<25	<25
Co	6	7	7	5	6	5	2	2
Pb	19	17	15	13	31	41	7	12
Mo	67	20	<1	<1	40	15	2	2
Ni	7	10	8	11	15	13	NA	NA
Ag	1.5	1.0	1.0	1.5	0.8	0.8	<2.5	<2.5
Sr	7	5	2	3	4	3	NA	NA
Sn	14	17	14	14	5	5	NA	NA
Tl	11	11	12	15	11	13	NA	NA
V	<2	<2	8	9	13	14	NA	NA
Unit Sampled	Mabton Member		Mabton Member		Mabton Member		Grande Ronde Formation	

*All constituents are expressed in parts per billion.

NA Not analyzed for.
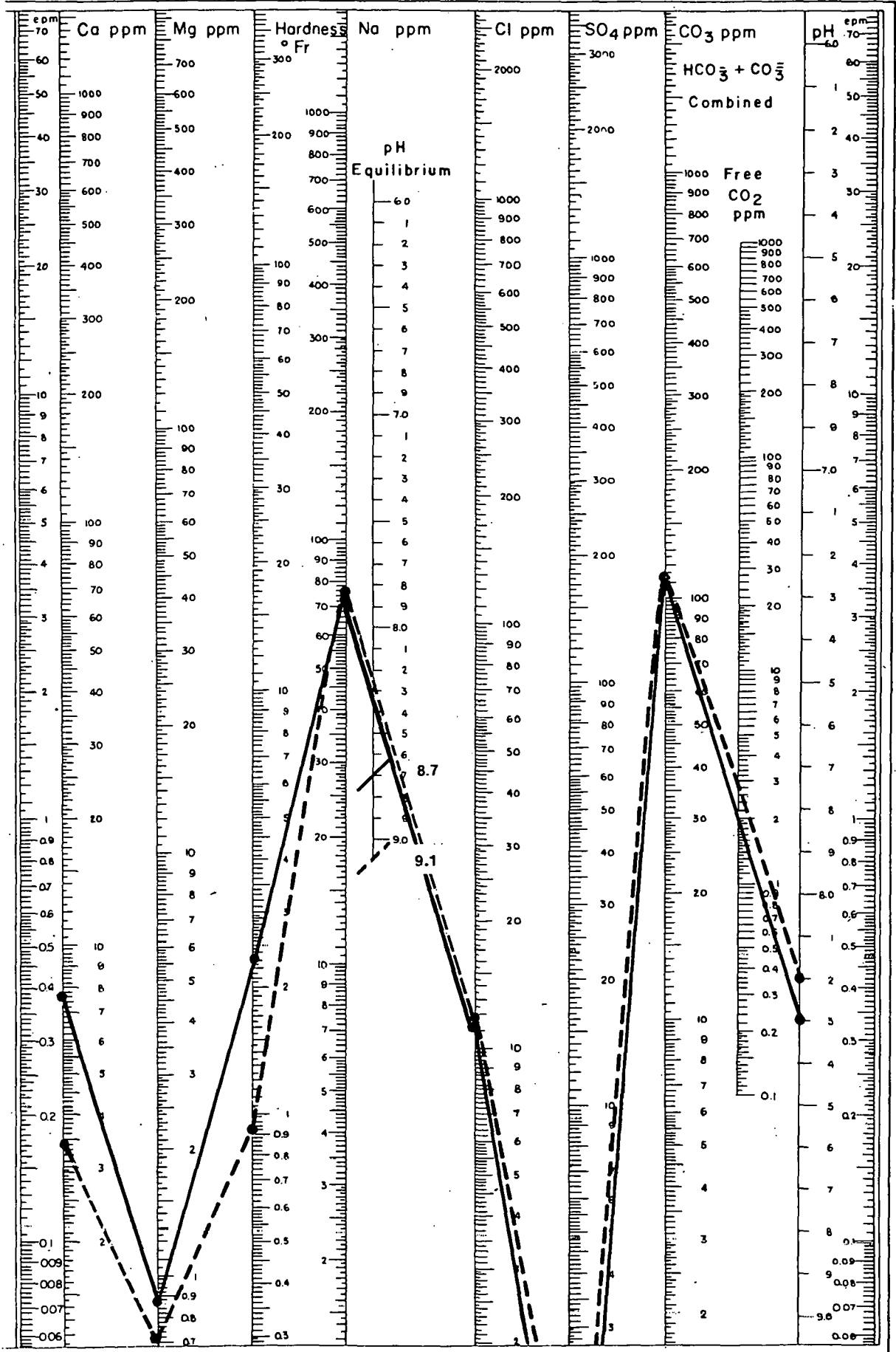
FIGURE 8

MAJOR CONSTITUENTS IN DB-1 (DUPLICATE SAMPLES) WATER FROM THE MABTON MEMBER
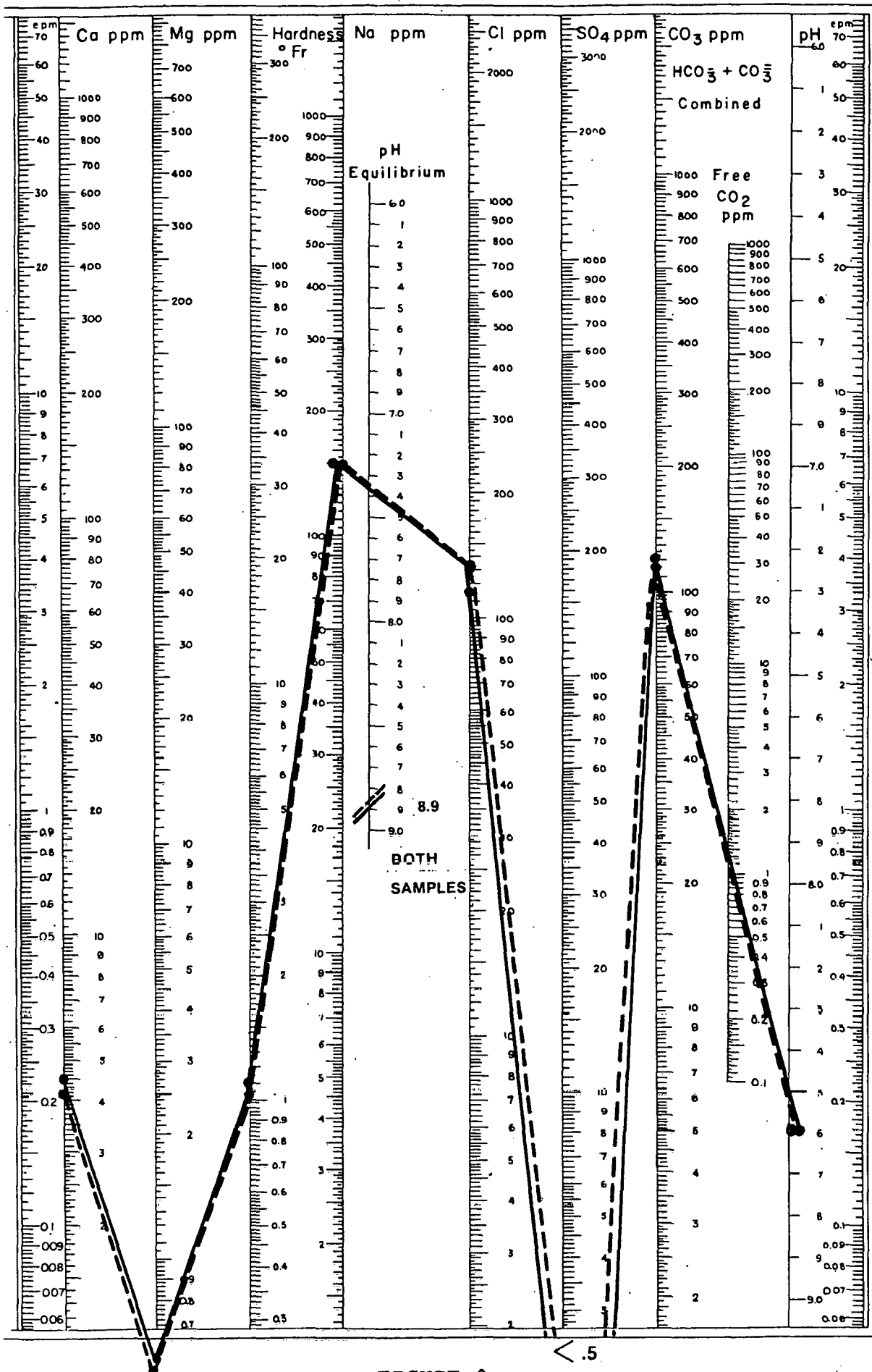
FIGURE 9

MAJOR CONSTITUENTS IN DB-2 (DUPLICATE SAMPLES) WATER FROM THE MABTON MEMBER
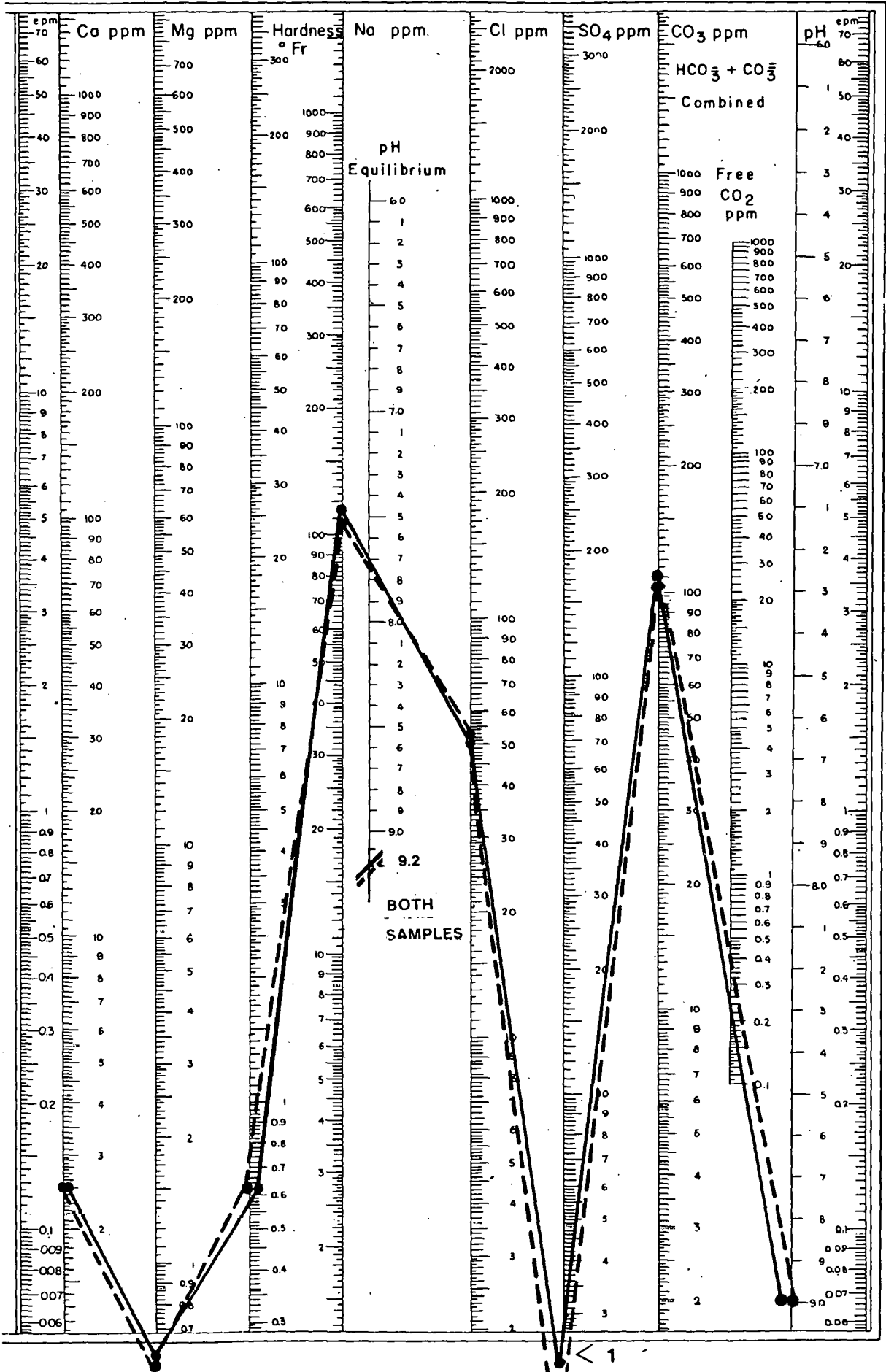
FIGURE 10

MAJOR CONSTITUENTS IN DB-7 (DUPLICATE SAMPLES) WATER FROM THE MABTON MEMBER
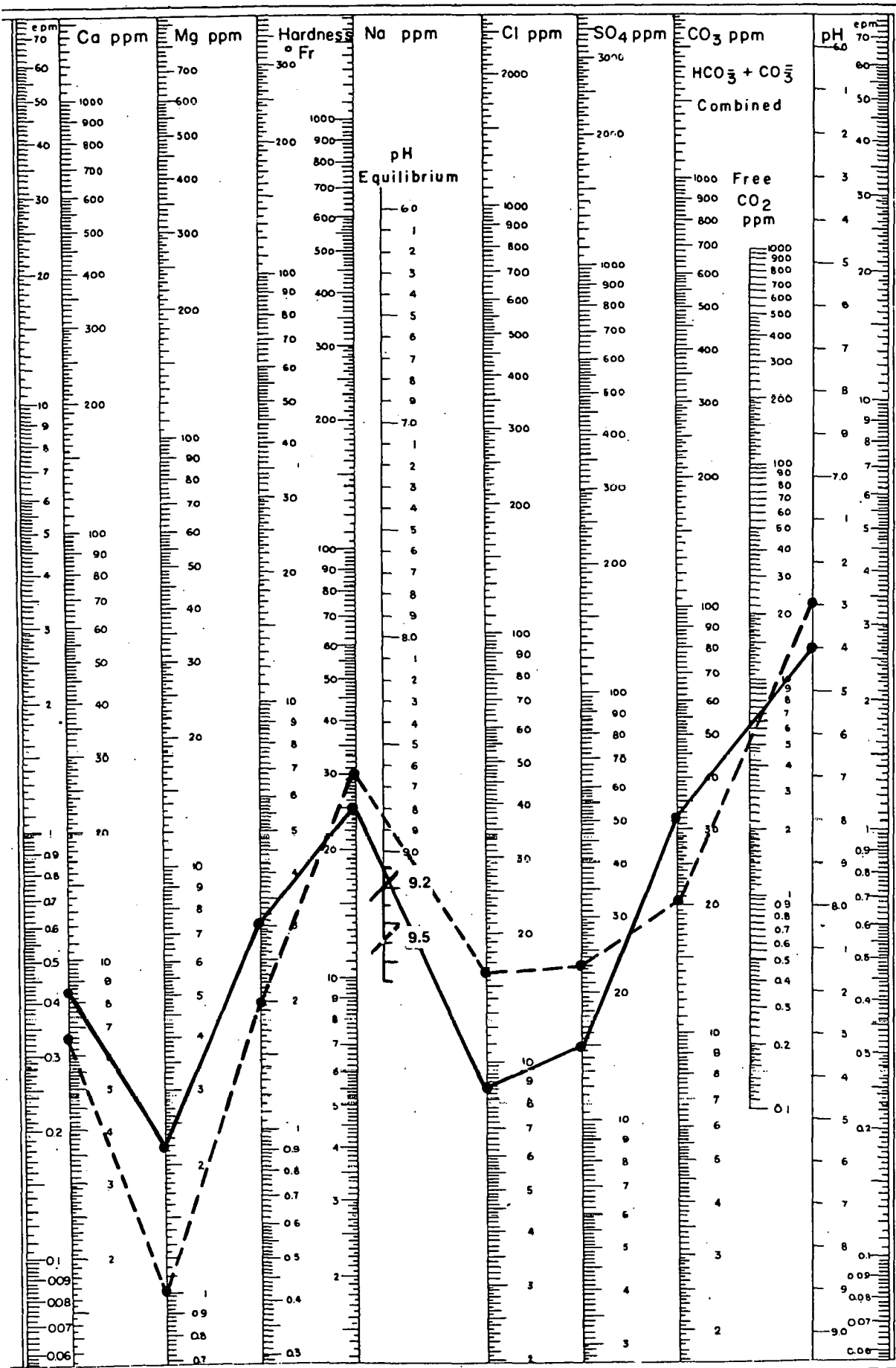
FIGURE 11

MAJOR CONSTITUENTS IN RSH-1 (DUPLICATE SAMPLES) WATER FROM THE GRANDE RONDE
FORMATION

Application of the Palmer classification[18] to the
waters from DB-1, DB-2, DB-7, and RSH-1 shows that all the
waters are Class I waters and in the bulk of the samples, the
primary alkalinity is dominant, indicating waters in contact
with sedimentary strata. Well DB-7 shows also a high primary
salinity, probably due to the basaltic influence on the water
composition.

In the waters depicted in Figures 8-11, sodium is the
predominant cation present. These waters appear to be in
equilibrium with a feldspar of about equal calcium and sodium
content.

The cation-anion balances of the waters from DB-1, DB-2,
DB-7, and RSH-1 are within 0.8-14.8 percent, averaging 5.5 per-
cent. In over 60 percent of the samples, the balance is
within 2 percent.

The main trace constituents are Zn, Cu, Ba, Pb, and Mo.
Zinc is present in concentrations as high as 39 ppm (RSH-1 sample).

ENGINEERED BARRIERS

The present concept is to enclose spent unreprocessed
fuel in a container constructed of stainless steel after the
spent unreprocessed fuel has cooled in a water pool for five
to ten years. The container would serve only to permit handling
and temporary storage of 50 years.

The term "overpack" refers to the material emplaced between
the borehole wall and the canister. At present, the spent
unreprocessed fuel stored in a repository must be retrievable,
and overpacks should be engineered that permit retrieval of the
spent unreprocessed fuel. However, long-term storage will
require a permanent overpack.

There is considerable promise for further research into canister materials design for long-term containment or isolation of radionuclides (i.e., approximately 10^6 years).

There is a need for much further research into overpack materials selection and design for long-term containment of radionuclides. Opportunities for the design of an effective overpack barrier are promising.

The functions of the overpack should be as follows:

Chemical Functions

- Must absorb leaking nuclides;

- Should control oxidation potential and pH to limit solubility of nuclides;

- Should react chemically with migrating nuclides to minimize solubility;

- Could act as a dehydrating agent, preventing access of water to the waste;

- Should provide protection from corrosion to the container.

Physical Functions

- Should act as a heat transfer medium;

- Should provide stress relief (both static and dynamic);

- Should act as a permeability barrier;

- Should act as radiation shield and permit inspection above the storage well during the initial storage period.

Several container materials are presently being studied by investigators abroad. These include hot pressed Al_2O_3 and copper. The Swedish government has indicated an intention to use a copper container. Overpacks may include one or more of the following:

- Layer silicates;

- Zeolites;

- Concrete;

- Eh-pH buffer pairs; e.g., CuS_2-CuS, NiO-FeO;

- pH buffers, e.g., carbonates;

- Silica-alumina gels

Overpack materials should be tailored only to prevent the migration of radionuclides that would possess a high mobility through the host rock environment and could not otherwise be contained.

SCENARIOS TO BE MODELED

During the first few decades of geologic isolation, the heat of radioactive decay in the wastes could raise considerably the immediate repository temperature. Temperatures significantly above the normal 40-45° C ambient for deep repository would persist for up to several hundred years depending on the placement of the waste containers and the thermal conductivity of the host rock. If ground water should come in contact with waste sealed in a repository during this thermal period of isolation, reactions would be expected.

The expectation is that hydrothermal solutions would transport species to and from the waste solid and the host rock, a process very similar to contact metamorphism. The result would be a zone around the waste container, a contact aureole, in which there would be developed new "minerals" which might or might not correspond to known mineral species. The thickness of the aureole would be limited by the falloff of temperature away from the container. The phases in the aureole would depend primarily on the compositions of the waste form and of the repository rock with perhaps some contribution from the container and overpack. These phases could provide either

better or worse long-term fixation depending on their solu-
bility in percolating ground water. Largely crystalline waste
solids would react more slowly than poorly crystalline or non-
crystalline solids such as glasses; yet, unless they were in
thermodynamic equilibrium with the pressure-temperature-
chemical environment of the waste repository site, they too
should eventually interact.

Once the thermal period (200-600 years) is over, the mixture
of these interaction products and the remnants of the waste form
and its containment would constitute a "new" waste form. It
is this "new" waste form which will act as a source of radio-
nuclides for any additional transport over the functional life-
time of the repository.

To simulate the behavior during the operating and post-
operating phases of a repository, waste/basalt interaction studies
must be conducted using the experimental conditions noted in
Table IX. These experiments will involve typical Columbia
River Basalt waters in flooded or wet areas and container
materials as needed. The results of the studies should then
be used to determine the types of overpack needed to contain
any radionuclides that would otherwise migrate through the
environment and cause a higher than maximum permissible concen-
tration to get to the biosphere.

TABLE IX

EXPERIMENTAL CONDITIONS FOR
WASTE/BASALT COMPATIBILITY EVALUATIONS

	Dry Repository (H_2O from Minerals Only)	Wet Repository Low Transport (Closed System)	Flooded Repository High Transport (Open System)
LOW PRESSURE (No Lithostatic Load) $P \sim 1$ Bar Open to Atmosphere	**A** ——— 50 - 400 °C ——— Experimental Method Sealed Gold or Glass Ampuls 1. Waste + Basalt ± Metal 2. Specific Mineral Systems ± Metal		**B** ——— 25 - 90 °C ——— Experimental Method Water Circulating Through Columns of Waste/Basalt 1. Waste + Basalt + H_2O ± Metal 2. Specific Mineral Systems + H_2O ± Metal
HIGH PRESSURE P = 50 - 500 Bars Sealed Repository	**C** ——— 50 - 400 °C ——— Experimental Method Hydrothermal: Cold Seal or Morey Vessels 1. Waste + Basalt ± Metal 2. Specific Mineral Systems ± Metal	**D** ——— 50 - 400 °C——— Experimental Method Hydrothermal: Cold Seal or Morey Vessels 1. Waste + Basalt + H_2O ± Metal 2. Specific Mineral Systems + H_2O ± Metal	**E** ——— 50 - 400 °C——— Experimental Method Circulating Water Hydro-thermal 1. Waste + Basalt + H_2O ± Metal 2. Specific Mineral Systems + H_2O ± Metal

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APPENDIX A

PETROGRAPHIC DESCRIPTION OF THE POMONA TYPE SECTION

PETROGRAPHIC DESCRIPTION OF THE POMONA TYPE SECTION

Latitude - 46° 42' N

Longitude - 120° 28' W

SAMPLE A-1270 - (Taken from 8 feet below the flow top)

Description

Numerous cumulate-like clots of plagioclase, as well as separate phenocrysts of the two minerals in the same size range: plagioclase, 0.5 to 1 mm; pyroxene 0.3 to 0.6 mm. This thin section has caught only a few segments of the large phenocrysts with poikilitic inclusions of pyroxene in the center of the plagioclase, which are one major characteristic of the Pomona Flow. The sliced parts of these phenocrysts are not larger than sliced sections of some of the microphenocrysts. Microlites of plagioclase are mostly 0.1 to 0.2 mm long; pyroxene microlites 0.05 to 0.1 mm. Olivine rare, saponitized on edges and in cracks. Much black dusty tachylyte. Iron ores are in the tachylyte. Opal fills some small vesicles, others are empty. Opal appears to replace a rim of earlier chlorophaeite in some vesicles.

POINT COUNT (1000 POINTS)

Minerals	Volume %	Control Points 1st 500	Control Points 2nd 500
Plagioclase	33.9	173	166
Phenocrysts	1.6	8	8
Microphenocrysts	6.5	33	32
Microlites	25.8	132	126
Pyroxene	37.2	179	193
Microphenocrysts	0.7	5	2
Microlites	36.5	174	191
Olivine (fresh)	2.8	14	14
Opaques	5.5	25	30
Tachylyte	17.1	93	78
Opal (some is replacing chlorophaeite)	3.5	16	19
	100.0	500	500

Plagioclase/pyroxene = 0.91

100-(glass + opaque)/pyroxene = 2.08

Solidification Index: SI = 35.1124

SAMPLE A-1268 (Taken from 30 feet below the flow top)

Description

The rock is full of small phenocrysts of plagioclase
(0.5 to 0.8 mm), and of clots of this plagioclase with micro-
phenocrysts (0.4 mm) of pyroxene. The larger phenocrysts of
plagioclase (greater than 1 mm) that have cores of poikilitic
pyroxene are rare, but as in A-1270, there are a few of them -
none however, are much larger than the microphenocrysts. They
contain inclusions of bubbly-brown glass as well as pyroxene. The
matrix of the rock is a black irresolvable tachylyte. Olivine
is in sparse microphenocrysts (0.8 mm). It is fresh, and diffi-
cult to tell from pyroxene. Microlite sizes are 0.05 to 0.3 mm
for plagioclase; 0.05 mm grains for pyroxene, which however, is
clotted into welded aggregates up to 0.5 mm long. One pyroxene
phenocryst has inclusions of glass and olivine. There is a
peculiar interstitial yellow-green mineraloid. Apparently it is
opal, some of which has relic features (shrinkage cracks,
inclusions) that indicate that it replaced chlorophaeite.

POINT COUNT (1000 POINTS)

	Volume %	Control Points	
		1st 500	2nd 500
Plagioclase		32.8	169	159
Phenocrysts	2.6	15	11
Microphenocrysts	6.0	31	29
Microlites	24.2	123	119
Pyroxene		32.5	158	167
Microphenocrysts	1.3	6	7
Microlites	31.2	152	160
Olivine (fresh)		1.0	6	4
Opaques		3.5	20	15
Tachylyte		27.4	134	140
Opal		2.8	13	15
		100.0	500	500

Plagioclase/pyroxene = 1.01

100-(glass + opaque)/pyroxene = 2.13

Solidification Index: SI = 35.6244

SAMPLE A-1267 (Taken from 60 feet below the flow top)

Description

    This thin section is very similar to A-1270 and A-1268, the
same description applies. It may be somewhat more crystalline -
at least the tachylyte has slightly less fuzzy boundaries,
although it is still filled with black irresolvable dust and in
places with larger skeletal magnetites. A striking example of
a feldspar phenocryst with inclusions of pyroxene and glass was
observed. It shows good resorption features both in early zones,
and in a big "peninsula" of groundmass from one edge. Another
example contains a carlsbad and some pericline twins. An olivine
phenocryst with picotite(?) inclusions was also noted.

POINT COUNT (1000 POINTS)

Minerals	Volume %	Control Points 1st 500	Control Points 2nd 500
Plagioclase	28.7	143	144
Phenocrysts	2.3	11	12
Microphenocrysts	4.7	24	23
Microlites	21.7	108	109
Pyroxene	30.8	151	157
Microphenocrysts	0.9	5	4
Microlites	29.9	146	153
Olivine	1.4	10	4
Opaques	2.8	13	15
Tachylyte	34.5	176	169
Opal	1.8	7	11
	100.0	500	500

Plagioclase/pyroxene = 0.93

100-(glass + opaque)/pyroxene = 2.04

Solidification Index: SI = 36.9604

APPENDIX B

POMONA AND UMTANUM CHEMICAL COMPOSITION

POMONA AND UMTANUM CHEMICAL COMPOSITION

Results of Pomona and Umtanum whole rock analyses using atomic absorption and trace element analyses using neutron activation for holes DH-2, DH-4, DH-5, DDH-1, DDH-3, and DC-1 are reported in Table B-1. Table B-2 reports recent analyses of Pomona and Umtanum samples using X-ray fluorescence. Location of all holes sampled is shown in Figure B-1.

TABLE B-1

POMONA AND UMTANUM CHEMICAL COMPOSITION

DEPTH	SAMPLE SERIAL NUMBER	WHOLE ROCK ANALYSIS; Atomic Absorption															TRACE ELEMENT ANALYSIS; Neutron Activation (BMv)									
		SiO_2 %	Al_2O_3 %	FeO %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	MnO %	TiO_2 %	P_2O_5 %	SrO %	BaO %	Vol %	Mtl Bal%	Cr ppm	Rb ppm	La ppm	Sm ppm	Co ppm	Sc ppm	Eu ppm	Tb ppm	Hf ppm	Ta ppm
DH-2 COREHOLE	POMONA BASALT MEMBER																									
46	Flow top																									
54	CA-53	53	12.9	12.4	-	5.9	10.2	2.3	0.7	0.18	1.8	-	-	0.05	0.8	100.2										
110	CA-54	53	14.1	13.1	-	6.7	10.7	2.3	0.7	0.20	1.8	-	-	0.05	1.2	103.8										
130	A1057	52	14.0	11.0	-	7.9	10.0	2.3	0.4	-	1.5	-	-	0.06	3.5	102.7										
171	Flow bottom																									
DH-4 COREHOLE	POMONA BASALT MEMBER																									
45	Flow top																									
56	A4004	50	13.6	10.9	-	7.1	10.2	2.2	0.1	0.17	1.6	-	0.03	0.07	3.0	99.0										
64	A4005	51	13.6	11.4	-	7.6	10.4	2.2	0.2	0.17	1.6	-	0.02	0.05	2.3	100.8	138	36	16	4.8	43	35	1.4	-	3.5	-
88	A4006	51	13.6	10.8	-	7.5	10.2	2.3	0.2	0.17	1.6	-	0.02	0.06	1.9	99.4	87	35	19	5.3	46	33	1.5	-	4.8	-
120	A4007	51	13.5	10.9	-	7.3	10.1	2.3	0.2	0.18	1.6	-	0.03	0.05	2.7	99.9	100	35	18	4.9	43	34	1.3	-	4.2	-
142	A4008	51	13.5	10.9	-	7.6	10.2	2.3	0.3	0.19	1.6	-	0.03	0.06	1.4	99.1	112	44	17	4.9	41	33	1.5	-	5.1	-
160	A4009	51	13.3	10.8	-	7.4	10.2	2.4	0.3	0.17	1.7	-	0.03	0.06	1.5	98.9	92	42	17	4.8	42	33	1.6	-	5.1	-
167	Flow bottom																									
2306	"UMTANUM BASALT UNIT" (Assignment tentative)																									
	Flow top (?)																									
2320	A4100	50	13.2	12.4	-	4.6	7.1	2.7	1.2	0.25	2.1	-	0.03	0.08	4.7	98.4										
2332	A4101	52	13.4	11.5	-	4.1	7.1	3.1	1.2	0.24	2.1	-	0.04	0.10	5.9	100.7										
2358	A4102	53	12.8	12.4	-	3.8	6.8	3.1	1.3	0.21	2.0	-	0.03	0.09	2.2	97.7	13	58	25	6.6	35	32	1.7	-	5.3	-
2370	A4103	54	13.0	12.3	-	3.8	6.9	3.2	1.3	0.21	2.0	-	0.03	0.10	2.1	98.9	22	53	25	6.6	36	32	1.8	-	3.9	-
2398	A4104	55	13.0	13.3	-	3.5	7.0	3.2	1.4	0.20	2.1	-	0.04	0.10	1.9	100.7	11	84	24	6.7	35	32	1.9	-	5.0	-
2418	A4105	56	13.1	13.2	-	3.5	7.2	3.3	1.4	0.20	2.1	-	0.04	0.10	1.7	101.8										
2435	Flow bottom (?)																									
DH-5 COREHOLE	POMONA BASALT MEMBER																									
324	Flow top																									
336	A5006	53	14.0	10.8	-	7.1	9.7	2.4	0.3	0.16	1.6	-	0.02	0.05	3.8	103.6										
352	A5007	53	13.9	10.8	-	7.4	9.7	2.2	0.3	0.17	1.7	-	0.02	0.05	4.5	103.7	96	26	18	5.0	40	32	1.4	-	3.2	-
388	A5008	52	14.2	11.0	-	7.6	8.6	2.4	0.7	0.18	1.6	-	0.03	0.05	2.4	100.8										
402	A5009	52	14.2	11.4	-	7.7	9.6	2.4	0.7	0.19	1.6	-	0.03	0.05	2.3	102.2	106	32	17	4.8	41	32	1.4	-	3.1	-
430	A5010	52	14.2	11.0	-	7.0	9.5	2.4	0.5	0.19	1.6	-	0.03	0.05	2.4	101.7										
456	A5011	51	13.8	10.6	-	7.4	9.4	2.4	0.6	0.17	1.6	-	0.03	0.05	1.4	98.5	104	21	19	4.7	43	33	1.4	-	3.3	-
460	Flow bottom																									
2616	"UMTANUM BASALT UNIT" (Assignment tentative)																									
	Flow top																									
2650	A5101	52	12.7	12.7	-	3.9	7.6	3.1	1.5	-	2.2	-	-	0.08	1.4	97.2										
2670	A5102	53	12.9	12.9	-	3.9	7.3	3.0	1.5	-	2.2	-	-	0.10	1.9	98.6	18	-	24	6.8	41	32	1.4	-	5.5	-
2692	A5103	54	12.7	12.4	-	3.8	7.0	3.2	1.6	-	2.2	-	-	0.08	1.7	98.7										
2712	A5104	53	12.9	12.8	-	3.8	7.1	3.1	1.6	-	2.2	-	-	0.08	1.6	98.0	27	-	26	7.4	38	32	1.6	-	5.6	-
2732	A5105	52	12.6	12.7	-	3.8	7.4	3.1	1.6	-	2.2	-	-	0.08	1.0	96.5										
2752	A5106	54	12.7	12.7	-	3.7	7.0	3.1	1.6	-	2.1	-	-	0.08	1.1	98.3	33	-	25	6.9	39	31	1.5	-	4.5	-
2772	A5107	55	12.8	12.8	-	3.9	7.3	3.3	1.3	-	2.2	-	-	0.08	0.6	99.3										
2796	A5108	55	12.8	12.9	-	3.9	7.5	3.2	1.2	-	2.2	-	-	0.09	2.7	101.5	117	-	25	7.3	39	33	1.7	-	7.5	-
2812	A5109	55	12.6	12.5	-	3.9	7.3	3.1	1.9	-	2.1	-	-	0.09	2.4	100.9										
2820	Flow bottom																									

Table B-1 (continued)

DEPTH	SAMPLE SERIAL NUMBER	WHOLE ROCK ANALYSIS; Atomic Absorption															TRACE ELEMENT ANALYSIS; Neutron Activation (BNW)									
		SiO_2 %	Al_2O_3 %	FeO %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	MnO %	TiO_2 %	P_2O_5 %	SrO %	BaO %	Vol %	Mtl Balz	Cr ppm	Rb ppm	La ppm	Sm ppm	Co ppm	Sc ppm	Eu ppm	Tb ppm	Hf ppm	Ta ppm
DDH-1 COREHOLE	POMONA BASALT MEMBER																									
248	Flow top																									
254	CA-6	54.1	14.0	11.0	-	5.4	9.3	1.0	0.5	0.17	2.0	-	0.03	0.05	-	99.1										
264	CA-7	51.5	14.0	10.0	-	5.0	9.3	2.0	0.4	0.19	2.0	-	0.03	0.04	-	90.0										
274	A1031	51	13.9	10.0	-	5.7	9.5	2.3	0.4	-	1.6	-	-	0.06	4.0	94.4										
290	A1033	51.5	13.3	10.6	-	7.2	9.9	2.2	0.3	-	1.5	-	-	0.06	2.7	96.5										
300	CA-10	51.9	14.1	11.9	-	7.0	10.3	2.3	0.6	0.20	2.0	-	0.03	0.04	-	100.3										
356	A1034	52.	14.8	10.9	-	8.0	9.6	2.5	0.5	-	1.6	-	-	0.05	1.9	101.8										
360	CA-11	50.8	14.3	10.4	-	6.7	10.8	2.5	0.6	0.26	1.9	-	0.03	0.04	-	90.3										
400	CA-12	51.9	14.3	11.7	-	7.1	9.9	2.5	0.5	0.20	1.9	-	0.03	0.04	-	100.2										
410	A1035	52	14.6	11.1	-	8.0	9.9	2.5	0.4	-	1.5	-	-	0.06	0.4	101.0										
440	CA-13	51.2	14.5	11.3	-	6.9	10.0	2.3	0.4	0.17	1.0	-	0.03	0.04	-	90.6										
442	Flow bottom																									
DDH-3 COREHOLE	POMONA BASALT MEMBER																									
400	Flow top																									
504	A2011	54	13.5	11.3	-	7.2	10.2	2.1	0.4	-	1.7	-	-	0.04	1.1	101.5	114	-	17	5.2	44	34	1.5	-	2.8	-
526	A2012	54	13.5	11.4	-	7.3	9.1	2.3	0.6	-	1.7	-	-	0.04	2.2	102.1	101	-	18	5.0	41	32	1.4	-	3.5	-
556	A2013	54	14.1	11.3	-	7.5	9.4	2.4	0.5	-	1.7	-	-	0.04	2.0	102.9	111	-	17	5.4	42	32	1.5	-	3.3	-
612	A2014	57	14.0	11.1	-	7.6	9.1	2.4	0.6	-	1.8	-	-	0.04	1.4	105.0	94	-	16	5.2	42	34	1.5	-	3.1	-
670	Flow bottom																									
	"UMTANUM BASALT UNIT"																									
3066	Flow top																									
3096	A2108	55	11.9	11.3	-	3.2	5.4	2.8	2.3	-	1.9	-	-	0.13	6.7	100.6	22	-	27	7.7	36	38	2.7	-	7.9	-
3126	A2109	56	11.9	11.7	-	3.2	6.6	2.8	1.2	-	1.8	-	-	0.16	3.3	98.6	5	-	21	6.5	38	35	2.2	-	7.1	-
3146	A2110	54	12.5	11.2	-	3.5	6.6	2.7	2.2	-	1.9	-	-	0.10	5.1	99.8	13	-	26	7.3	41	38	2.4	-	5.6	-
3176	A2111	55	12.6	12.7	-	3.5	6.8	3.0	1.7	-	2.0	-	-	0.10	2.0	99.4	13	-	24	5.8	33	29	1.7	-	4.4	-
3192	A2112	55	12.0	12.4	-	3.6	6.6	3.1	1.6	-	2.0	-	-	0.12	1.9	99.1	16	-	22	5.9	33	30	1.9	-	4.5	-
3206	A2113	53.5	12.4	12.8	-	3.6	6.6	3.1	1.3	-	2.0	-	-	0.10	2.1	97.5	34	-	24	5.4	34	29	1.7	-	4.7	-
3224	A2114	52	12.5	12.6	-	3.7	6.5	3.3	1.4	-	2.1	-	-	0.08	2.2	96.4	15	-	22	6.1	37	32	2.1	-	5.1	-
3242	A2115	52	12.5	13.3	-	3.6	6.5	3.0	1.3	-	2.1	-	-	0.08	5.1	99.5	16	-	22	6.1	38	32	1.9	-	5.8	-
3272	A2116	55	13.2	13.0	-	3.6	6.7	3.3	1.3	-	2.0	-	-	0.10	2.1	100.3	17	-	23	6.0	36	32	2.0	-	4.9	-
3200	A2117	55	13.2	12.9	-	3.8	6.9	3.4	1.4	-	2.0	-	-	0.10	1.9	100.6	15	-	21	6.0	32	36	1.9	-	4.9	-
3296	A2119	54.5	13.3	12.4	-	3.7	6.8	3.2	1.4	-	2.0	-	-	0.09	1.3	98.7	19	-	22	6.2	35	32	1.9	-	5.2	-
3320	A2120	57	12.8	12.5	-	3.5	6.8	3.3	1.6	-	2.1	-	-	0.11	1.1	100.0	17	-	22	6.0	38	34	2.2	-	6.7	-
3340	A2121	57	11.9	13.5	-	3.6	6.7	3.1	1.5	-	2.1	-	-	0.10	1.6	100.1	12	-	22	6.0	36	33	2.1	-	5.7	-
3354	Flow bottom																									
ARH DC-1 BOREHOLE "UMTANUM BASALT UNIT", Flow top 2958																										
3087	A1072	57	13.2	12.7	-	3.5	6.8	3.2	1.5	-	2.0	-	-	0.08	0.6	-	13	-	28	5.8	35	31	1.5	0.94	5.3	1.6
3127	A1073	55	13.5	12.1	-	3.2	7.0	3.3	1.7	-	2.0	-	-	0.08	0.8	-	13	-	27	6.2	36	34	2.0	1.4	6.1	1.7
3126	A1138	53.5	13.1	12.1	-	3.5	6.6	3.1	1.6	-	1.9	-	-	0.08	1.2	-										
3178	Flow bottom																									

TABLE B-2

POMONA AND UMTANUM X-RAY FLUORESCENCE

DEPTH	SAMPLE SERIAL NUMBER	WHOLE ROCK ANALYSES; X-Ray Fluorescence										
		SiO_2 %	Al_2O_3 %	TiO_2 %	Fe_2O_3 %	FeO %	MnO %	CaO %	MgO %	K_2O %	Na_2O %	P_2O_5 %
DH-4 COREHOLE	"UMTANUM BASALT UNIT" (Assignment tentative)											
2306	Flow top (?)											
2378	A3085	54.65	15.09	2.07	2.00	11.16	0.21	6.93	3.42	1.50	2.64	0.34
2406	A3084	54.78	14.66	2.13	2.00	11.05	0.22	7.20	3.44	1.52	2.66	0.34
2435	Flow bottom (?)											
DH-5 COREHOLE	POMONA BASALT MEMBER											
374	Flow top											
410	A3146	52.98	15.63	1.58	2.00	8.99	0.19	8.89	6.79	0.55	2.97	0.25
443	DH50443	51.87	15.02	1.55	2.00	8.89	0.19	10.58	7.68	0.39	2.23	0.19
460	Flow bottom											
	"UMTANUM BASALT UNIT" (Assignment tentative)											
2616	Flow top (?)											
2655	A3124	54.13	15.33	2.15	2.00	11.31	0.21	6.80	3.43	1.48	2.82	0.34
2750	A3125	53.89	14.35	2.18	2.00	11.06	0.22	7.45	3.63	1.64	3.22	0.36
2802	A3126	54.58	14.88	2.14	2.00	11.10	0.22	6.99	3.48	1.51	2.74	0.35
2820	Flow bottom (?)											
DC-2 COREHOLE	POMONA BASALT MEMBER											
294	Flow top											
377	DC20377	52.39	14.92	1.58	2.00	8.21	0.18	10.94	6.94	0.53	2.09	0.22
439	DC20439	52.01	14.88	1.55	2.00	8.99	0.19	10.62	7.17	0.35	2.02	0.21
483	Flow bottom											
	"UMTANUM BASALT UNIT"											
2958	Flow top											
3044	DC23044	54.88	14.28	2.13	2.00	11.08	0.22	7.30	3.44	1.62	2.70	0.35
3126	DC23126	55.05	14.42	2.19	2.00	11.47	0.23	7.34	3.49	1.61	1.86	0.35
3160	DC23160	54.78	14.23	2.23	2.00	11.47	0.21	7.23	3.57	1.41	2.49	0.36
3178	Flow bottom											
DC-6 COREHOLE	POMONA BASALT MEMBER											
514	Flow top											
616	DC60616	52.78	15.50	1.60	2.00	8.90	0.19	8.73	7.22	0.53	2.24	0.31
675	DC60675	52.04	15.11	1.61	2.00	8.95	0.20	10.44	6.97	0.34	2.22	0.23
694	Flow bottom											
	"UMTANUM BASALT UNIT"											
3036	Flow top											
3125	DC63125	54.65	14.41	2.13	2.00	11.07	0.21	7.24	3.49	1.65	2.81	0.34
3177	DC63177	54.77	14.23	2.12	2.00	11.23	0.22	7.15	3.40	1.58	2.95	0.35
3243	DC63243	54.45	14.47	2.19	2.00	11.07	0.22	7.21	3.71	1.64	2.71	0.33
3258	Flow bottom											
DC-10 COREHOLE	POMONA BASALT MEMBER											
125	Flow top											
216.5	DC10	51.18	15.72	1.60	2.00	8.81	0.18	10.81	6.78	0.45	2.22	0.25
290	DC10	52.14	15.57	1.59	2.00	8.43	0.18	10.73	6.40	0.50	2.24	0.23
298	Flow bottom											
DC11 COREHOLE	POMONA BASALT MEMBER											
96	Flow top											
143	DC11	51.30	15.44	1.60	2.00	8.89	0.19	10.86	6.86	0.44	2.19	0.24
266	DC11	51.18	15.53	1.62	2.00	9.00	0.19	10.80	6.85	0.56	2.03	0.24
278	Flow bottom											

DH-5

DH-4

N

D

H

N

K

B AND C   DC-10

DC-11

DDH-1   DC-6

DC-1

200 E

DC-2

200 W

LEGEND

● CORE HOLE
○ HYDROLOGICAL HOLE

DH-2

300 AREA

DDH-3

MILES

0   2   4   6   8

0   5   10   15

KILOMETERS

YAKIMA RIVER

RICHLAND
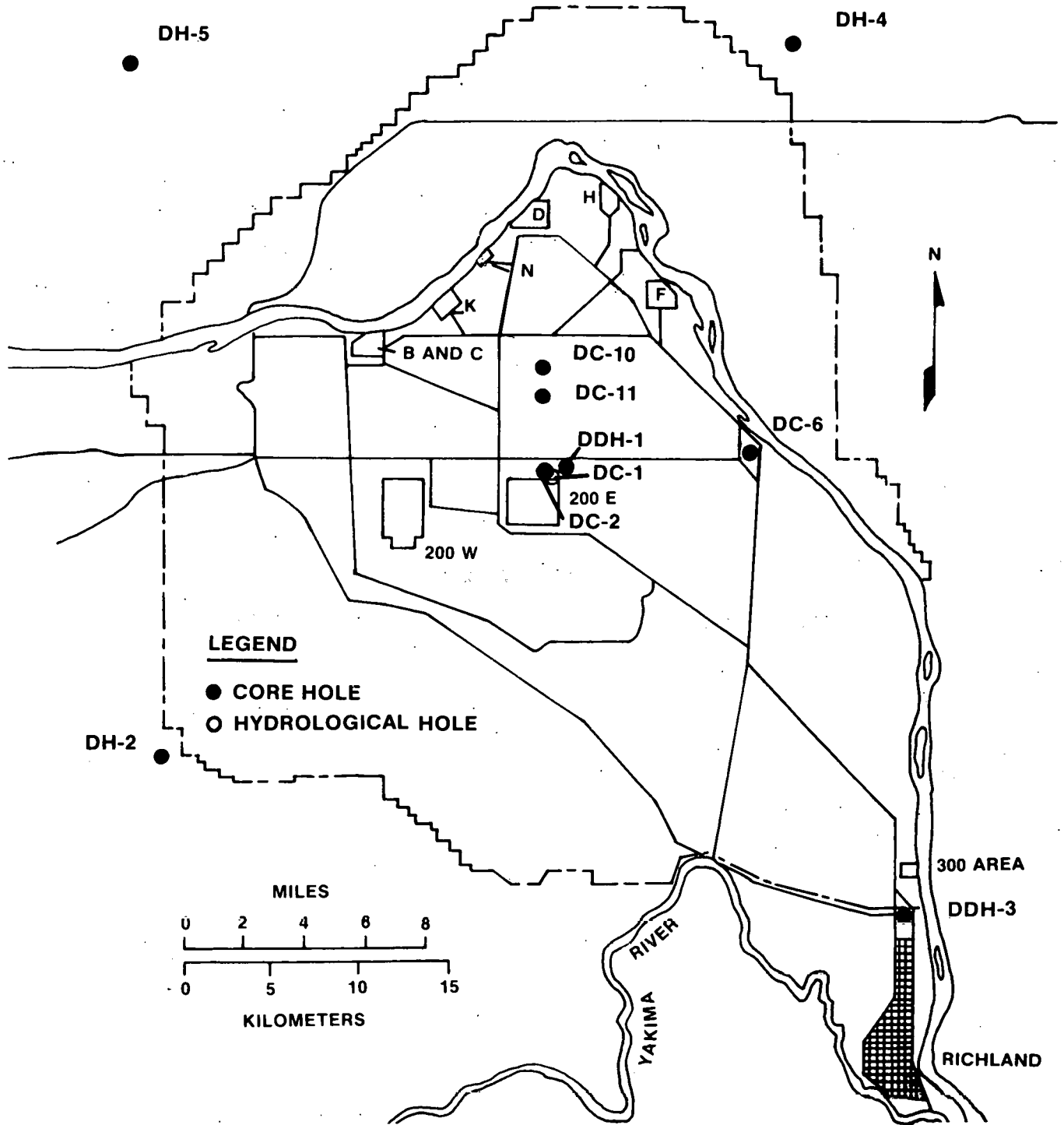
V7804-4.6

FIGURE B-1

HANFORD AREA MAP SHOWING LOCATION OF WELLS SAMPLED

APPENDIX C

PETROGRAPHIC DESCRIPTION OF THE UMTANUM FLOW

PETROGRAPHIC DESCRIPTION OF THE UMTANUM FLOW

Well DDH-3

Top of Umtanum Flow at 3,125 feet

Base of Umtanum Flow at 3,325 feet

SAMPLE A-2117 (Taken from a depth of 3,280 feet)

Description

An extremely fine grained, glassy rock consisting of
tachylyte pools crowded against a feeble network of thin (0.1 mm
long and 0.025 mm thick) plagioclase microlites and shapeless
grains of pyroxene (0.3 to 0.4 mm in diameter). Scattered small
vesicles are partly filled with altered chlorophaeite and opal.

POINT COUNT (1000 POINTS)

Minerals	Volume %	Control Points	
		1st 500	2nd 500
Plagioclase	22.7	110	117
Phenocrysts	0.8	5	3
Microlites	21.9	105	114
Pyroxene	24.1	115	126
Phenocrysts	0.8	5	3
Microlites	23.3	110	123
Olivine	0	0	0
Tachylyte glass (opaques included)	52.3	268	255
Altered Chlorophaeite and Opal	0.9	7	2
	100.0		

Plagioclase/pyroxene ratio: 0.94

100-(glass + opaques)/pyroxene: 1.98

Solidification Index: SI = 17.665

SAMPLE A-2120 (Taken from a depth of 3,320 feet)

Description

Section is thick. Shows the usual microphenocrysts of
plagioclase (0.7 mm long). Rounded grains, tabular clotted
plates, and rare microphenocrysts of green pyroxene, large
euhedral opaques, and a deep brown glass - nearly clear except
for a spattering of tiny spherical opaques. Only a little
chlorophaeite.

POINT COUNT (1000 POINTS)

Minerals	Volume %	Control Points	
		1st 500	2nd 500
Plagioclase	38.6	190	196
Microphenocrysts	1.1	5	6
Microlites	37.5	185	190
Pyroxene	38.9	196	193
Olivine (saponitized)	0.2	1	1
Opaques	7.6	38	38
Glass + crystallites	14.4	73	71
Chlorophaeite	0.0	0	0
Apatite	0.3	2	1
	100.0	500	500

Plagioclase/pyroxene = 0.99

100-(glass + opaque)/pyroxene = 2.26

Solidification Index: SI = 16.746

Well DH-5

Top of Umtanum Flow at 2,615 feet

Base of Umtanum Flow at 2,825 feet

SAMPLE A-5101 (Taken from a depth of 2,650 feet)

Description

Although this rock appears aphanitic to glassy, point
counting indicates not more than 20-30 percent glass, but the
microlites which compose most of its bulk are so tiny (mostly
less than 0.25 mm) that they "swim" in glass of the thickness of
a thin section. Because the dark brown glass is transparent,
the amount of glass is constantly understated by the method of
point counting, as microlites can be seen through it. Micro-
phenocrysts are almost nil. Only 6 of plagioclase and 1 of
pyroxene were encountered in counting 1000 points. Apatite is
much more abundant than normal, but because it is in such tiny
crystals, it was rarely counted. The small amount of mineraloid
in the rock has been largely replaced by opal and chalcedony.

POINT COUNT (1000 POINTS)

Minerals	Volume %	Control Points 1st 500	Control Points 2nd 500
Plagioclase	46.4	236	228
Pyroxene	26.2	135	127
Opaques	5.1	18	33
Glass	19.0	97	93
Chlorophaeite	2.9	12	17
Apatite	0.1	0	1
Opal and Chalcedony (after chlorophaeite)	0.3	2	1
	100.0	500	500

Plagioclase/pyroxene = 1.77

100-(glass + opaques)/pyroxene = 3.28

SAMPLE A-5103 (Taken from a depth of 2,692 feet)

Description

    This second thin section, taken 42' deeper in the 210-foot
flow (or flow units) than A-5101 is richer in glass, but never-
theless, will make a more accurate point count. The tachylyte
has cleared by nucleating small beads of opaque, which can be
clearly discriminated from the translucent brown glass. Also
this rock shows clearly what could only be anticipated from the
ones above - the "poker-chip" structure is formed by the
stretching and smearing out of tiny vesicles and diktytaxitic
patches, and infilling of the cavities by chlorophaeite, some
of which has altered to clay, opal, and chalcedony.

    The rock is essentially without microphenocrysts; only three
were encountered in 1000 points counted. All were plagioclase
less than 0.7 mm long. Microlites range from 0.07 to 0.10 mm.

<div align="center">

POINT COUNT (1000 POINTS)

</div>

Minerals	Volume %	Control Points	
		1st 500	2nd 500
Plagioclase	32.1	162	159
Pyroxene	19.4	90	104
Opaques	4.1	15	26
Glass	40.7	216	191
Chlorophaeite	3.2	14	18
Opal, Chalcedony, Zeolite	0.5	3	2
	100.0	500	500

Plagioclase/pyroxene = 1.64

100-(glass + opaques)/pyroxene = 2.84

SAMPLE A-5106 (Taken from a depth of 2,752 feet)

Description

  Unlike the preceding thin sections, this one shows a few microphenocrysts (0.6 mm) and a single small plagioclase pheno-cryst (1.5 mm). Plagioclase and pyroxene microlites are very small (0.1 to 0.05 mm). The glass is deep brown and relatively clear. Opaques have nucleated into clearly defined euhedral grains. Only a trace of mineraloid (chlorophaeite) is present, and clays or other alteration products are virtually nil. Because this is the best thin section, and because of the importance of this flow as a marker, two sets of 1000 points were counted by two separate operators with these results:

	Combined %	Operator 1		Operator 2	
Plagioclase	36.35	171	180	185	191
Microphenocrysts		6	13	3	6
Microlites		165	167	182	185
Pyroxene	25.50	127	128	131	124
Microphenocrysts		8	2	2	0
Microlites		119	126	129	124
Opaques	5.50	37	30	21	22
Glass	32.10	164	161	157	160
Apatite	0.10	0	1	1	0
Chlorophaeite	0.45	1	0	5	3
	100.00	500	500	500	500

The 2000 points combined give the mode (volume %) listed in the first column, and the mineral ratios indicated below.

Plagioclase/pyroxene = 1.43

100-(glass + opaques)/pyroxene = 2.45

SAMPLE A-5109B (Taken from a depth of 2,812 feet)
Description

    Two thin sections were cut at different angles with the
platy structure. The larger one "B" was point counted.

    The rock is exceedingly fine grained. Tiny (0.2 mm) plagio-
clase microlites are loosely grouped into bundles of 2 to 4 laths.
Even smaller grains of pyroxene are more closely grouped into
tiny clots or elongate clusters. Some clusters appear to be on
the way toward making larger microlites (or microphenocrysts)
by synneusis. Microphenocrysts of either plagioclase or pyroxene
are virtually absent - less than a dozen in the entire thin section.
The opaques are euhedral microlites; as a result, the glass is
relatively clear. Chalcedony rims one vesicle, and slightly
altered chlorophaeite has been smeared along the platy structure
in places.

POINT COUNT (1000 POINTS)

	Volume %	Control Points	
		1st 500	2nd 500
Plagioclase	44.1	216	225
Pyroxene	34.3	167	176
Opaques	5.4	30	24
Glass	15.8	85	73
Apatite	0.2	0	2
Chlorophaeite	0.2	2	0
	100.0	500	500

Plagioclase/pyroxene = 1.29

100-(glass + opaques)/pyroxene = 2.30

APPENDIX D

BCR-1 DATA

TABLE D-1

BCR-1 DATA FROM ARHCO AND ROCKWELL ANALYSIS

DEPTH	SAMPLE SERIAL NUMBER	WHOLE ROCK ANALYSES; X-Ray Fluorescence										
		SiO_2 %	Al_2O_3 %	TiO_2 %	Fe_2O_3 %	FeO %	MnO %	CaO %	MgO %	K_2O %	Na_2O %	P_2O_5 %

BCR-1 BASALT STANDARD

ARHCO BASALT ANALYSES JUNE-JULY 1977 (WSU Special Report)

	K5218	54.14	14.71	2.22	2.00	10.74	0.21	7.00	3.70	1.89	3.07	0.32
	K5219	54.38	14.70	2.16	2.00	10.93	0.20	7.12	3.53	1.87	2.78	0.33
	K5220	54.55	14.62	2.22	2.00	10.67	0.20	6.91	3.66	1.94	2.90	0.33
	K5221	54.39	15.03	2.19	2.00	10.25	0.21	7.34	3.66	1.89	2.71	0.33
	K5222	54.22	14.74	2.23	2.00	10.76	0.21	6.91	3.65	1.92	3.03	0.33
	K5223	54.28	15.08	2.17	2.00	10.72	0.21	7.14	3.54	1.84	2.69	0.33
	K5224	54.44	14.70	2.23	2.00	10.73	0.21	6.92	3.51	1.88	3.05	0.33
	K5225	54.30	14.60	2.17	2.00	10.60	0.21	7.15	3.55	1.86	3.03	0.32
	K5235	54.54	15.16	2.21	2.00	10.89	0.20	7.17	3.74	1.74	2.01	0.33
	K5236	54.87	15.04	2.21	2.00	10.72	0.20	7.15	3.78	1.78	1.92	0.33
	K5237	54.59	14.98	2.23	2.00	11.05	0.21	7.22	3.68	1.77	1.95	0.33
	K5238	55.02	14.91	2.24	2.00	10.60	0.21	7.27	3.61	1.84	1.96	0.34
	K5239	54.70	15.09	2.20	2.00	10.75	0.20	7.14	3.77	1.73	2.01	0.32
	K5240	54.83	14.55	2.26	2.00	10.95	0.21	7.30	3.57	1.86	2.12	0.34
	K5241	54.51	15.08	2.21	2.00	11.09	0.20	7.14	3.67	1.75	2.02	0.33
	K5242	54.82	14.53	2.26	2.00	10.83	0.21	7.31	3.56	1.86	2.26	0.34
	K5243	54.75	15.07	2.22	2.00	10.82	0.21	7.22	3.66	1.76	1.95	0.33
	K5244	54.93	15.02	2.24	2.00	10.51	0.21	7.21	3.67	1.80	2.08	0.33
	K5245	54.89	14.71	2.24	2.00	10.62	0.21	7.35	3.62	1.82	2.21	0.34
	K5246	55.01	14.98	2.23	2.00	10.58	0.21	7.27	3.63	1.81	1.95	0.33

DEPTH	SAMPLE SERIAL NUMBER	WHOLE ROCK ANALYSES; X-Ray Fluorescence										
		SiO_2 %	Al_2O_3 %	TiO_2 %	Fe_2O_3 %	FeO %	MnO %	CaO %	MgO %	K_2O %	Na_2O %	P_2O_5 %

BCR-1 BASALT STANDARD

WSU Report ROCKWELL 1, 14 March 1978
BCRP900	55.24	14.56	2.25	2.00	10.54	0.19	6.95	3.70	1.74	2.49	0.33

WSU Report ROCKWELL 2, 22 April 1978
BCRP900	54.50	14.23	2.20	2.00	10.31	0.18	6.80	3.49	1.79	4.15	0.33

WSU Report ROCKWELL 3, 24 March 1978
BCRP900	53.93	14.26	2.24	2.00	10.49	0.19	6.97	3.61	1.85	4.11	0.34

WSU Report ROCKWELL 4, 21 April 1978
BCRP900	55.34	14.50	2.26	2.00	10.55	0.19	6.97	3.51	1.85	2.49	0.34

WSU Report ROCKWELL 5, 13 April 1978
BCRP900	54.94	14.70	2.25	2.00	10.43	0.19	6.93	3.50	1.84	3.18	0.36

WSU Report ROCKWELL 6, 19 April 1978
BCRP900	54.97	14.60	2.26	2.00	10.49	0.19	6.93	3.47	1.84	2.88	0.38

WSU Report ROCKWELL 7, 22 April 1978
BCRP900	55.18	14.55	2.25	2.00	10.59	0.19	6.88	3.41	1.80	2.80	0.34

WSU Report ROCKWELL 8, 1 May 1978
BCRP900	55.05	14.67	2.26	2.00	10.53	0.19	6.87	3.47	1.81	2.82	0.34

WSU Report ROCKWELL 9, 8 May 1978
BCRP900	55.49	14.33	2.26	2.00	10.63	0.19	6.92	3.41	1.81	2.63	0.35

WSU Report ROCKWELL 10, 12 May 1978
BCRP900	55.38	14.33	2.24	2.00	10.50	0.19	6.87	3.48	1.80	2.85	0.36

WSU Report ROCKWELL 11,
BCRP900	54.96	14.72	2.27	2.00	10.69	0.19	6.88	3.43	1.84	2.69	0.34

WSU Report ROCKWELL 12, 2 June 1978
BCRP900	54.56	14.63	2.28	2.00	10.63	0.19	6.94	3.51	1.83	3.08	0.35

WSU Report ROCKWELL 13, 19 June 1978
BCRP900	55.11	14.47	2.26	2.00	10.61	0.19	6.86	3.51	1.82	2.84	0.34

WSU Report ROCKWELL 14, 19 June 1978
BCRP900	55.15	14.37	2.26	2.00	10.63	0.19	6.87	3.50	1.83	2.86	0.35

WSU Report ROCKWELL 15, 23 June 1978
BCRP900	54.93	14.50	2.27	2.00	10.59	0.19	6.89	3.45	2.01	2.83	0.35

WSU Report ROCKWELL 16, 7 July 1978
BCRP900	54.91	14.53	2.26	2.00	10.54	0.19	6.89	3.53	1.82	2.97	0.36

WSU Report ROCKWELL 17,
BCRP900	55.20	14.57	2.27	2.00	10.59	0.19	6.89	3.52	1.84	2.57	0.36

WSU Report ROCKWELL 18, 24 July 1978
BCRP900	55.05	14.59	2.26	2.00	10.50	0.19	6.84	3.50	1.84	2.88	0.36

WSU Report ROCKWELL 19, 3 August 1978
BCRP900	55.06	14.62	2.27	2.00	10.64	0.19	6.93	3.48	1.86	2.60	0.36

WSU Report ROCKWELL 20,
BCRP900	55.10	14.03	2.24	2.00	10.60	0.19	6.87	3.45	1.82	2.79	0.34

TABLE D-2

1972 VALUES FOR INTERNATIONAL GEOCHEMICAL STANDARDS FOR BASALT

(After Flanagan,[15]
 data for recommended, averages, or magnitudes)

	Andesite	Basalts			
	USGS-AGV-1	CRPG-BR	GSJ-JB-1	USGS-BCR-1	ZGI-UM[1]
Major and minor constituents (%)					
SiO_2	59·00	38·20	52·09	54·50	49·60
Al_2O_3	17·25	10·20	14·53	13·61	16·20
Fe_2O_3	4·51	5·58	2·30	3·68	1·60
FeO	2·05	6·57	6·06	8·80	7·28
MgO	1·53	13·28	7·70	3·46	7·46
CaO	4·90	13·80	9·24	6·92	6·44
Na_2O	4·26	3·05	2·70	3·27	4·64
K_2O	2·89	1·40	1·42	1·70	0·20
H_2O^+	0·81	2·30	1·00	0·77	3·62
H_2O^-	0·16	0·50	0·08	0·80	—
TiO_2	1·04	2·60	1·34	2·20	1·14
P_2O_5	0·49	1·04	0·26	0·36	0·11
MnO	0·097	0·20	0·15	0·18	0·15
CO_2	0·06	0·86	0·10	0·03	1·34
SUM	99·91	99·64	100·03	100·28	99·87
Total Fe as Fe_2O_3	6·76	12·88	9·04	13·40	9·68

(1) Major and minor constituents on moisture-free basis. Total includes: S, 0·03; BaO, 0·03; SrO, 0·03.

Trace elements (ppm, or units shown)

	USGS-AGV-1	CRPG-BR	GSJ-JB-1	USGS-BCR-1	ZGI-UM
Ag (ppm)	0·11	—	—	0·036	0·06
As (ppm)	0·8	—	—	0·70	14
Au (ppb)	0·6	—	—	0·95	5
B (ppm)	5	—	10	5	9
Ba (ppm)	1208	1050	400	675	203
Be (ppm)	3	1	—	1·7	1·3
Bi (ppm)	0·057	—	—	0·050	0·3
Br (ppm)	0·5	—	0·6	0·15	—
C (ppm)	—	—	—	330	—
Cd (ppm)	0·09	—	0·1	0·12	—
Ce (ppm)	63	—	67	63·9	23
Cl (ppm)	110	—	190	50	100
Co (ppm)	14·1	50	30	38	34
Cr (ppm)	12·2	420	417	17·6	123
Cs (ppm)	1·4	—	1	0·95	1·7
Cu (ppm)	60·7	70	52	18·4	45
Dy (ppm)	3·5	—	4·1	6·3	4
Er (ppm)	1·2	—	2·23	3·59	3
Eu (ppm)	1·7	—	1·52	1·94	1·1
F (ppm)	435	—	360	470	250
Ga (ppm)	20·5	20	17	20	15
Gd (ppm)	5·5	—	4·80	6·6	6
Ge (ppm)	1·3	—	—	1·54	1·5
Hf (ppm)	5·2	—	3·5	4·7	3·1
Hg (ppb)	15	—	14	10·7	20
Ho (ppm)	0·6	—	—	1·2	1·5
I (ppm)	—	—	—	<1	—
In (ppm)	0·04	—	—	0·095	0·03
Ir (ppb)	0·011	—	—	0·004	6
La (ppm)	35	85	36	28	8·6
Li (ppm)	12	9	10·2	12·8	70
Lu (ppm)	0·28	—	0·31	0·55	0·4
Mn (ppm)	763	—	—	1406	1125
Mo (ppm)	2·3	3	—	1·1	0·6
N (ppm)	44	—	—	30	—
Nb (ppm)	15	—	—	13·5	10
Nd (ppm)	30	—	25	29	16
Ni (ppm)	18·5	270	139	15·8	57
O (%)	47·24	—	—	45·18	—
Os (ppb)	<3·4	—	—	0·1	—
Pb (ppm)	35·1	—	14	17·6	12
Pd (ppb)	<9·5	—	—	12	—
Pr (ppm)	7	—	—	7	3·5
Pt (ppb)	1	—	—	2	<5
Ra (ppb)	0·69	—	0·72	0·56	—
Rb (ppm)	67	45	41	46·6	12
Re (ppb)	<5	—	—	0·8	—
Rh (ppb)	—	—	—	0·2	—
Ru (ppb)	—	—	—	1	—
S (ppm)	<10	—	50	393	—
Sb (ppm)	4·5	—	0·2	0·69	2
Sc (ppm)	13·4	—	26	33	34
Se (ppm)	<0·14	—	—	0·10	—
Sm (ppm)	5·9	—	4·8	6·6	4
Sn (ppm)	4·2	8	2·3	2·6	1·7
Sr (ppm)	657	1330	433	330	230
Ta (ppm)	0·9	—	4	0·91	0·4
Tb (ppm)	0·70	—	0·5	1·0	1
Te (ppm)	<1	—	—	<1	—
Th (ppm)	6·41	—	0·4	6·0	3
Ti (ppm)	6190	—	—	12760	6840
Tl (ppm)	1	—	—	0·30	0·2
Tm (ppm)	0·4	—	—	0·0	—
U (ppm)	1·88	—	1·8	1·74	1
V (ppm)	125	240	300	399	180
W (ppm)	0·55	—	—	0·40	1
Y (ppm)	21·3	27	—	37·1	20
Yb (ppm)	1·7	4	2·1	3·36	3·5
Zn (ppm)	84	100	83	120	107
Zr (ppm)	225	240	300	190	105