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Distribution of Selected Elements in Surficial Marine Sediments of the Northern Gulf of Mexico Continental Shelf and Slope

By Charles W. Holmes

U. S. Geological Survey

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2. Distribution of selected elements in surficial marine sediments of the northern Gulf of Mexico continental shelf and slope, by Charles W. Holmes. 25 p., 19 figs., 4 tables. USGS, University of Corpus Christi, Corpus Christi, Texas (P.O. Box 6732), 78411.

3. Northeastern United States regional aeromagnetic maps, by Isidore Zietz, Francis Gilbert, and John R. Kirby. 13 sheets, scale 1:250,000.

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DISTRIBUTION OF SELECTED ELEMENTS IN SURFICIAL MARINE SEDIMENTS OF THE NORTHERN GULF OF MEXICO CONTINENTAL SHELF AND SLOPE

By Charles W. Holmes

Abstract

Analyses for barium, beryllium, boron, calcium, cobalt, chromium, copper, iron, lanthanum, magnesium, manganese, molybdenum, niobium, nickel, lead, scandium, tin, strontium, titanium, vanadium, yttrium, zinc, and zirconium were performed on 1,304 sediment samples from the continental shelf and slope of the northern Gulf of Mexico. Approximately 40 percent of the samples were collected in two relatively small regions, one seaward of Galveston, Texas, between long. 94° and 95° W. and the other around the Dry Tortugas on the south Florida shelf. The remaining samples represent a broad reconnaissance survey extending from the Rio Grande to the Florida Keys.

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In general these elements are most abundant in the sediments on the continental slope, on the shelf of south Texas and central Louisiana, and in the lower part of the DeSoto Canyon, where sediments are presently accumulating. They are least abundant in the sediments on the central shelf seaward of Galveston, Texas, and on the south Florida shelf. In the continental shelf area seaward of Galveston Bay, relict sediments now exposed at the surface were subject to subaerial weathering during the Pleistocene. The sediments of the south Florida shelf are predominantly carbonates and are low in most elements analyzed with the exception of calcium, magnesium, and strontium. On the continental slope southeast of Galveston and in the central and lower sections of the DeSoto Canyon, the sediments contained the highest amounts of iron and manganese. These concentrations were apparently produced by migration within the sediment column and subsequent precipitation in the surface layers. On the northwestern shelf, barium concentrations within the sediments are nearly twice the reported concentration of other sediments from similar environments. This concentration may be the result of the extensive use of barite mud in drilling in the southwestern section of the United States during the past century.

The semiquantitative determinations of these elements establish base data for future environmental and geochemical studies.

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Introduction

The currently increasing quantity of waste discharged into coastal waters contains trace metals; these metals present a potential hazard to marine organisms and subsequently to man. If the potential hazard to the coastal ecological systems is to be evaluated, information is required on the toxicity of the metallic and other elements at specific levels of concentration, and the rate at which these levels are being approached. To evaluate this rate, the current levels of concentrations must be established, to which subsequently determined levels can be compared. Maps in this report show distribution of concentrations of certain elements in surficial sediments on the continental shelf of the Gulf of Mexico. These data can serve as base for later determining rates of change and for studies of the processes by which chemical elements are transported and concentrated in the marine environment.

I wish to acknowledge the help and support of Dr. Robert E. Stevenson and Mr. John R. Grady, U.S. Bureau of Commercial Fisheries, who made the sample material available to the U.S. Geological Survey for trace element analysis. The spectrographic analyses were done by E. L. Mosier, K. C. Watts, J. Curray, J. Motooka, and E. F. Cooley, U.S. Geological Survey. I also wish to thank R. E. Hunter, Ray G. Martin and L. E. Garrison for critical reading of the manuscript.

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Sediments of the Continental Shelf and Slope

The continental margin of the northern Gulf of Mexico can be divided into a western and a southern sedimentary province by a boundary zone in the vicinity of the DeSoto Canyon in the northeastern Gulf (fig. 1). In the western province, the continental margin is composed of thick clastic deposits ranging in age from Jurassic (?) to Holocene. The continental shelf in this region was formed by the coalescing of three major delta systems--the Rio Grande, the Colorado-Brazos, and the Mississippi. The original structural attitudes of these sediments have been modified by salt intrusions which have contributed significantly to the topography of the region, particularly on the continental slope.

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The complex sedimentary patterns on the surface of the shelf and upper slope in the western province (fig. 1) are the result of presently active sedimentological regimes. Curray (1960) has shown that Holocene muds are not being deposited far off shore except in the Mississippi River Delta area and in an area of semipermanent convergence on the western part of the shelf, centered approximately 60 nautical miles east-southeast of Corpus Christi, Texas. A plume of Holocene material also parallels the coastline from the mouths of the Colorado and Brazos Rivers to a point approximately 30 miles east of Corpus Christi. The remainder of the shelf surface, west of the DeSoto Canyon, is covered by alternating sand, silt, and clay which are presumed to be relict deposits. Many banks on the outer edge of the continental shelf are principally the surface expressions of salt intrusions. Many of these banks have been capped by calcareous algal and coral deposits.

In the southern province, southeast of the axis of the DeSoto Canyon, the continental shelf is predominantly a carbonate platform. The steep scarp of this platform appears to be the result of Cretaceous reef growth, behind which the continental shelf has been formed by prograding and upbuilding during post-Cretaceous time (Antoine and others, 1967). Carbonate deposits in the northern section of the platform are covered by a thin veneer of siliceous sands, silts, and clays. In the south, the outer shelf is almost entirely covered by carbonate sediment whereas the inner shelf has a thin veneer of quartz sand.

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Collection and Analysis of Geochemical Data

Sampling.--The 1304 samples analyzed in this investigation were collected by the U.S. Bureau of Commercial Fisheries, for the purpose of investigating the relationship between sediment types and shelf fauna. They were collected by grab samplers and represent the top 10 cm of sediment. About 40 percent of the samples were collected from two relatively small regions, one seaward of Galveston Bay, Texas, between long. 94° and 95°W. and the other around the Dry Tortugas on the south Florida shelf. The remaining samples were collected during a broad reconnaissance survey from the mouth of the Rio Grande to the Florida Keys. The sample locations are shown on the accompanying maps (figs. 2-19).

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Chemical procedure.--Each bulk sample was analyzed for 30 elements by the six-step semiquantitative spectrographic method developed for the rapid determination of selected elements in geologic materials (Grimes and Marranzino, 1968). The results of these analyses are reported as a series of geometric classes with theoretical class boundaries equal to the concentrations of the elements in standards used. The semiquantitative analyses determined in the U.S. Geological Survey laboratories are reported as the geometric midpoints (0.1, 0.15, 0.2, 0.3, 0.5, 0.7, 1.0, and so forth percent or parts per million) of geometric brackets having the boundaries of 0.083, 0.12, 0.18, 0.26, 0.38, 0.56, 0.83, 1.2, and so forth. The precision of a reported value is approximately plus or minus one bracket at the 68-percent level of confidence and plus or minus two brackets at the 95-percent level (Shacklette and others, 1971).

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The limits of detection of the analytical method are given in table 1. In reporting concentrations greater than the upper limit of determination, the upper limit value is prefaced by "G" signifying "greater than"; concentrations below the limit of determination are noted by "N" (not detected). If the spectographer detects the presence of an element, but the analytical line is too faint for an accurate estimate of elemental concentration, the elemental values are reported by "L", which denotes that the element is present but in concentrations less than the lower limit of determination.

Method of Data Analysis

The values obtained from the analyses for each element were plotted on charts and contoured. From these charts, maps were constructed with patterns representing the field between contour intervals. The contour interval for each map was chosen subjectively to show the regional variations. The patterns represent a subjective smoothing to avoid clutter in the areas of high sample density. Only those elements which were detected in more than 50 percent of the samples have been mapped.

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TABLE 1.

Analytical Range of Detection
(Data Reported in Parts Per Million)

Element		Lower limit	Upper limit
Ag	Silver	0.5	5,000
As	Arsenic	200	10,000
Au	Gold	10	500
B	Boron	10	2,000
Ba	Barium	20	5,000
Be	Beryllium	1	1,000
Bi	Bismuth	10	1,000
Ca	Calcium	500	200,000
Cd	Cadmium	20	500
Co	Cobalt	5	2,000
Cr	Chromium	5	5,000
Cu	Copper	5	20,000
Fe	Iron	500	200,000
La	Lanthanum	20	1,000
Mg	Magnesium	200	100,000
Mn	Manganese	10	5,000
Mo	Molybdenum	5	2,000
Nb	Niobium	10	2,000
Ni	Nickel	5	5,000
Pb	Lead	10	20,000
Sb	Antimony	100	10,000
Sc	Scandium	5	100
Sn	Tin	10	1,000
Sr	Strontium	100	5,000
Ti	Titanium	20	10,000
V	Vanadium	10	10,000
W	Tungsten	50	10,000
Y	Yttrium	10	200
Zn	Zinc	200	10,000
Zr	Zirconium	10	1,000

For comparative purposes, the shelf was divided into three segments: (1) the northwestern shelf and upper slope west of the Mississippi River Delta and north of lat 28°N.; (2) the northeastern shelf and slope east of the Mississippi River Delta and north of lat 28°N.; and (3) the south Florida shelf and slope from lat 28°N. to the Florida Keys. Latitude 28° was chosen as the southern limit of the northwestern region to exclude Rio Grande sediments. The sediments in the northwestern shelf are primarily non-carbonate clastics, whereas the sediments in south Florida area are wholly in a carbonate environment. The northeastern area represents the transition zone between the noncarbonate and carbonate areas. Statistical summarization of the elemental composition of each of the three areas allows chemical comparison and differentiation based on sediment type to be made.

The data were computer summarized by a program which yielded a listing of the data, the maximum and minimum values, a histogram plot, the frequency distribution, and a statistical summary which included the geometric mean and geometric deviation. Before these computations were performed, all "G" (greater than) values were removed from the data by assigning these values to the next higher geometric class midpoints. This type of manipulation was necessary for calcium, manganese, strontium and zirconium. Justification for this procedure comes from the analysis of the data and known chemical distributions.

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The geometric mean and geometric deviation are antilogs of the arithmetic mean and standard deviation of the logarithms of the analytical values. If samples had elemental concentrations less than the lower limit of detection, the geometric mean and deviations were estimated by a censored-distribution method (Cohen, 1959). The geometric mean is a more consistent measure of the central tendency of a frequency distribution than the arithmetic mean and thus is an estimate of the typical or most common concentration of an element. The geometric means and deviations are given in table 2.

The arithmetic means of the analytical data were computed from the estimated geometric means and deviations by using the method described by Miesch (1967) and is based on the techniques presented by Cohen (1959) and Sichel (1952). The arithmetic means listed in table 3 are estimates of geochemical abundance (Miesch, 1967) and are directly comparable to the arithmetic means (geochemical averages) reported in the literature (Shacklette and others, 1971).

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Table 2 - Geometric means and geometric deviations of elements in the surface sediments on the continental shelf and slope of the Gulf of Mexico bordering the United States. (Geometric means reported in part per million.)

ELEMENT	The Continental Shelf and Slope of the Gulf of Mexico N=1304		Northwestern Shelf and Slope N=795		Northeastern Shelf and Slope N=206		South Florida Shelf and Slope N=148	
	Geometric Mean	Geometric Deviation	Geometric Mean	Geometric Deviation	Geometric Mean	Geometric Deviation	Geometric Mean	Geometric Deviation
Ba	295	2.96	480	1.56	84	3.56	69	2.84
B	48	1.91	55	1.86	47	1.77	26	1.89
Ca	40700	5.03	15,800	3.33	125,600	2.47	286,000	1.21
Co	8	1.43	8	1.41	7	1.44	2	3.27
Cr	40	2.18	47	2.05	31	2.89	26	1.88
Cu	10	1.81	10	1.70	9	1.85	N.E.	N.E.
Fe	10300	2.99	15,100	2.09	12,100	3.33	3,710	3.74
La	25	2.04	32	1.79	18	2.63	6	2.65
Mg	10200	2.39	7,400	1.98	12,500	2.62	24,100	1.37
Mn	230	3.36	401	1.75	217	4.96	95	4.34
Ni	17	2.21	19	2.07	16	2.48	5	3.52
Pb	24	1.87	24	1.77	23	1.99	N.E.	N.E.
Sc	9	1.55	9	1.54	8	1.51	0.6	4.56
Sr	500	4.21	198	1.98	1060	2.17	3580	1.85
Ti	1200	3.16	2,800	1.81	820	2.97	296	2.68
V	48	2.52	73	2.01	36	2.47	19	2.29
Y	20	1.54	21	1.51	18	1.53	9	2.19
Zr	121	4.72	309	2.36	55	2.63	11	2.26

Table 3 - Average constants reported for elements in surface sedimentary material and marine sediments (Data in parts per million; each average represents arithmetic mean.)

ELEMENT		This Report				Horn & Adams (1966)				Turekian & Wedepohl (1961)				
		North Shelf	N.W. Shelf	N.E. Shelf	S.F. Shelf	Carb	Shale	SS	Mobile Belt Sed.*	Carb	Shale	SS	Deep Sea CO^3	Deep Sea Clay
Ba	Borium	341	509	140	66	35	263	199	233	10	580	X**	190	2,300
B	Boron	57	64	56	31	12	79	25	56	20	100	35	55	230
Ca	Calcium	151,320	31,760	182,140	286,000	272,000	22,200	22,200	26,900	302,300	22,100	39,100	312,400	29,000
Co	Cobalt	6	8	5	3	.2	8	.5	5	0.1	19	0.3	7	74
Cr	Chromium	52	64	48	32	7	427	121	295	11	90	35	11	90
Cu	Copper	9	11	7	X**	4	47	15	34	4	45	X**	30	250
Fe	Iron	18,450	18,910	25,290	8,920	8,660	39,600	21,000	31,100	3,800	47,200	9,800	9,000	65,000
La	Lanthanum	32	37	30	9	6	25	11	18	X**	92	30	10	115
Mg	Magnesium	14,920	8,920	19,420	24,680	45,500	16,600	8,760	13,900	47,000	15,000	7,000	4,000	21,000
Mn	Manganese	519	442	740	257	385	300	10	188	1,100	850	X**	1,000	6,700
Ni	Nickel	21	23	21	10	13	33	3	21	20	68	2	30	225
Pb	Lead	21	25	21	X**	6	20	7	15	9	20	7	9	80
Sc	Scandium	7	9	6	2	1	11	1	7	1	13	1	2	19
Sr	Strontium	1,300	273	1,436	4,264	544	242	24	168	610	300	20	2,000	180
Ti	Titanium	2,410	2,730	1,400	470	389	4,520	2,100	3,430	400	4,600	1,500	770	4,600
V	Vanadium	77	91	54	25	13	102	21	68	20	130	20	20	120
Y	Yttrium	18	22	17	12	6	12	2	8	30	26	40	42	90
Zr	Zirconium	375	431	89	15	18	144	206	160	19	160	220	20	150

* Mobile belt sediments are defined as 59% shale, 36% sandstone, 2% carbonate and 3% evaporites with porosity of 28.1%.

** In some cases, only order of magnitude estimates could be made. These are indicated by the symbol X.

Correlation coefficients--those statistical parameters which "measure" the reliability of one variable in predicting another--were calculated on the logs of the analytical values. The computer program[1] used for these calculations ignores data in which one or more values are qualified. Therefore, the correlation coefficient for some element pairs is based on less than the total number of samples. In these cases, the data are derived from censored distributions and should be considered as an "index of association" (A. T. Miesch, written commun., 1971). However, if only a few values are qualified in a large data set, the calculated correlation coefficient may be used for statistical evaluation. The correlation coefficients for the elements in each area are given in table 4.

RESULTS

The results of this investigation are presented in a series of maps depicting regional elemental patterns (figs. 2-19). The data are also summarized in tables 2-4, which list the geometric means and geometric deviations, the arithmetic means, and correlation coefficients.

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[1] Selner, G. I., 1968, Correlation analysis. Program No. D0101: U.S. Geol. Survey, Computer Center Division, Denver, Colo.

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Table 4.--Bielement correlation coefficients based on analyses of surficial marine sediments on the northern continental shelf and slope of the Gulf of Mexico

[Coefficients are given in the upper right; number of samples upon which coefficients are based are given in the lower left]

Northwestern shelf and slope north of lat 28°N (795 samples in this region)

n \ r	Ba	B	Ca	Co	Cr	Cu	Fe	La	Mg	Mn	Ni	Pb	Sc	Sr	Ti	V	Y	Zr
Ba	--	.31	-.22	.28	.32	.09	.45	.42	.21	.23	.35	.16	.10	-.28	.57	.30	.22	.10
B	785	--	-.18	.67	.37	.09	.70	.17	.57	.43	.66	.49	.46	-.25	.62	.63	.22	.37
Ca	795	785	--	-.02	.13	-.05	-.04	.11	.28	.10	.01	-.14	.15	.85	-.09	-.09	.25	-.32
Co	692	692	692	--	.51	.19	.74	.26	.63	.49	.70	.58	.57	-.07	.56	.73	.43	-.12
Cr	787	777	787	690	--	.03	.63	.22	.68	.40	.66	.47	.68	.03	.55	.70	.56	-.08
Cu	717	712	717	635	710	--	.03	.14	.05	.24	.08	.31	.24	-.12	.18	.14	.15	.01
Fe	795	785	795	692	787	717	--	.37	.79	.62	.77	.66	.63	-.11	.71	.81	.45	.01
La	696	696	696	626	695	630	696	--	.33	.25	.31	.29	.31	.15	.31	.16	.38	-.05
Mg	795	785	795	692	676	717	795	696	--	.61	.75	.64	.74	.23	.51	.71	.56	-.25
Mn	795	785	795	692	787	717	795	696	795	--	.52	.52	.57	.09	.44	.55	.45	-.11
Ni	760	756	760	692	753	693	760	671	760	760	--	.65	.77	-.03	.56	.81	.44	-.23
Pb	664	659	664	600	664	610	664	643	664	664	644	--	.62	-.16	.42	.66	.34	-.23
Sc	678	675	678	628	678	634	678	646	678	678	665	624	--	.06	.48	.77	.52	-.42
Sr	795	785	795	692	787	717	795	696	795	795	760	664	678	--	-.29	-.18	.16	-.40
Ti	795	785	795	692	787	717	795	696	795	795	760	664	678	795	--	.67	.45	.37
V	779	770	779	689	776	704	779	694	779	779	749	664	678	779	779	--	.53	-.05
Y	764	755	764	680	763	694	764	693	764	764	734	660	676	764	764	760	--	-.04
Zr	795	785	795	692	787	717	795	696	795	795	760	664	678	795	795	779	764	--

Northeastern shelf and slope north of lat 28° N. (206 samples in this region)

n \ r	Ba	B	Ca	Co	Cr	Cu	Fe	La	Mg	Mn	Ni	Pb	Sc	Sr	Ti	V	Y	Zr
Ba	--	.74	.-01	.56	.64	.69	.59	.47	.23	.78	.82	.77	.74	-.29	.86	.73	.55	.55
B	196	--	.15	.27	.66	.56	.69	.26	.39	.74	.70	.65	.62	-.08	.75	.78	.54	.42
Ca	196	206	--	-.15	.26	.01	.34	-.15	.76	.32	.27	-.16	-.09	.86	-.03	.27	.16	-.29
Co	93	94	94	--	.27	.58	.42	.40	.17	.43	.52	.52	.65	-.26	.43	.38	.11	.23
Cr	175	184	184	94	--	.39	.81	.10	.58	.77	.80	.60	.56	.01	.58	.85	.58	.21
Cu	117	118	118	85	107	--	.50	.28	.34	.65	.69	.61	.70	-.16	.46	.60	.40	.09
Fe	194	203	203	93	183	117	--	.37	.71	.83	.75	.67	.71	.12	.57	.84	.49	.17
La	102	104	104	83	104	83	103	--	.03	.16	.16	.54	.39	-.25	.45	.04	.03	.32
Mg	196	206	206	94	184	118	203	104	--	.56	.51	.32	.39	.65	.16	.58	.30	-.21
Mn	196	206	206	94	184	118	203	104	206	--	.86	.67	.61	.05	.70	.89	.54	.22
Ni	148	151	151	94	143	101	150	100	151	151	--	.76	.81	-.05	.70	.90	.62	.22
Pb	128	129	129	88	129	97	129	91	129	129	118	--	.76	-.40	.67	.65	.44	.34
Sc	96	96	96	86	96	91	96	83	96	96	96	95	--	-.33	.56	.73	.40	.07
Sr	196	206	206	94	184	118	203	104	206	206	151	129	96	--	-.26	-.01	-.03	-.39
Ti	196	206	206	94	184	118	203	104	206	206	151	129	96	206	--	.67	.50	.68
V	193	203	203	94	184	117	201	104	203	203	151	129	96	206	203	--	.63	.23
Y	157	162	162	92	162	102	162	101	162	162	133	126	96	162	162	162	--	.30
Zr	196	206	206	94	184	118	203	104	206	206	151	129	96	206	206	203	162	--

South Florida shelf (148 samples in this region)

n \ r	Ba	B	Ca	Co	Cr	Cu	Fe	La	Mg	Mn	Ni	Pb	Sc	Sr	Ti	V	Y	Zr
Ba	--	.60	-.61	.69	.62	.58	.78	.51	-.28	.73	.78	.47	.82	-.67	.81	.68	.50	.64
B	66	--	-.55	.74	.48	.38	.28	.15	.02	.28	.54	.20	.88	-.22	.64	.55	.32	.56
Ca	67	146	--	-.72	-.43	-.35	-.46	-.55	.22	-.38	-.52	-.13	-.77	.51	-.59	-.67	-.33	-.60
Co	31	33	34	--	.78	.21	.71	-.16	.05	.33	.67	.05	.66	-.73	.63	.71	.37	.65
Cr	67	145	147	34	--	.44	.65	.50	.02	.38	.60	.18	.67	-.34	.65	.62	.48	.60
Cu	40	42	42	28	42	--	.49	.52	-.01	.53	.61	.67	.87	-.39	.59	.47	.17	.54
Fe	67	138	139	34	139	42	--	.75	-.27	.75	.81	.46	.85	-.75	.71	.79	.69	.47
La	12	23	23	12	23	12	23	--	-.43	.68	.39	.38	.95	-.74	.69	.68	.49	.71
Mg	67	146	148	34	147	42	139	23	--	-.29	-.42	-.01	.10	.44	-.18	-.34	-.13	-.19
Mn	67	146	148	34	147	42	139	23	148	--	.83	.49	.44	-.75	.73	.73	.56	.41
Ni	60	83	84	34	84	40	84	12	84	84	--	.39	.76	-.79	.79	.83	.74	.44
Pb	32	41	41	26	41	29	41	12	41	41	37	--	.70	-.28	.39	.22	.72	.61
Sc	18	20	20	18	20	18	20	12	20	20	18	16	--	-.61	.89	.75	.18	.22
Sr	67	146	148	34	147	42	139	23	148	148	84	41	20	--	-.58	-.75	-.57	-.39
Ti	67	142	144	34	143	42	135	21	144	144	84	41	20	144	--	.80	.54	.71
V	67	136	138	34	138	42	133	23	138	138	84	41	20	138	135	--	.64	.67
Y	60	79	80	34	80	41	80	20	80	80	66	34	20	80	80	80	--	.32
Zr	67	146	148	34	147	42	139	23	148	148	84	41	20	138	144	138	80	--

Of the 30 elements for which analyses were performed, 18 had sufficient concentrations to be detected in more than 50 percent of the samples and these data are shown on figures 2-19. Five of the remaining twelve elements were found in some samples as follows: Beryllium, in 44.5 percent of the samples, ranging from 1 to 10 ppm; molybdenum, in 7.6 percent of the samples, ranging from 5 to 15 ppm; niobium, in 34.7 percent of the samples, ranging from 10 to 30 ppm; tin, in 4.3 percent of the samples, ranging from 10 to 500 ppm; and zinc, in 0.2 percent of the samples, ranging from 300 to 1,500 ppm. The remaining seven elements were looked for in all samples but were not detected. These elements and their lower limit of detection (in parts per million) are as follows: Antimony, 100; arsenic, 200; bismuth, 10; cadmium, 20; gold, 10; silver, 0.5; and tungsten, 50.

DISCUSSION AND CONCLUSION

Examination of the maps accompanying this report (figs. 2-19) reveals certain regional variations in the concentrations of the elements. Because of operative bias in the analytical method, mapped patterns based on a single sample which varies by only one class from neighboring samples may be meaningless. However, individual values that differ by more than two classes from surrounding sample points are considered to be significant.

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867-100

In general, the concentrations of most elements are highest in the silty and clayey sediments on the continental slope off south Texas, on the outer shelf and slope off central Louisiana, and in the lower reaches of the DeSoto Canyon. Terrigenous material is presently being deposited in these regions (Curray, 1960; Ludwick, 1964). In the sediments on the central Texas shelf southeast of Galveston, and on the south Florida shelf, the amounts of trace and minor elements are comparatively low.

In the relict sediments of the shelf southeast of Galveston, subaerial weathering during the Pleistocene sea-level fluctuations has depleted the supply of trace and minor elements. Those elements which occur in chemically resistant minerals, however, show a relative enrichment in these sediments. For example, Holmes (1971) demonstrated that the zirconium enrichment in the sediments of this region marks relict strand lines. The calcium, strontium, and magnesium in a few samples from this area represent relict shelly sediments. These sediments are probably lagoonal material deposited at some epoch during the Pleistocene.

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On the south Florida shelf, the sediments are predominantly carbonates formed primarily from chemical species in sea water which is depleted in trace elements. As a result, carbonate sediments are similarly depleted in trace and minor elements with the exception of strontium and magnesium.

Superimposed on these regional patterns are several anomalous elemental concentrations. Iron and manganese are enriched in the sediments on the lower slope south of Galveston and on the central and lower sections of the DeSoto Canyon. The vertical concentration patterns of iron and manganese in cores from these areas indicate that both elements have become concentrated at the surface, possibly the result of upward migration of these elements within the sediment column (unpublished data). In the DeSoto Canyon region, the surficial sediments also contain greater amounts of barium, cobalt, copper, magnesium, and nickel than the surrounding sediments. Jenne (1968) has pointed out that the chemical complexes of iron and manganese which are free to migrate also act as chemical "sinks" for other elements. This may account for the high concentration of other elements in this region.

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Along the upper slope south of Louisiana, the high calcium and strontium content of the sediments reflects the presence of the carbonate banks, for example, the Flower Gardens (Parker and Curray, 1956). A similar calcium and strontium anomaly on the upper reaches of the DeSoto Canyon denotes the carbonate bank present on the rim of the canyon (Ludwick and Walton, 1957).

Sediment samples taken in the vicinity of bay and river mouths often have a high concentration of trace elements. Directly seaward of Galveston Bay, barium, copper, iron, lanthanum, and lead are relatively high. South of Mobile Bay, barium, copper, iron, lead, scandium, titanium, vanadium, and yttrium are anomalously high. West of the delta of the Mississippi, barium, boron, cobalt, copper, iron, lanthanum, nickel, lead, titanium, vanadium, and yttrium are concentrated relative to the surrounding sediment. Although it is difficult to determine the origin of these trace elements, their disposition suggests that they are deposited almost immediately after entering the marine environment. To determine which elements occur naturally and which are artifically introduced by man will require a more extensive investigation into the chemical nature and the distribution of these elements in the sediments, organisms, and waters of these areas.

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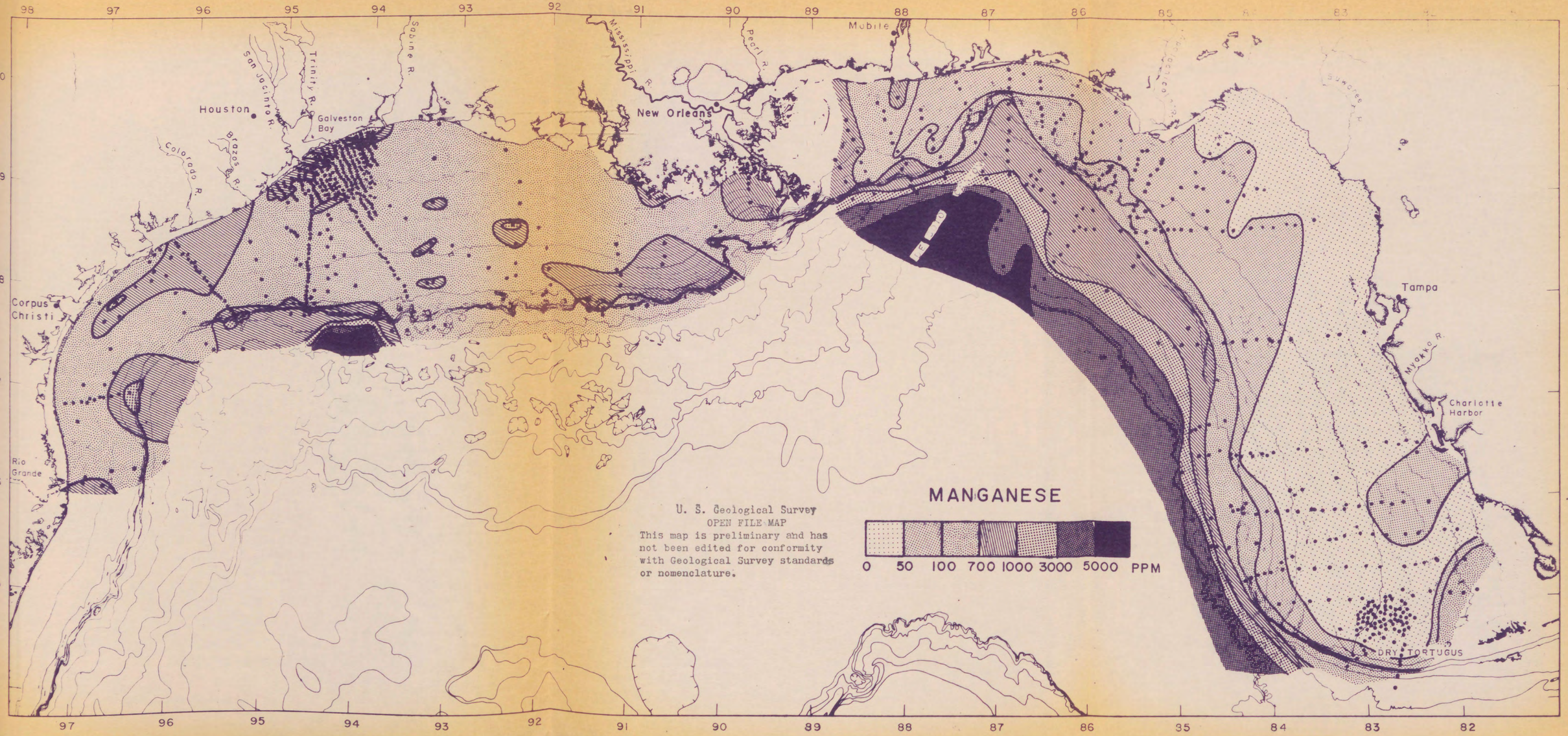
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Colorado R.
Brazos R.
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Charlotte Harbor
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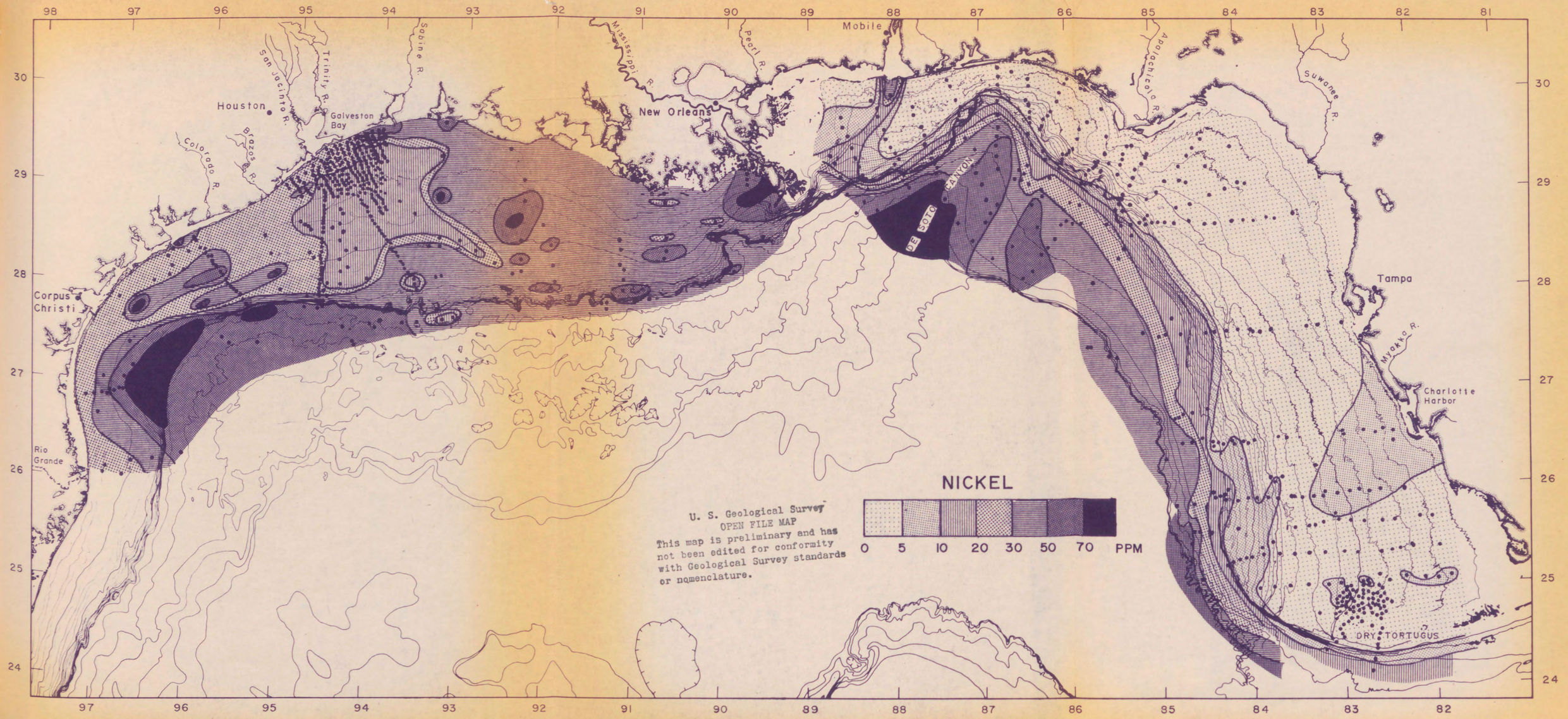
NICKEL
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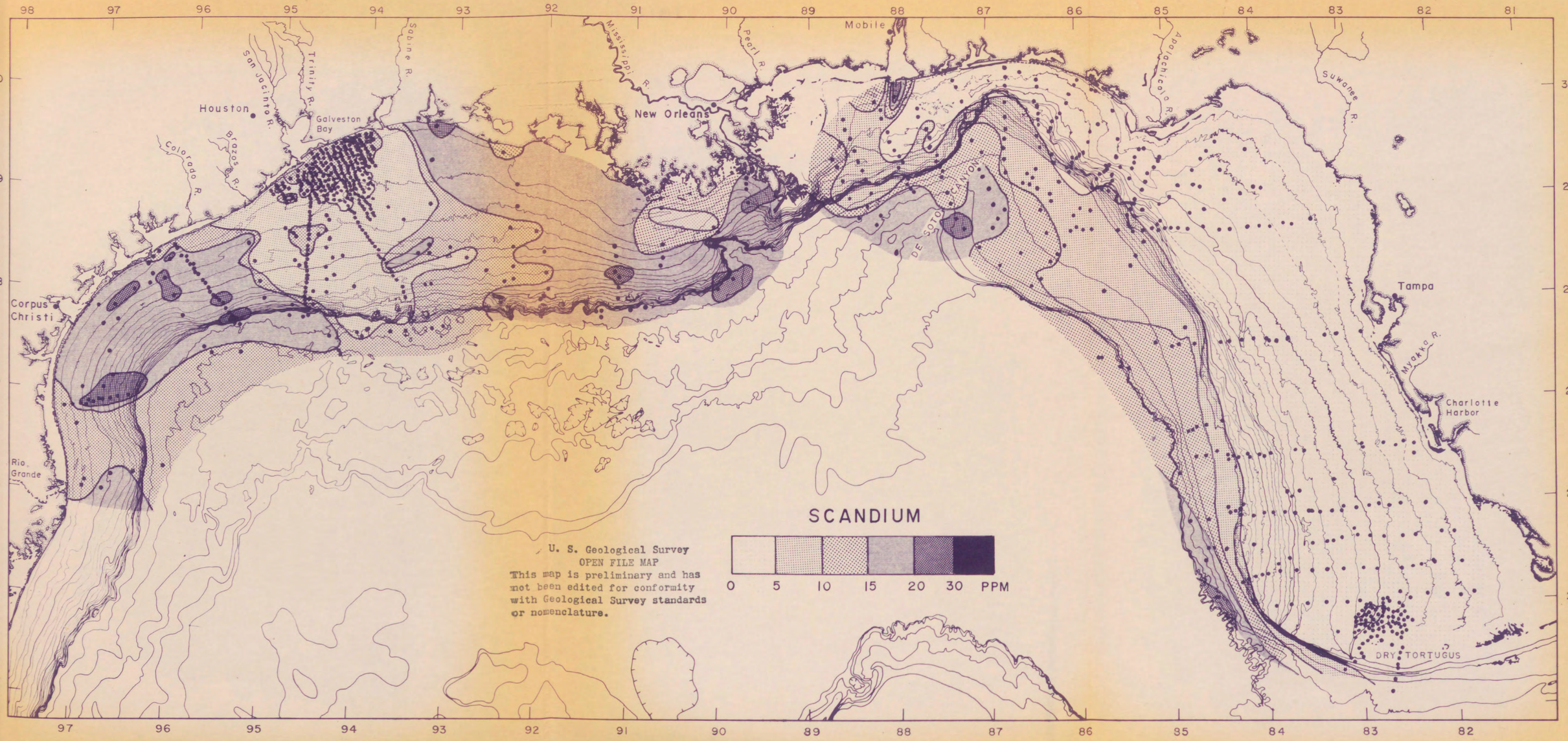
SCANDIUM
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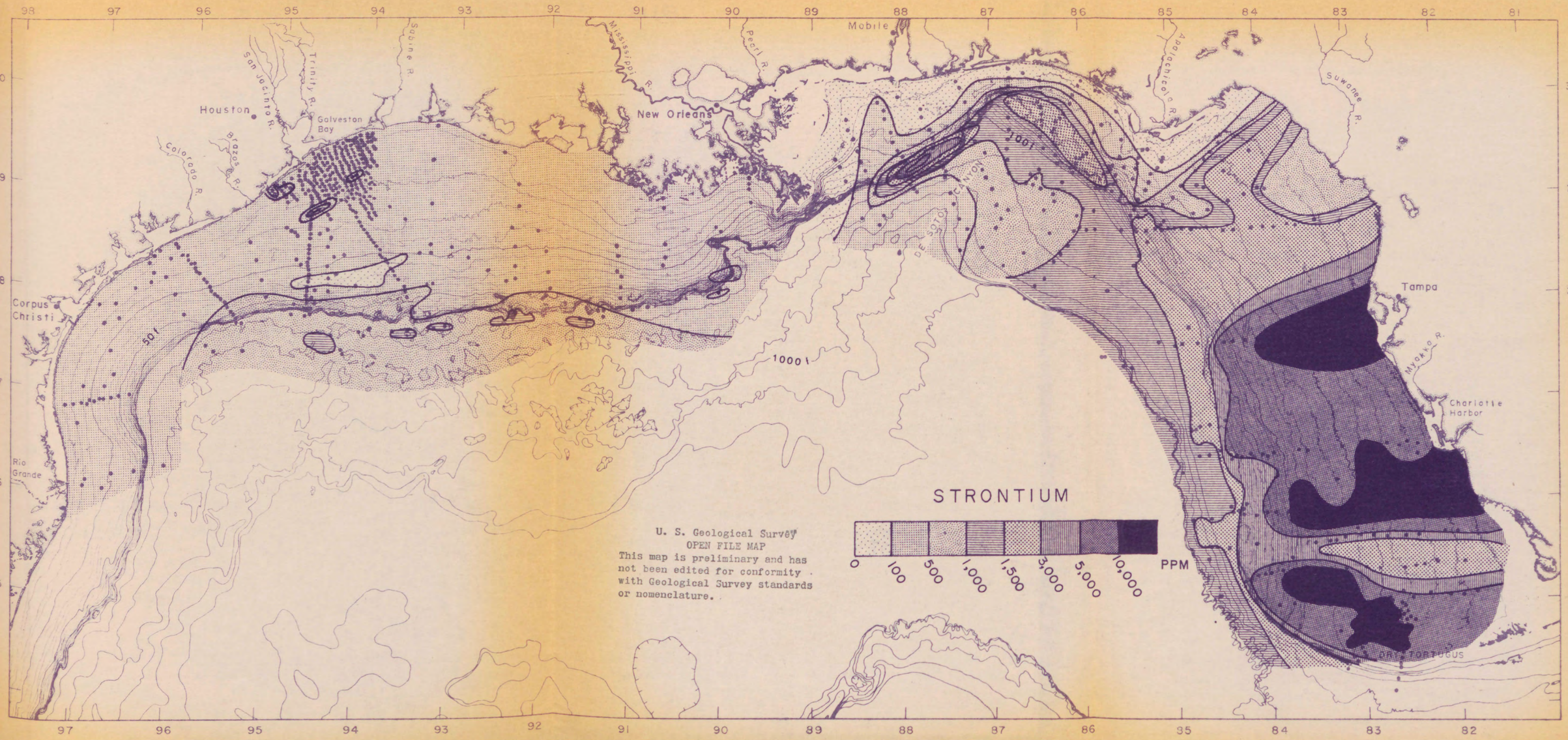
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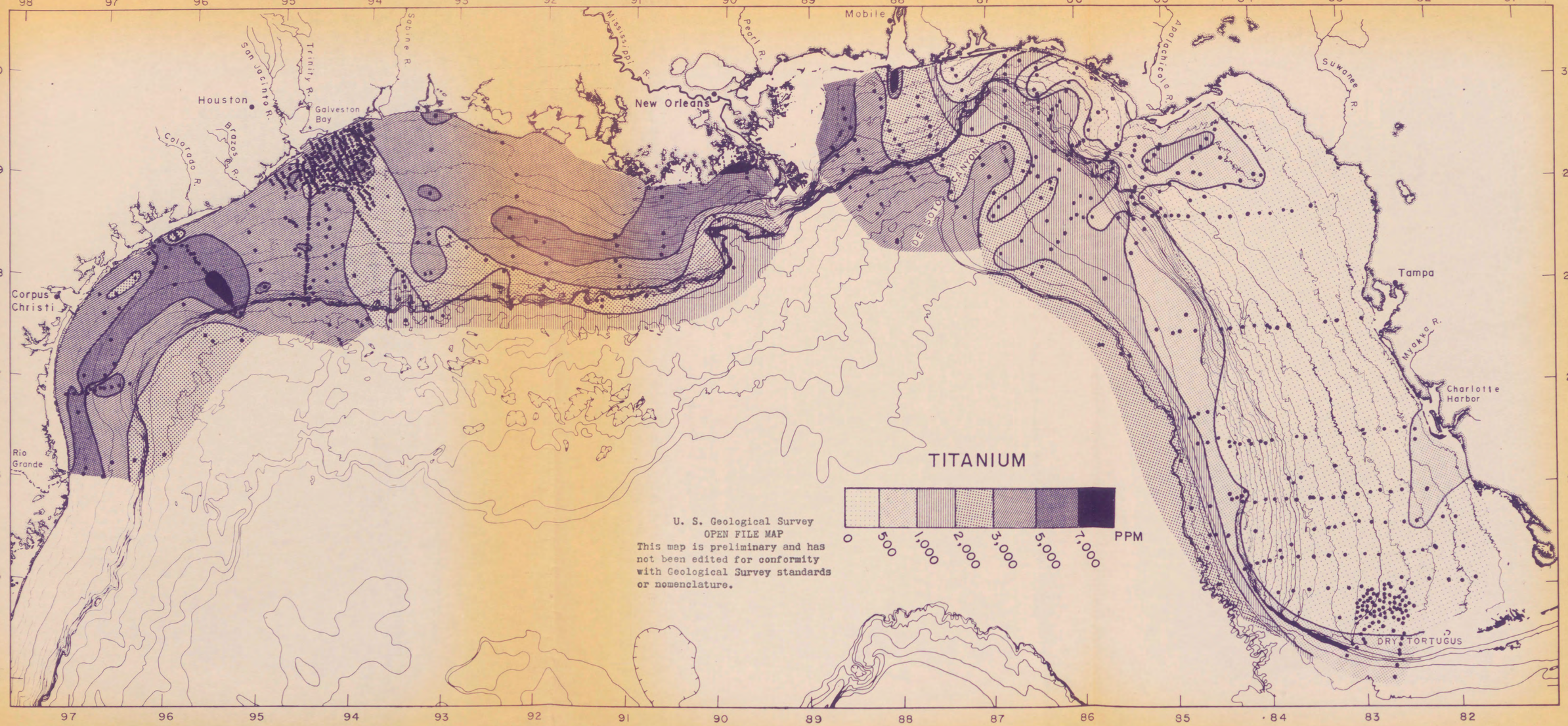
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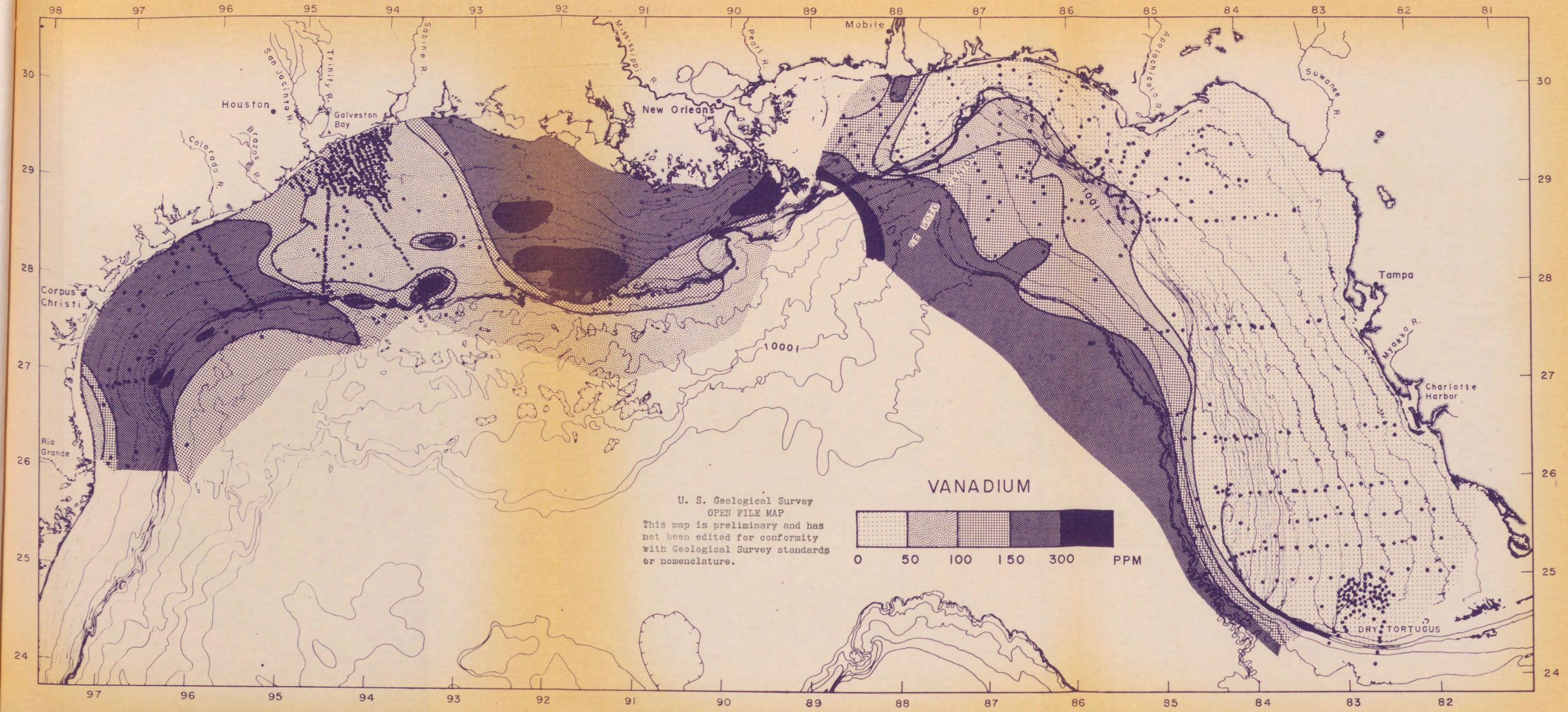
VANADIUM
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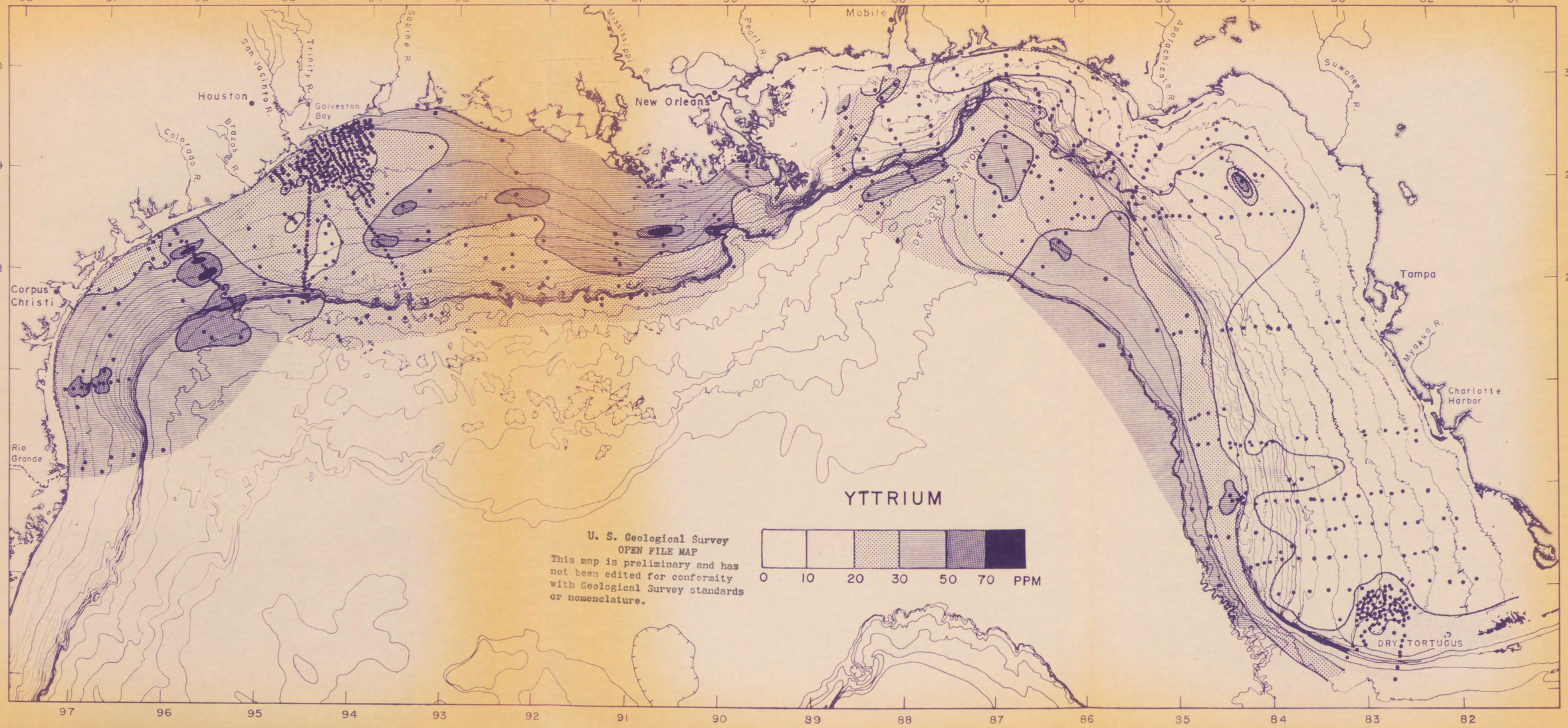
YTTRIUM
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