DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Heavy Mineral, Clay Mineral, and Geochemical Data of Surface Sediments from Coastal Northern California Rivers

by

Florence L. Wong[1] and David H. Klise[2]

Open-File Report 86-574

[1] U.S. Geological Survey, Menlo Park, California 94025 [2] Ventura, California

1986

INTRODUCTION

Thirteen streams drain coastal northern California basins (Figure 1a) that range from 250 to 29,000 km^2 in area and have mean annual sediment discharges of 140,000 to 24,000,000 metric tons per year (Table 1). In 1981, bottom and suspended sediment samples were collected from those streams to obtain background information on heavy mineral, clay mineral, and geochemical content. We report the results of these analyses. Other heavy mineral data from the Smith, Klamath, and Eel Rivers and Redwood Creek are available (Day and Richards, 1906; Kulm and others, 1968; Borgeld, 1985; all cited in compilation by Kulm and others, 1986).

REGIONAL SETTING

Coastal northern California streams drain the Coast Ranges and Klamath Mountains. These areas include three major geologic provinces: the Franciscan Complex, the Klamath terranes, and Cenozoic sedimentary and volcanic rocks (Figure 1b).

The Klamath Mountains are underlain by a series of four accreted Paleozoic and Mesozoic terranes. The Eastern Klamath terrane consists of metasedimentary and metavolcanic rocks from an ancient island arc that rested on crust and upper mantle now represented by an ophiolite. The Central Metamorphic terrane is made up of hornblende and mica schist. The Paleozoic and Triassic belt hosts slightly metamorphosed sedimentary and metavolcanic rocks, and marble. The Western Klamath terrane is a collection of amphibolite facies metamorphic rocks, gabbro, peridotite, and calc-alkaline volcanic rocks. Granitic intrusions occur in all the Klamath terranes (Blake and others, 1985a; Irwin, 1985).

The Franciscan complex in the northern California Coast Ranges consists of eastem, central, and coastal belts, each made up of one or more tectonostratigraphic terranes. Eastern belt Franciscan rocks exhibit regional metamorphism to blueschist facies and consist of Jurassic to Upper Cretaceous quartz-mica-lawsonite schist, metavolcanic rocks, metagraywacke, graywacke, alkalic basalt, and gabbro. The central belt Franciscan consists of a Jurassic to Upper Cretaceous melange of sandstone, greenstone, serpentinite, pillow lava, chert, limestone and exotic blocks of blueschist, eclogite, and amphibolite in a matrix of sandstones similar to the contemporaneous Great Valley Sequence. The coastal belt Franciscan includes Upper Cretaceous to Miocene highly disrupted to well-bedded marine sedimentary, volcanic, and prehnite-pumpellyite facies metamorphic rocks and rare blueschist exotic blocks (Blake and others, 1985b).

The Plio-Pleistocene Sonoma Volcanics crop out at the southern end of the northern Coast Ranges. These volcanic rocks include andesite, basalt, and minor rhyolite flows and pyroclastics (Taylor, 1981; Fox, 1983). Isolated Cenozoic sediments occur in the Coast Ranges and Klamath Mountains that consist of marine and continental sandstones, siltstones and shales derived from the Klamath, Franciscan and volcanic rocks (Jennings and others, 1977).

METHODS

Surface samples were taken from the river bottom and/or from the banks 0.5-1.0 km upstream of the mouths using a Van Veen grab sampler or scooped up by hand (Table 2). As many as three samples were taken at each river. Heavy minerals were determined for one sample from each river, clay mineralogy for most samples, and geochemistry for all samples; additional analyses were performed on several replicates as a check of techniques.

Heavy Minerals

Approximately 5-cm^3 subsamples were taken for heavy mineral analyses. The samples were wet sieved to retain the 63-250 μ fraction, which yielded 0.5-5.5 g per sample. Heavy minerals were separated from the light fraction in tetrabromoethane diluted to sp. gr. = 2.89. Samples were weighed before and after separation to determine weight proportions.

The heavy grains were embedded in piccolyte (r.i.=1.52) for permanent mounts. 300-600 grains were counted for one sample from each river. The data are listed in Table 3.

Clay Minerals

Sample preparation for clay mineral analyses by X-ray diffraction is similar to methods used by Hein and others (1976). A fixed amount of talc was added to all samples as an internal standard (Heath and Pisias, 1979). Details of these procedures are given in Klise (1984) so only a brief summary is given here.

Separate X-ray diffractograms taken after Mg-saturation, glycolation, and heating to 550°C identify minerals and yield abundances in the clay fraction. Samples that are Mg saturated and air dried establish the presence of these groups or single species: smectite/chlorite/vermiculite, illite, chlorite/kaolinite, and serpentine. Further treatment with glycol identifies smectite/illite mixed-layer clay, chlorite/vermiculite, and vermiculite alone, and distinguishes kaolinite and chlorite. Final heating isolates illite, chlorite, and serpentine.

Clay mineral proportions are calculated from peak areas (Biscaye, 1965) and by comparison to the talc internal standard. The results for the major mineral groups smectite, illite, and kaolinite + chlorite are listed in Table 4.

Geochemistry

Bulk geochemistry was analyzed by inductively coupled argon plasma-atomic emission spectrometry (ICAP-AES), which is a rapid analysis method that yields semiquantitative data. One gram of -80 mesh (<177 μ) sample is digested in heated acids before spectroscopic analysis (Crock and others, 1983). As many as 50 elements may be detected, but silicon is absent because of the acid treatment. Table 5 lists the results for the 23 major, minor, and trace elements that occur in amounts above the detection limit.

RESULTS

Heavy Minerals

The 63-250 μ heavy mineral fraction is 0.8-30.8% (by weight) of the river samples; the largest amounts come from the Klamath, Smith, and Eel Rivers. By volume, the heavy mineral fraction consists of 37-67% nonopaque monomineralic grains, 8-37% opaque grains, and 17-33% rock fragments (Figure 2a).

The main nonopaque heavy minerals are hornblende, tremolite-actinolite, clinopyroxene, epidote, glaucophane, garnet, lawsonite, zircon, and sphene. The distribution of these minerals is illustrated in Figure 2b; actual values are tabulated in Table 3. The number of primary mineral species increases from north to south. Hornblende, tremolite-actinolite, clinopyroxene, and epidote are the primary heavy minerals from the Smith and Klamath Rivers and Redwood Creek. Glaucophane and garnet are additional components to the heavy mineral suite from the Mad, Eel, and Mattole Rivers. The rivers south of Cape Mendocino include all of these heavy minerals as well as lawsonite and zircon.

Among the nonmetamorphic amphiboles, pleochroic green and brown hornblendes are the primary minerals. The grains are angular fragments with prismatic to blocky cleavage. Rare (<1%) basaltic hornblende is pleochroic to bright red.

Metamorphic amphiboles include tremolite-actinolite and glaucophane. All colorless amphiboles were counted as tremolite. Actinolite is pleochroic pale-green or colorless (parallel to the fast ray x′) to blue-green (parallel to the slow ray z′). Glaucophane is distinctively pleochroic lavender (x′) to deep blue (z′).

Clinopyroxene grains occur as colorless, pale green or pale yellow, slightly elongate and blocky fragments. Blocky, subrounded hypersthene is pleochroic pink (x′) to colorless (z′) and usually mottled by exsolved blebs of clinopyroxene(?).

Epidote is pale yellow to bright yellow-green and anhedral with distinctive moderately high or anomalous blue birefringence. Lawsonite is common as euhedral cleavage fragments displaying zones {100} and {101} on pseudo-rhombic (010) faces with low birefringence and moderate relief.

Garnet occurs as colorless to pale-pink euhedral to anhedral isotropic grains that usually host inclusions. Zircons are colorless singly and doubly terminated crystals. Sphene appears as brown anhedral or sphenoidal crystals.

Rock fragments in the heavy mineral fraction are generally extremely altered grains. Identifiable rock fragments included felty volcanics, greenschist, and fine-grained sediment. Opaque minerals were not separately analyzed.

Clay Minerals

Clay mineral distributions from the rivers are well illustrated by three primary groups: smectite (Ca, Na, Al, Mg, Fe), illite (K, Al), and kaolinite (Al)/chlorite (Mg, Al, Fe) (Figures 2c, 3). The analytical method used does not give absolute values, but does allow descriptions of general relationships among the mineral groups. Except for the larger values from the Klamath River and Redwood Creek, the relative amounts of illite in all the rivers are the same. Relative amounts of smectite increase from north to south and kaolinite/chlorite shows a complementary decrease. These apparent trends are similar to those from clay data reported by Griggs and Hein (1980).

Geochemistry

Geochemical variations of some of the elements among the 13 rivers can be broadly fitted to three patterns (Figures 3, 4): (1) Ti decreases from Smith River to Redwood Creek and increases from Redwood Creek to Russian River, (2) Fe, Mg, Cr, and V decrease from Smith River to Redwood Creek and level off southward, and (3) Na, K, Al, Sr and Ba increase steadily from Smith to Russian Rivers. No regular patterns are discernible for other analyzed elements.

DISCUSSION

The source areas for the coastal northern California rivers define several provenances: (1) the Smith and Klamath Rivers primarily drain Klamath terranes plus central belt Franciscan, (2) the Eel, Mad and Mattole Rivers drain all Franciscan terranes, (3) the small coastal drainages south of Cape Mendocino drain primarily coastal belt Franciscan, and (4) the Russian River drains coastal and central belt Franciscan and Tertiary volcanic areas. Redwood Creek sediments are transitional between provenances 1 and 2.

The Smith River drains a relatively small area of northwestern California and southeastern Oregon that is dominated by the Klamath Western Jurassic belt; a short (~6 km) stretch of central belt Franciscan rocks and Quaternary terrace deposits underlies the mouth. Heavy minerals are 25 wt% of the sample; the nonopaque fraction consists of hornblende, tremolite-actinolite, clinopyroxene, and epidote. The dominant clays are kaolinite/chlorite and illite. Ca, Fe and Mg contents are greater than for any of the other rivers sampled.

The Klamath River has the largest drainage of the all the north coast rivers and the second largest sediment discharge (Table 1). Its tributaries cross all the Klamath terranes; near the mouth it crosses a narrow exposure of central belt Franciscan rocks. The Klamath sample is 31 wt% heavy minerals; nonopaque minerals differ from that of the Smith River only in a greater proportion of tremolite-actinolite. Kaolinite/chlorite and illite are the clays. The bulk chemistry has no unusual values.

The heavy mineral assemblage, kaolinite/chlorite, and dominant elements in both the Smith and Klamath Rivers reflect the metamorphic lithologies of the Klamath terranes. Illite and chlorite are common components of Franciscan sandstones and shales (Griggs and Hein, 1980).

Redwood Creek drains a small valley underlain by eastern belt Franciscan rocks and small outcrops of central belt Franciscan rocks. The heavy mineralogy includes the northernmost appearance of glaucophane in the coastal northern California rivers. The clays are split between kaolinite/chlorite and illite; no smectite was detected. Total analyzed elements is the lowest of all samples; K and Mg are especially depleted.

The Eel, Mad, and Mattole Rivers drain coastal, central, and eastern belt Franciscan terranes. The Eel River has an average annual discharge of almost 24,000,000 metric tons per year, almost three times that of the Klamath (Table 1). Glaucophane and garnet are common nonopaque heavy minerals in these river samples; they make up 11 wt% of the Eel sample. Illite is the dominant clay with slightly less kaolinite/chlorite; smectite is a minor component. The bulk geochemistry of the samples from the three rivers differs only in the lesser amount of Al out of the Eel River.

The Ten Mile, Noyo, Big, Navarro, Garcia, and Gualala Rivers lie in small basins between the Russian River basin and the coast that drain predominantly central belt Franciscan rocks. Additionally, the Garcia and Gualala Rivers cross a limited exposure of the Upper Cretaceous sedimentary rocks of the Point Arena terrane (Howell and others, 1977; Blake and others, 1982).

Heavy minerals in these streams are a minor component of the sediment (5% or less) but consist of some distinctive minerals (glaucophane, lawsonite, garnet, zircon and sphene) that are attributable to blueschists in the Franciscan. Unlike the streams to the north, illite and smectite dominate the clay fraction and, consequently, K, Ca, and Na are enriched.

The Russian River has the third largest drainage basin and the largest sediment discharge between Cape Mendocino and San Francisco Bay (Table 1). It crosses central and coastal belt Franciscan, Tertiary volcanics, serpentinite, and Tertiary sedimentary or siliciclastic deposits. Exotic blocks of blueschist and eclogite are exposed near the mouth of the river. The heavy minerals, clay mineralogy and major elements of the Russian River are similar to those for the small coastal streams described in the previous paragraph. The amount of Ti is the greatest of all of the sampled rivers and may be partially attributable to sphene.

ACKNOWLEDGMENTS

This report was improved by reviews by Michael E. Field and James V. Gardner. Michael E. Field, James V. Gardner, and Robert Hall helped collect the samples. Anne Jennings conducted the heavy mineral separations.

REFERENCES

Biscaye, P.E., 1965, Mineralogy and sedimentation of Recent deep-sea clay in the Atlantic ocean and adjacent seas and oceans: Geological Society of America Bulletin, v. 76, p. 803-832.

Blake, M.C., Jr., Howell, D.G., and Jones, D.L., 1982, Preliminary tectonostratigraphic terrane map of California: U.S. Geological Survey Open-File Report 82-593, 9 p., 3 maps, scale 1:750,000.

Blake, M.C., Jr., Engebretson, D.C., Jayko, A.S., and Jones, D.L., 1985a, Tectonostratigraphic terranes in southwest Oregon, *in* Howell, D.G., ed., Tectonostratigraphic terranes of the circum-Pacific region, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, v. 1: Houston, Circum-Pacific Council for Energy and Mineral Resources, p. 147-157.

Blake, M.C., Jr., Jayko, A.S., and McLaughlin, R.J., 1985b, Tectonostratigraphic terranes of the northern Coast Ranges, California, *in* Howell, D.G., ed., Tectonostratigraphic terranes of the circum-Pacific region, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, v. 1: Houston, Circum-Pacific Council for Energy and Mineral Resources, p. 159-171.

Borgeld, J.C., 1985, Holocene stratigraphy and sedimentation on the northern California continental shelf: Seattle, Wash., University of Washington, Ph.D. dissertation, 177 p.

Crock, J.G., Lichte, F.E., and Briggs, P.H., 1983, Determination of elements in National Bureau of Standards' geological reference materials SRM 278 obsidian and SRM 688 basalt by inductively coupled argon plasma-atomic emission spectrometry: Geostandards Newsletter, v. 7, n. 2, p. 335-340.

Day, D.T., and Richards, R.H., 1906, Useful minerals in the black sands of the Pacific slope, *in* Mineral Resources of the United States, 1905: U.S. Geological Survey, p. 1175-1221.

Fox, K.F., Jr., 1983, Tectonic setting of late Miocene, Pliocene, and Pleistocene rocks in part of the Coast Ranges north of San Francisco, California: U.S. Geological Survey Professional Paper 1239, 33 p.

Griggs, G.B. and Hein, J.R., 1980, Sources, dispersal, and clay mineral composition of fine-grained sediment off central and northern California: Journal of Geology, v. 88, p. 541-566.

Heath, G.R. and Pisias, N.G., 1979, A method for the quantitative estimation of clay minerals in north Pacific deep-sea sediments: Clays and Clay Minerals, v. 27, p. 175-184.

Hein, J.R., Scholl, D.W., and Gutmacher, C.E., 1976, Neogene clay minerals of the far NW Pacific and southern Bering Sea, *in* Bailey, S.W., ed., International Clay Conference, Mexico City, 1975, Proceedings: Wilmette, Ill., Applied Publishing Ltd., p. 71-80.

Howell, D.G., Vedder, J.G., McLean, H., Joyce, J.M., and Clarke, S.H., Jr., 1977, Review of Cretaceous geology, Salinian and Nacimiento blocks, Coast Ranges of central California, *in* Howell, D.G., Vedder, J.G., and McDougall, K., eds., Cretaceous geology of the California Coast Ranges, west of the San Andreas fault, Pacific Coast Paleogeography Field Guide 2: Los Angeles, Society of Economic Paleontolo-

gists and Mineralogists, p. 1-46.
Irwin, W.P., 1985, Age and tectonics of plutonic belts in accreted terranes of the Klamath Mountains, California and Oregon, *in* Howell, D.G., ed., Tectonostratigraphic terranes of the circum-Pacific region, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, v. 1: Houston, Circum-Pacific Council for Energy and Mineral Resources, p. 187-199.
Jennings, C.W., Strand, R.G., and Rogers, T.H., compilers, 1977, Geologic map of California: California Division of Mines and Geology, scale 1:750,000.
Klise, D.H., 1984, Modern sedimentation on the California continental margin adjacent to the Russian River: San Jose, California, San Jose State University, M.S. thesis, 120 p.
Kulm, L.D., Scheidegger, K.F., Byrne, J.V., and Spigai, J.J., 1968, A preliminary investigation of the heavy mineral suites of the coastal rivers and beaches of Oregon and northern California: Ore Bin, v. 30, no. 9, p. 165-184.
Kulm, L.D., Peterson, C.D., and Stribling, M.C., 1986, Inventory of heavy minerals and metals, southern Washington, Oregon, and northern California shelf and coastal region: Oregon Department of Geology and Mineral Industries Open-File Report O-86-10, 111 p.
Taylor, G.C., 1981, Calistoga geothermal resource area: California Geology, v. 24, p. 208-217.
U.S. Geological Survey, 1959a, San Francisco Bay, scale 1:1,000,000.
U.S. Geological survey, 1959b, Mount Shasta, scale 1:1,000,000.

Table 1. Coastal northern California river drainage basins and discharge rates (from Griggs and Hein, 1980). Distance is *straight-line distance from the Smith River.*

River	Distance (km)	Drainage Basin Area (sq km)	Ave/Est Sediment Discharge (1000 metric tons/yr)
Smith	0	1,577	~680
Klamath	42	29,339	8,211
Redwood Crk	70	420	1,620
Mad	110	1,256	2,512
Eel	144	8,638	23,979
Mattole	180	622	1,600
Ten-Mile	266	290	~140
Noyo	280	275	~140
Big	294	446	~140
Navarro	306	785	~210
Garcia	332	254	~140
Gualala	354	901	~630
Russian	388	3,465	2,342

Table 2. Sample identification number, location, and analyses performed for coastal northern California river samples.
**H heavy minerals, C clay minerals, G geochemistry.*

Field No.	Collection Date	River	Collection Site	Analyses*
810110	6 Jul 81	Garcia	mid-river	H C G
810210	"	Navarro	N side	H C G
810220	"		mid-river	H C G
810230	"		S side	C G
810310	"	Big	N side	C G
810320	"		mid-river	H C G
810330	"		S side	C G
810410	7 Jul 81	Noyo	N side	H C G
810420	"		mid=river	C G
810510	"	Ten-Mile	N bank bridge	H C G
810520	"		S bank	C G
810610	8 Jul 81	Mattole	N bank	C G
810611	"		(replicate)	G
810620	"		S bank #1	H G
810630	"		S bank #2	C G
810710	"	Eel	mid-river	C G
810720	"		S bank	H C G
810810	10 Jul 81	Mad	N side	C G
810820	"		mid-river	C G
810830	"		S and mid-river	H C G
810910	9 Jul 81	Redwood Crk	N bank	H C G
811010	"	Klamath	N and mid-river	C G
811011	"		(replicate)	G
811020	"		S side #1	H C G
811030	"		S side #2	C G
811110	"	Smith	N bank #1	C G
811120	"		N bank #2	H G
811130	"		S bank	C G
811131	"		(replicate)	G
811210	Apr 81	Gualala	N bank	H C G
610RR	3 Dec 80	Russian		H C G
620RR	"			H C G
630RR	"			H C G

Table 3. Coastal northern California rivers heavy mineral data (F. Wong, analyst). Cnt count, Nopq nonopaque, Opq opaque, RF rock fragments, Unk unknown, Alt altered, Volc volcanic, Met metamorphic, Fine fine-grained, Nmet nonmetamorphic, B-g blue-green, Trem tremolite, Glau glaucophane, Opx orthopyroxene, Cpx clinopyroxene, Epi epidote, Laws lawsonite, Sph sphene, Zir zircon, Grnt garnet, Apat apatite, Oth others. Blank = not detected.

Volume % of heavy minerals in 63-250 micron fraction

River	Field#	Wt%	Cnt	Nopq	Opq	RF	Unk	Rock Fragments Alt	Volc	Met	Fine
Smith	811120	25.0	317	64	13	18	4	12	1	1	3
Klamath	811020	30.8	300	67	8	23	2	18	2	3	<1
Redwood Crk	810910	2.1	602	38	28	33	1	6	2	22	2
Mad	810830	7.2	393	54	15	29	2	22	4	1	1
Eel	810720	10.7	393	34	37	27	2	7	3	3	14
Mattole	810620	1.7	486	55	24	18	3	12	2	3	<1
Ten-Mile	810510	2.0	433	56	23	17	4	16	<1	<1	
Noyo	810410	3.6	446	54	25	17	4	16		<1	<1
Big	810320	1.1	556	38	32	27	3	24	<1	<1	<1
Navarro	810220	3.6	603	37	34	24	5	22	<1	<1	<1
Garcia	810110	0.8	477	48	25	24	3	21	<1	2	<1
Gualala	811210	5.3	510	44	28	26	2	23	2	1	<1
Russian	*	4.9	560	45	28	24	3	22	2	<1	<1

* values are average of 3 samples 610RR, 620RR, and 630RR.

Nonopaques as % of nonopaques less mica

River	Amphiboles- - - - - Nmet	B-g	Trem	Glau	Opx	Cpx	Epi	Laws	Sph	Zir	Grnt	Apat	Oth
Smith	41	8	12		3	25	11						
Klamath	29	37	7		4	13	8		1				
Redwood Crk	29	26	4	2	1	9	19		4		<1	<1	1
Mad	31	11	4	18	<1	11	19		5		1		
Eel	27	5	15	18	<1	20	6		5	1	3		
Mattole	12	2	2	2	2	20	31		6	4	16	2	
Ten-Mile	14	3	5	10	<1	22	20	5	7	5	6	1	
Noyo	18	3	7	1	2	10	19	<1	3	13	23	<1	<1
Big	13	2	2	<1	4	12	35	1	3	9	16		<1
Navarro	17	10	9	13	<1	14	17	11	2	1	3	<1	2
Garcia	24	2	5	12	<1	28	11	7	2	3	4	<1	
Gualala	21	<1	5	14	<1	22	9	22	1	2	3		
Russian	19	6	6	20	1	24	13	6	<1	<1	2	<1	2

Table 4. Coastal northern California clay mineral data in weight % (D. Klise, analyst).

Field No.	River	Smectite	Illite	Kaolinite+ Chlorite
810110	Garcia	37.0	33.3	29.6
810210	Navarro	45.8	32.1	22.1
810220		46.7	30.1	23.2
810230		44.7	31.2	24.1
810310	Big	42.6	32.6	24.8
810320		38.0	36.5	25.5
810330		35.7	34.9	29.4
810410	Noyo	29.7	42.4	27.9
810420		35.1	35.1	29.8
810510	Ten-Mile	37.1	30.9	32.0
810520		32.1	28.6	39.3
810610	Mattole	25.8	33.4	40.8
810630		13.2	35.5	51.3
810710	Eel	25.9	32.8	41.4
810720		18.1	38.9	43.0
810810	Mad	20.4	36.8	42.7
810820		19.3	38.3	42.4
810830		22.7	38.8	38.5
810910	Redwood Cr	0.0	57.4	42.6
811010	Klamath	6.1	41.1	52.8
811020		6.8	49.4	43.7
811030		6.3	42.5	51.1
811110	Smith	7.0	36.8	56.2
811130		8.1	37.8	54.1
811210	Gualala	47.7	30.2	22.1
*	Russian	44.0	25.0	31.0

* average of three samples 610RR, 620RR, 630RR from Klise (1984, p. 120)

Average for each river

Smith	8	37	55
Klamath	6	44	49
Redwood Crk	0	57	43
Mad	21	38	41
Eel	22	36	42
Mattole	20	34	46
Ten-Mile	35	30	36
Noyo	32	39	29
Big	39	35	27
Navarro	46	31	23
Garcia	37	33	30
Gualala	48	30	22
Russian	44	25	31

Table 5. Coastal northern California rivers geochemical data (P. Briggs, USGS, Denver, Colorado, analyst).

	(wt%)								(ppm)														
no.	Al	Fe	Mg	Ca	Na	K	Ti	P	Ba	Ce	Co	Cr	Cu	La	Li	Mn	Nd	Ni	Sc	Sr	V	Y	Zn
810110	6.8	2.8	1.00	1.30	2.1	1.4	0.30	0.06	750	40	9	48	20	16	29	370	20	32	11	300	86	12	55
810210	4.8	1.9	0.88	1.10	2.1	1.4	0.27	0.03	610	20	11	100	14	11	19	320		46	8	190	53		34
810220	5.6	2.8	0.89	1.10	2.1		0.25	0.06	630	30	13	52	15	16	25	560	20	39	11	220	70	11	47
810230	5.1	2.7	0.92	0.95	1.9		0.27	0.06	540	30	14	52	18	15	27	570	20	36	10	210	70	11	46
810310	5.1	2.0	0.76	0.74	2.1	0.9	0.20	0.05	760	20	11	49	16	13	25	210		32		190	57	9	42
810320	5.7	2.1	0.76	0.65	2.2	0.5	0.23	0.05	620	30	10	48	17	13	25	230	10	31	10	210	62	9	46
810330	6.6	2.6	0.95	0.76	2.4	2.8	0.27	0.05	620	40	12	59	23	16	30	290	20	39	12	230	73	11	60
810410	7.0	3.5	1.40	0.64	2.8	1.3	0.37	0.05	470	40	16	74	36	23	52	330	30	47	16	170	110	16	83
810420	5.1	1.7	0.54	0.49	1.9	0.5	0.18	0.03	680	10	10	34	17	11	24	220	10	20		200	49		39
810510	7.3	4.2	1.30	1.00	2.6	1.3	0.42	0.09	840	40	16	61	35	18	29	850	20	32	17	370	130	14	72
810520	4.6	1.6	0.60	2.30	2.0	0.7	0.14	0.04	620	20	5	29	7	9	24	310	30	18		360	42		25
810610	5.9	2.2	0.80	0.77	1.9	0.9	0.21	0.04	700	20	90	45	21	13	26	330	20	32	9	230	66		47
810611	5.6	2.1	0.77	0.74	1.7	0.2	0.21	0.04	660	20	10	42	19	12	26	330		33	9	220	64		43
810620	6.6	2.9	1.00	0.97	2.2	1.1	0.29	0.05	750	30	10	53	23	17	29	430	10	32	11	260	81	10	56
810630	6.7	2.9	1.00	0.84	2.1	0.7	0.26	0.05	690	30	11	54	26	17	33	430	20	36	11	240	77	11	60
810710	4.7	2.7	1.10	0.90	1.6	0.4	0.23	0.05	580	20	11	62	23	11	25	600	10	50	11	140	74	10	47
810720	3.8	2.3	0.99	0.70	1.3		0.19	0.04	340	20	10	63	19	10	23	480		47	9	97	58	9	41
810810	5.4	3.0	1.70	1.00	1.7	0.3	0.24	0.05	350	20	14	95	24	11	28	510	10	78	12	93	87	11	55
810820	5.6	3.2	1.80	1.20	1.9	0.6	0.27	0.05	380	30	13	110	27	13	29	570	20	81	14	100	95	11	57
810830	4.5	2.6	1.50	0.91	1.6		0.20	0.05	330	30	15	77	21	9	24	530	20	74	10	89	73	9	46
810910	4.0	2.4	0.86	0.41	1.2	0.1	0.12	0.04	230	20	9	50	16		30	370		34		41	60		51
811010	3.9	2.4	2.30	1.10	1.1	0.2	0.15	0.04	280	20	14	140	20		18	420		140	10	100	67		40
811011	4.4	2.7	2.60	1.20	1.3	0.3	0.10	0.04	330	10	15	150	23		20	470		160	12	110	75		46
811020	4.9	3.1	2.80	1.60	1.4	0.1	0.21	0.04	350	20	16	190	24	8	21	530	20	160	14	120	92	9	49
811030	4.6	2.9	2.70	1.40	1.3	0.3	0.21	0.04	340	20	16	200	23	8	18	500		140	13	120	86	9	47
811110	5.1	4.8	6.10	3.30	1.5		0.31	0.03	160		33	520	34		11	750	10	400	26	120	140	12	49
811120	5.2	4.4	6.40	2.10	1.5	0.7	0.29	0.04	250	20	36	430	31		20	690	20	470	20	120	120	11	67
811130	5.1	4.9	6.40	2.50	1.3		0.34	0.04	300	20	37	810	33	9	17	720	10	490	23	120	130	12	65
811131	5.1	5.0	6.50	2.60	1.3		0.35	0.04	290	20	38	720	33	8	18	740		490	23	120	140	12	79
811210	5.9	3.1	1.30	1.80	1.8	0.3	0.31	0.06	530	20	14	80	27	12	24	540	10	40	15	200	98	13	51
610RR	7.5	3.7	2.30	1.00	3.2	1.2	0.44		500	20	22	200	37	24	38	630		200	16	150	120	15	77
620RR	5.1	2.8	1.40	1.10	2.0		0.34		320	20	15	100	20	18	25	670		100	12	110	87	11	48
630RR	5.4	3.2	1.60	1.40	2.0	0.5	0.38		340	20	17	100	21	18	28	790		140	14	130	90	13	55

Average for each river

Smith 4	5.1	4.8	6.35	2.63	1.4	0.7	0.32	0.04	250	20	36	620	33	9	17	725	13	463	23	120	133	12	65
Klam 4	4.5	2.8	2.60	1.33	1.3	0.2	0.17	0.04	325	18	15	170	23	8	19	480	20	150	12	113	80	9	46
Redwd	4.0	2.4	0.86	0.41	1.2	0.1	0.12	0.04	230	20	9	50	16		30	370		34		41	60		51
Mad 3	5.2	2.9	1.67	1.04	1.7	0.5	0.24	0.05	353	27	14	94	24	11	27	537	17	78	12	94	85	10	53
Eel 2	4.3	2.5	1.05	0.80	1.5	0.4	0.21	0.05	460	20	11	63	21	11	24	540	10	49	10	119	66	10	44
Matt 4	6.2	2.5	0.89	0.83	2.0	0.7	0.24	0.05	700	25	30	49	22	15	29	380	17	33	10	238	72	11	52
10Mi 2	6.0	2.9	0.95	1.65	2.3	1.0	0.28	0.07	730	30	11	45	21	14	27	580	25	25	17	365	86	14	49
Noyo 2	6.1	2.6	0.97	0.57	2.3	0.9	0.28	0.04	575	25	13	54	27	17	38	275	20	34	16	185	80	16	61
Big 3	5.8	2.2	0.82	0.72	2.2	1.4	0.23	0.05	667	30	11	52	19	14	27	243	15	34	11	210	64	10	49
Nava 3	5.2	2.5	0.90	1.05	2.0	1.4	0.26	0.05	593	27	13	68	16	14	24	483	20	40	10	207	64	11	42
Garcia	6.8	2.8	1.00	1.30	2.1	1.4	0.30	0.06	750	40	9	48	20	16	29	370	20	32	11	300	86	12	55
Guala	5.9	3.1	1.30	1.80	1.8	0.3	0.31	0.06	530	20	14	80	27	12	24	540	10	40	15	200	98	13	51
Russ 3	6.0	3.2	1.77	1.17	2.4	0.9	0.39	0.00	387	20	18	133	26	20	30	697	0	147	14	130	99	13	60

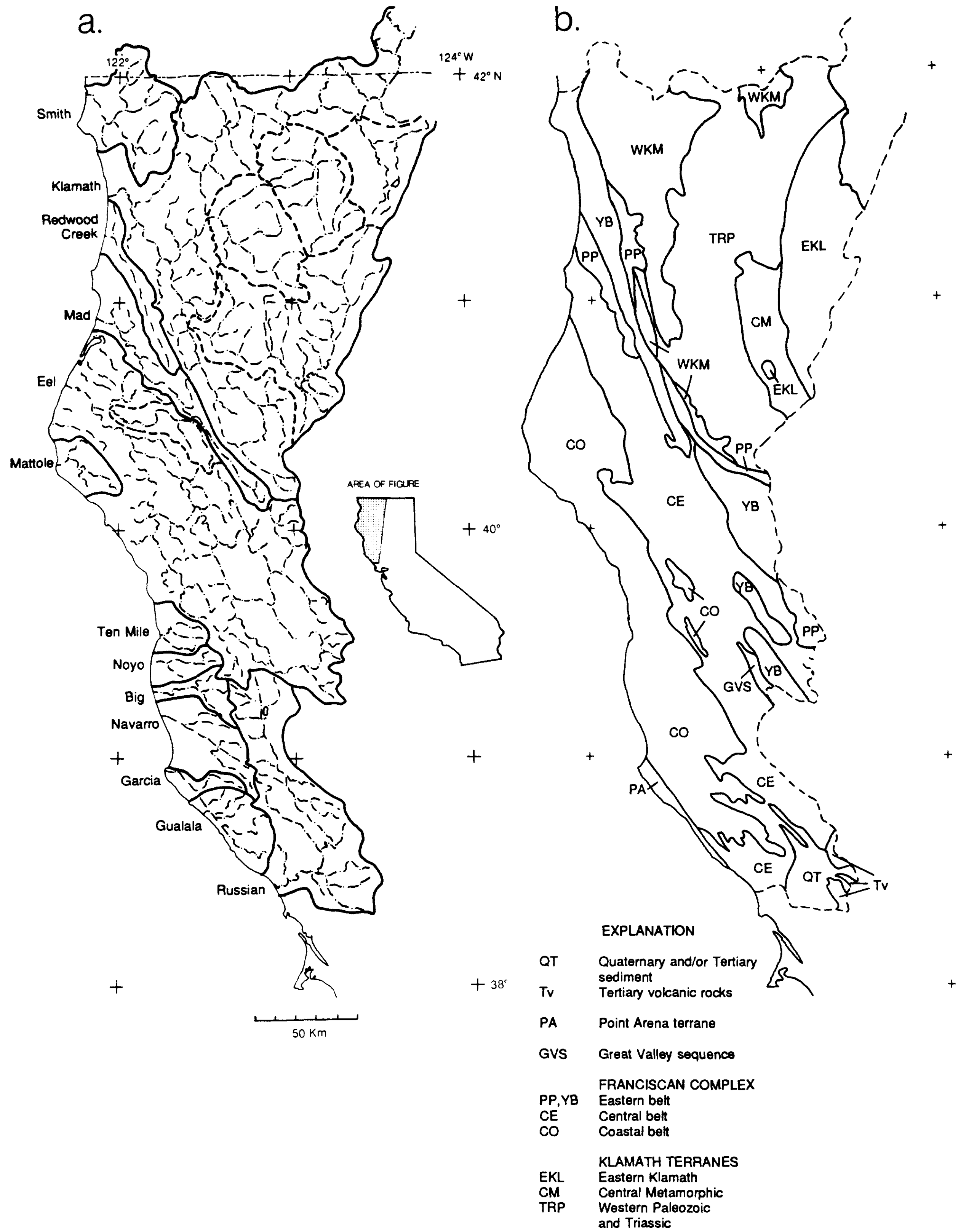

Figure 1. Maps of northwestern California. a. Drainage basins (derived from U.S. Geological Survey, 1959a, 1959b). b. Generalized geologic map (after Jennings and others, 1977; Blake and others, 1982; and Irwin, 1985).

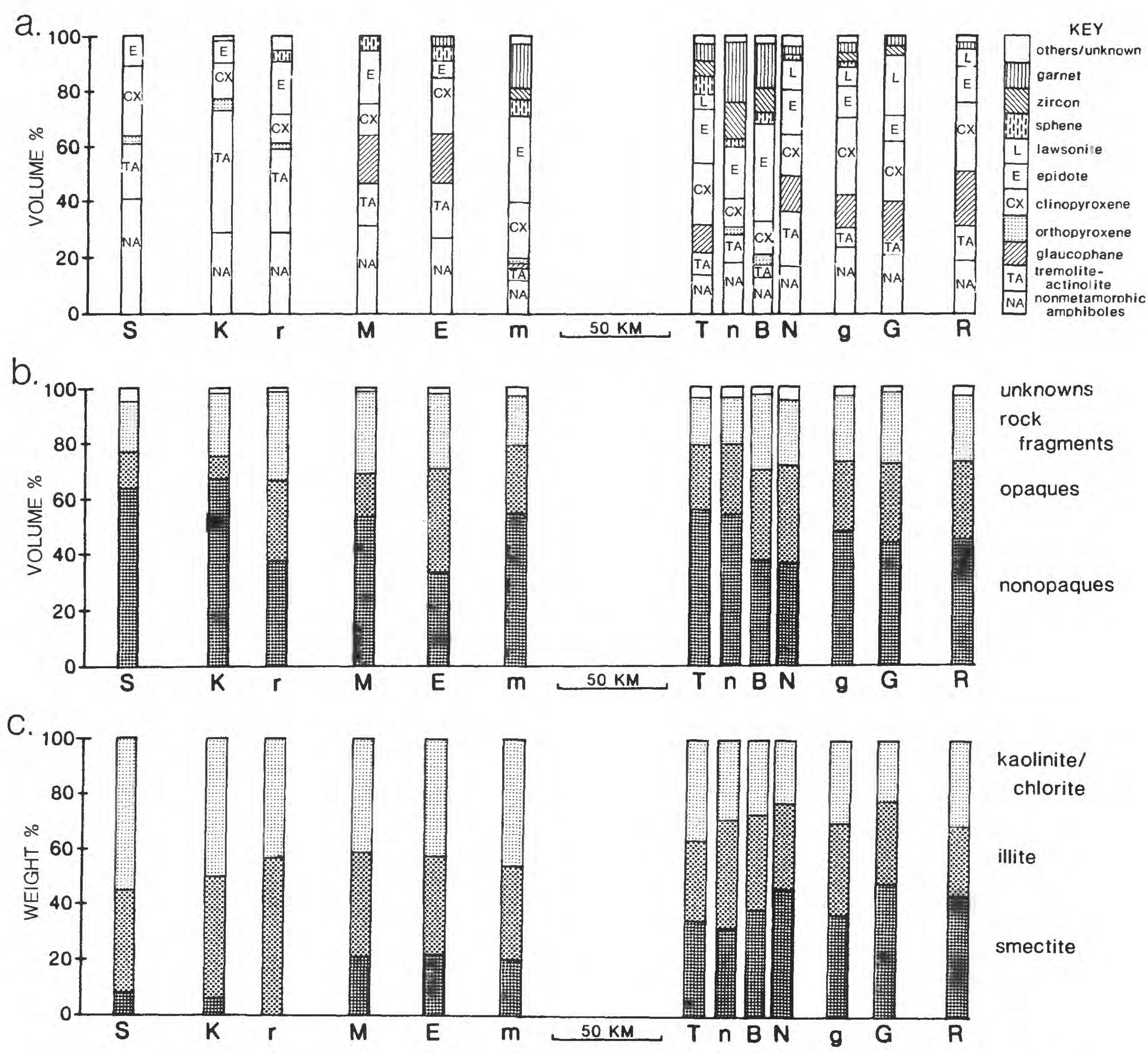

Figure 2. Histograms of a. heavy minerals in 63-250 μ fraction, b. nonopaque heavy minerals in 63-250 μ fraction, and c. clay minerals in coastal northern California rivers. Distance from north to south is plotted along the abscissa. Rivers: S Smith, K Klamath, r Redwood Creek, M Mad, E Eel, m Mattole, T Ten Mile, n Noyo, B Big, N Navarro, g Garcia, G Gualala, R Russian.

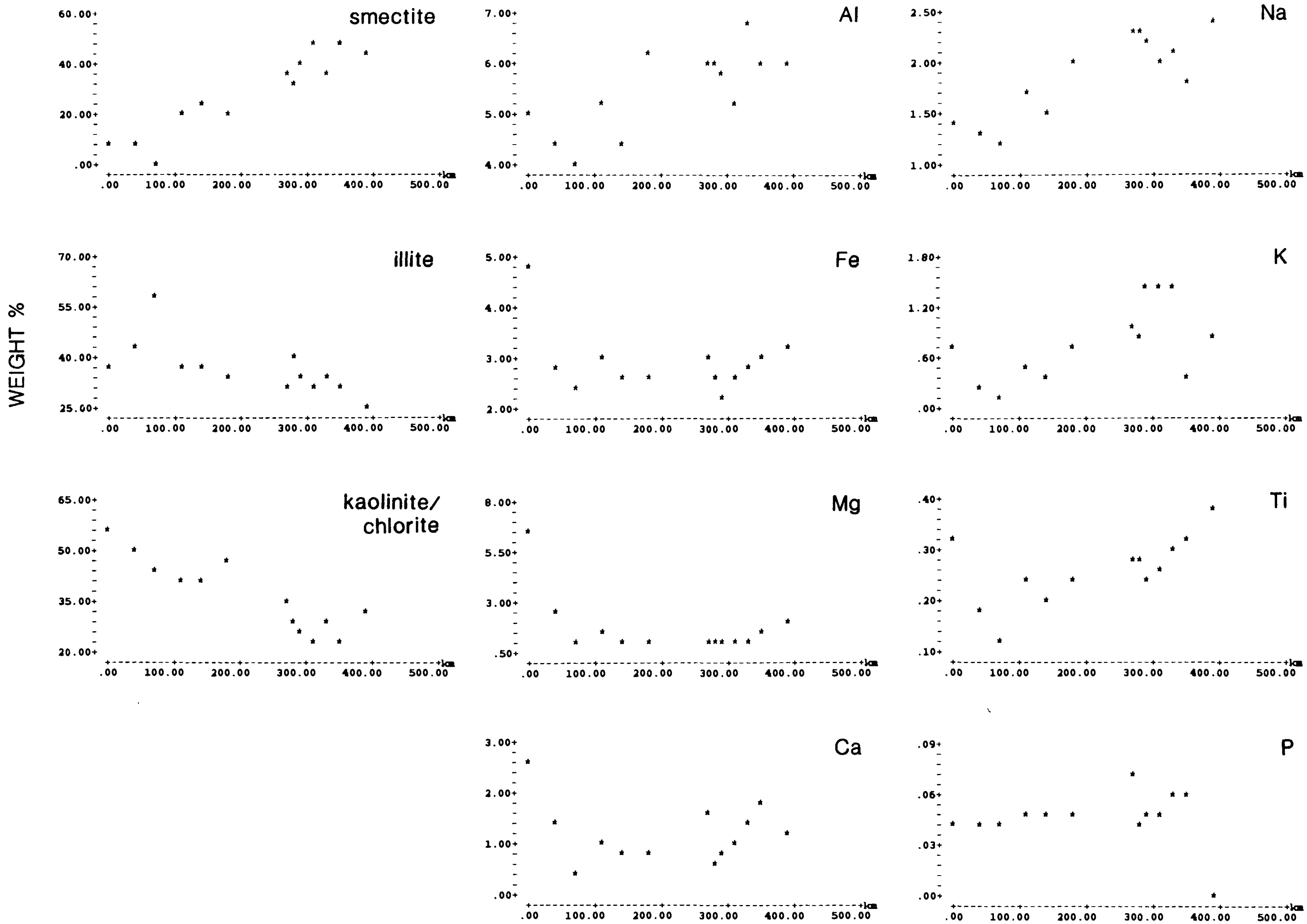

Figure 3. Clay mineral and major element abundance in coastal northern California rivers. Distance south from Smith River is plotted along the abscissa.

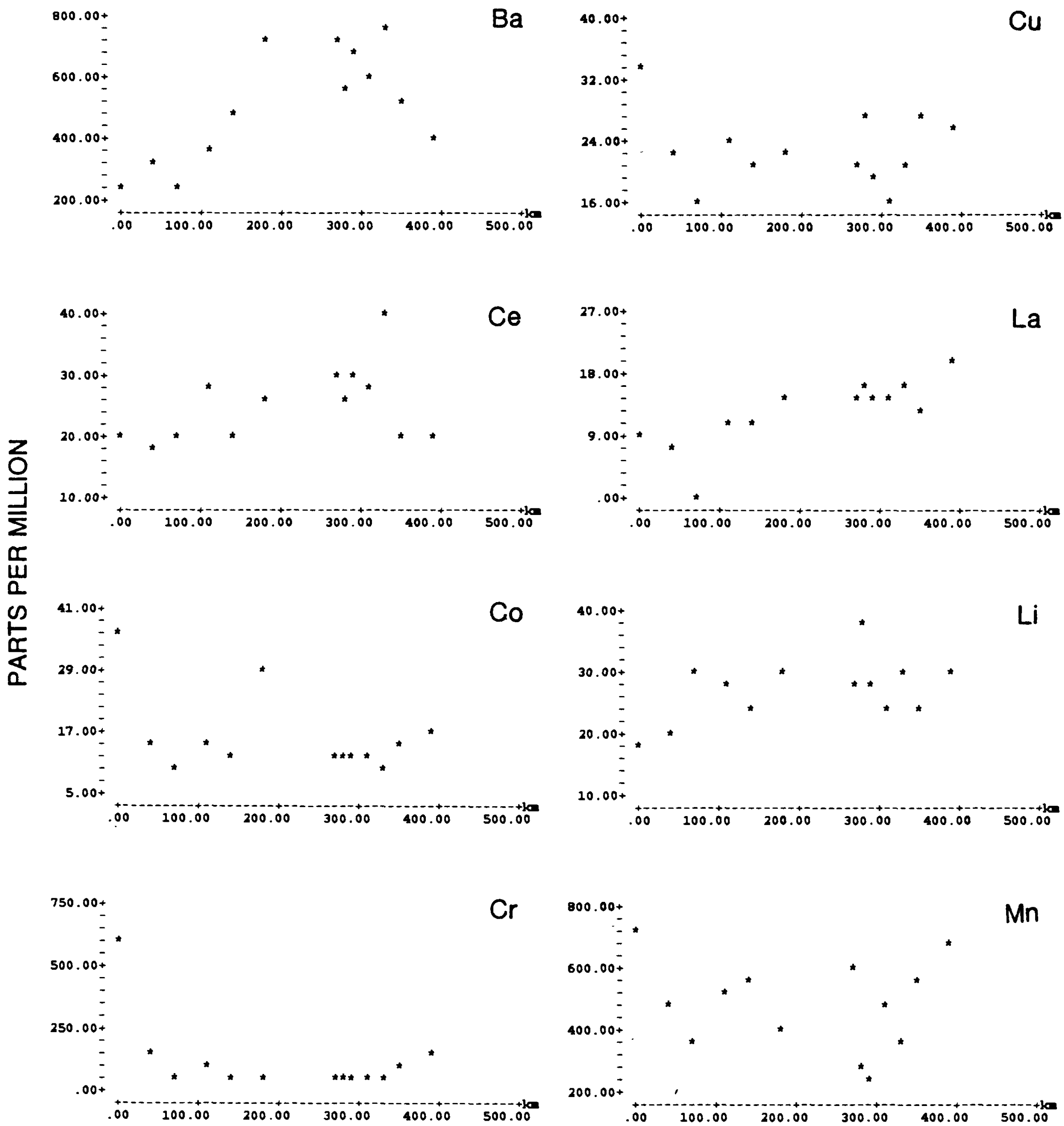

Figure 4a. Minor element abundances in coastal northern California rivers. Abscissa as in Figure 3.

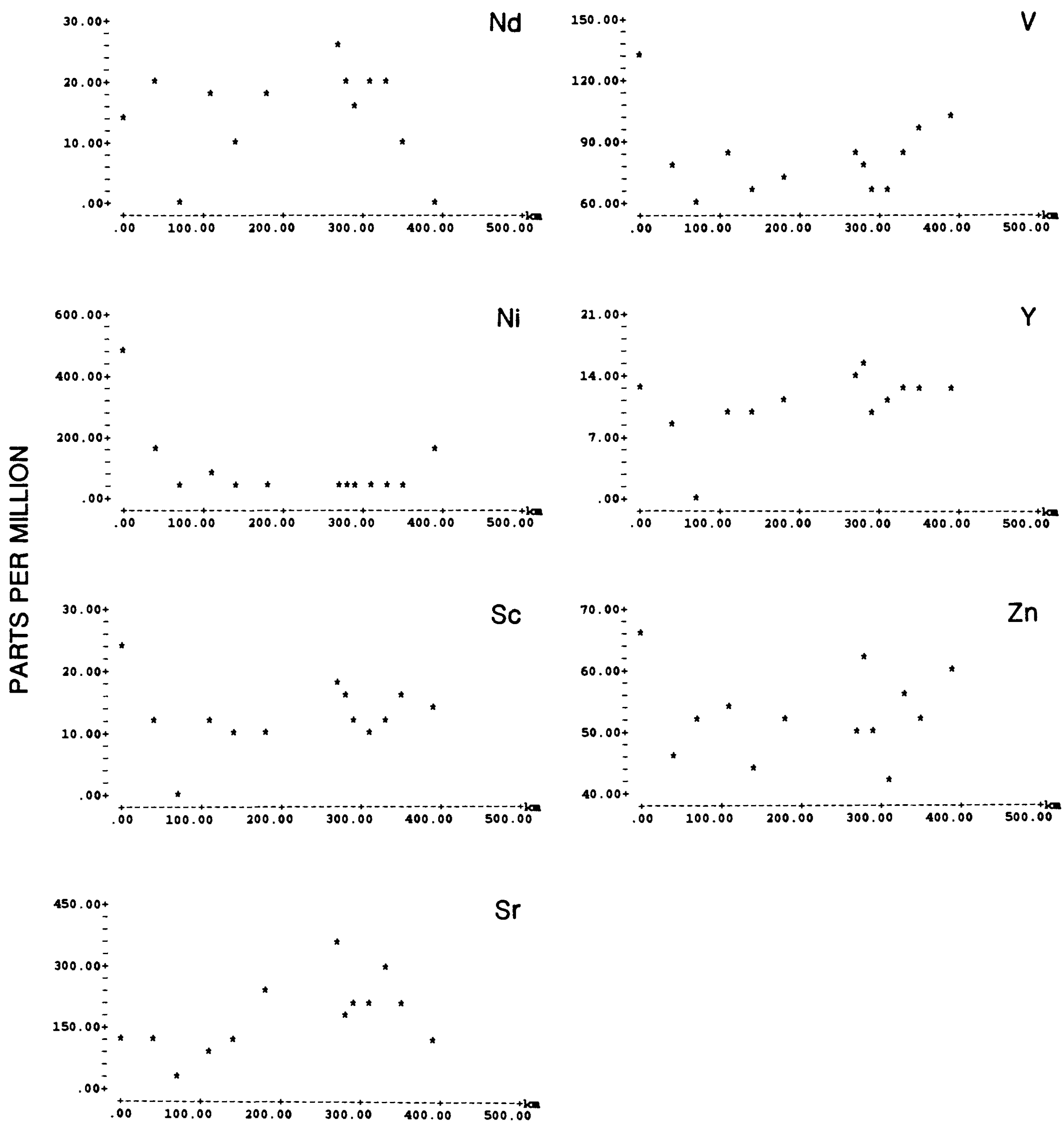

Figure 4b. Minor element abundances in coastal northern California rivers (continued).