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WELL WATER TRACE ELEMENT RECONNAISSANCE, EASTERN MARITIME CANADA

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ABSTRACT

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A geochemical survey involving the collection and analysis of about 2000 well water samples from an area of roughly 25,000 km^2 was carried out during the 1975 field season over parts of the Carboniferous basin of eastern Canada. This report describes the results of 1721 regional well sites. Three samples of water were collected from each site and analyzed in four different laboratories for twenty constituents. The distribution and relationships of U, Rn, He F, CH_4, Zn, Cu, Pb, Mn, Fe, pH, suspended matter, depth of well, conductivity and alkalinity are described.

The elements U, Rn, He, F, along with conductivity and alkalinity, show systematic regional patterns indicating broad regional belts of element enrichment which are being leached by circulating groundwaters. The close spatial association of these elements over many tens of miles suggests chemical reaction cells or fronts similar to those observed in the uranium mining districts of Colorado and Wyoming in the United States and elsewhere. Their relatively weak character suggests an intermediate cycle in the cyclic enrichment hypothesis believed to be responsible for the formation of epigenetic uranium ore deposits.

The heavy elements Zn, Cu, Pb, Mn, and Fe show positive correlation with each other but their spatial distribution is more spotty than that of the uranium elements. Broadly speaking the anomalies of these elements cluster mainly on the southern border of the survey area. Most of the anomalies can be explained in terms of known mineral occurrences

The most prominent CH_4 anomaly is located south of Moncton and is believed to be due to the old St. Josephs gas and oil field. Several weaker CH_4 anomalies are probably generated by swamps and peat bogs.

INTRODUCTION

To test the feasibility of using well waters as a means of tracing U occurrences a regional survey of parts of the Carboniferous basin of eastern Canada was carried out during the 1975 field season. The survey was conducted as a component of the newly established Federal-Provincial Uranium Reconnaissance Program (Darnley et al., 1975).

The Carboniferous basin of eastern Canada was chosen because of the numerous known U and Cu occurrences there (Gross 1957; Brummer, 1958; Smith, 1968; Little and Durham, 1971), because of the geologically favorable environment for epigenetic type deposits and the existence of ample wells.

This paper presents some of the more interesting results and more obvious conclusions. Detailed field and analytical methods employed, as well as all analytical results, mainly in the form of tables and maps on a 1 : 500,000 scale, have been released in a Geological Survey of Canada Open File Report (Dyck et al., 1976a).

GEOLOGICAL SETTING

Eastern maritime Canada is part of the Canadian Appalachian region which contains four orogenic belts. Between the Ordovician Taconian and the Devonian Acadian belts lies the Carboniferous basin. It consists mainly of Mississippian to Permian continental and marine sediments. The rocks lie with regional unconformity on granites or pre-Middle Devonian strata deformed by the Acadian orogeny. Locally they lie conformably on Post-Acadian rocks of Late Devonian age. The non-marine sediments of the Carboniferous basin were mainly gravels, sands, silts and muds deposited in fluvial and flood plain environments. The marine sediments include limestones and evaporites that commonly grade laterally into fine- to coarse-grained red beds (Poole et al., 1970).

This succession of relatively flat lying sandstones and shales and the geotectonic framework provide favorable environments for epigenetic type U and other deposits.

The Appalachian region coincides geologically with the Hercynian region, the most important U province in Europe (Ruzicka, 1971). The source rocks of the sediments and the evaporites were the potential sources of U and other trace elements according to modern models of roll-type or chemical cell-type deposits. The occurrence of numerous Cu and U showings in various parts of the Carboniferous basin attests to processes that must have taken place in the past; processes perhaps similar to those that produced the major known economic U ore deposits in the United States.

FIELD AND ANALYTICAL PROCEDURES

Three bottles of water were collected from taps from each of 1721 wells and sent to three different laboratories for analysis. Aerators on taps were removed to prevent sample degassing and lines flushed for one-half to one minute before collecting the samples. One unacidified sample in a glass bottle was sent to the field laboratory and analyzed within one to three days for the following elements: Rn, conductivity, O_2, Eh, pH, alkalinity, U, and F. An acidified sample in a glass bottle was sent to the analytical laboratories of the Geochemistry Section of the Geological Survey of Canada in Ottawa where the following elements were determined: H_2, CH_4, He, Zn, Cu, Pb, Mn, and Fe. An unacidified sample in a plastic bottle was sent to the analytical laboratories of the Inland Waters Directorate in Moncton, N.B., where the following components were determined on about one-half of the samples: K, Cl, Ca, SO_4, and NO_3.

In addition to the routine samples, duplicate sets were collected at some thirty sites and three sites were sampled throughout the season twice a week to determine the sampling plus analytical error.

The analytical procedures employed will be described very briefly and only for those elements discussed in this paper. The details of sampling and analytical procedures and errors are discussed in the Open File Report noted above (Dyck et al., 1976a).

The U analysis was carried out using the standard fluorimetric technique without any attempt to remove quenching elements. The results may therefore be low depending on the amount of these elements present.

The measured concentration of the three gases Rn, He, and CH_4 differs from the in-ground concentration due to the variability in the well water pumping and storage systems. There is no evidence of man-made contamination. Rn was determined using a degassing system and a ZnS (Ag-activated) alpha counter. He and CH_4 were determined mass spectrometrically.

F was determined using an ion-selective electrode.

Zn, Cu, Pb, Mn, and Fe were determined by atomic absorption spectroscopy. Since these analyses had to be carried out on acidified samples these element concentrations will be in error in cases where suspended matter was present in the water.

It is estimated from the analyses of replicate samples that in the case of values above the mean and considering all elements, one analytical result in 60 may be in error by more than a factor of two. On the average however, results are estimated to lie within 25% of the true value (Dyck et al., 1976b).

RESULTS AND DISCUSSION

This is the first attempt by the authors to relate the well water geochemical anomalies obtained from samples collected in 1975 to known mineral occurrences and/or rock formations and interpret the more obvious features of the anomalies. As noted in the previous section a number of factors are responsible for distortion of the data — such as human error, variability in the plumbing systems, analytical interferences, etc. One important cause of data distortion, namely the variation in depth of the sampled wells, must also be taken into consideration in evaluating the two-dimensional map data. The depth was recorded in about one half of the sites (many home owners did not know the depth of their wells).

TABLE I

Arithmetic data of variables of well water samples, Carboniferous basin, eastern Canada

Variable and dimensions	Total number of analyses	Detection limit (DL)	Number of analyses above DL	Values used in place of DL for calculation[2]	Range min	max.	Mode[3]	Arithm. mean	Standard deviation
Suspended matter (relative)	1436	—	88	0.1	0	6	0	0.2	0.4
Depth (m)	914	—	914	1.1	0	110	11	21	16
Radon (pc/l)	1704	2	1698	1.1	0	9900	550	857	816
Conductivity (μmhos/cm)	1695	5	1695	3.0	8	3660	189	301	298
pH	1695	2.0	1695	3.5	3.1	9.4	8.1	7.3	0.7
Alkalinity (ppm $CaCO_3$)	1695	0.5	1695	0.2	4	523	110	102	67
Uranium (ppb)	1706	0.2	897	0.1	0	52	0.1	1.0	3.0
Fluorine (ppm)	1706	0.1	310	0.05	0	10	0.07	0.14	0.58
Helium (std. $cm^3/l \times 10^5$)	1677	1.0	1677	0.5	2	10,200	27	55	381
Zinc[1] (ppb)	1630	3.0	1610	1.5	0	11,104	65	333	732
Copper[1] (ppb)	1630	0.5	1613	0.2	0	3813	8	87	282
Lead[1] (ppb)	1627	2.0 (20)	1359	2.0	0	794	2	12	27
Manganese[1] (ppb)	1630	10	986	5.0	0	15,234	52	104	480
Iron[1] (ppb)	1630	10	1696	5.0	3	32,720	160	651	1314
Methane (std $cm^3/l \times 10$)	1677	0.1	250	0.02	0	440	< 0.1	1.0	16

[1] Samples containing visible amounts of suspended matter were omitted for these variables in calculations and maps.

[2] In the case where most samples had an element content greater than the detection limit, DL, one-half the DL was used. In the case where most samples had an element content less than the DL, one-fifth the DL was used. In the case of pH, 3.5 was chosen because it seemed highly unlikely that water with pH of less than that would be used for consumption. Pb is a special case because about 500 samples were analyzed by direct aspiration with a DL of approximately 20.

[3] Mode was estimated from histograms.

TABLE II

Correlation coefficients (lower left half) and probabilities of Student's t coefficients of well water variables, Carboniferous basin, eastern Canada (normal distribution assumed)

	Susp.	Depth	Rn	Cond.	pH	Alka.	U	F	He	Zn	Cu	Pb	Mn	Fe	CH_4
Susp.				▲	▲	▲	▲		▲	▲			▲	▲	
Depth	0.02		▲	▲	▲	▲	▲	▲	▲	△			○		
Rn	−0.01	0.13		▲	▲	▲	▲	▲	●	○	○		○	△	
Cond.	0.11	0.11	0.09		▲	▲	▲	▲	▲		○		▲		●
pH	0.08	0.28	0.07	0.20		▲	▲	▲	▲	△	△				●
Alka.	0.10	0.17	0.16	0.51	0.49		▲	▲	▲	△	△	○	▲		▲
U	0.07	0.10	0.28	0.28	0.15	0.30			●		○				
F	0.04	0.18	0.11	0.24	0.16	0.27	0.01		▲	○					▲
He	0.07	0.16	0.05	0.31	0.09	0.15	0.05	0.43							
Zn	0.10	−0.10	−0.07	−0.04	−0.14	−0.09	−0.04	−0.05	−0.03		▲	●		▲	
Cu	−0.02	−0.06	−0.05	−0.06	−0.20	−0.16	−0.06	−0.04	−0.03	0.07		▲			
Pb	−0.01	−0.05	−0.02	−0.00	−0.03	−0.05	0.01	−0.01	−0.00	0.05	0.08				
Mn	0.08	−0.09	−0.05	0.10	−0.02	0.11	−0.03	−0.02	−0.01	0.03	−0.03	−0.00		▲	▲
Fe	0.19	−0.07	−0.07	0.01	0.01	0.01	−0.04	−0.00	−0.03	0.14	0.00	0.61	0.61		●
CH_4	−0.01	0.05	−0.04	0.07	0.06	0.21	−0.02	0.16	−0.00	−0.02	−0.01	−0.11	0.11	0.06	

Probability legend

direct ▲, inverse △ } ⩾ 99%

● ○ } ⩾95%, < 99%

It should be borne in mind, however, that there is a tendency in any one region to tap the same aquifer for drinking water and that on a regional scale ground waters from different aquifers intermix to a certain extent through fractures in the formations because the present-day slope of the terrain seldom coincides with the dip of formations. Depth adds another dimension to the significance of the results but also makes interpretations more difficult. One should in principle produce three-dimensional maps. In practice that would require much greater sample densities then were actually carried out and drilling new wells to different depths.

The variables discussed in this report, their dimensions, and some statistical parameters are listed in Table I. In cases where most of the values are below the detection limit, means and standard deviations are of little value. The correlation coefficients and probabilities of Student's t coefficients are given in Table II. In the left lower half the correlation coefficient matrix is given and in the upper right half the probability coefficients. Equations used for their calculation permit the correlation coefficient to vary between 1 and −1, and the probability coefficients between 1 and 0.

All calculations were carried out assuming a normal distribution. Actually, histograms and chi-square tests showed that the distributions were neither normal nor lognormal, although most showed definite positive skewness. However, some of this was no doubt due to lack of sensitivity in the analytical techniques.

The data plotting computer program used for the maps was developed by Belanger (1975) for continuous phenomena. It uses an interpolation algorithm to generate the contour lines. This mode gives smaller edge effects where data are missing than the extrapolation algorithm commonly used in general purpose contouring programs. For brevity only six element maps are shown and discussed in some detail, even though 15 variables are listed in the tables.

The most striking feature of the results is the broad regional trend of highs of U (Fig. 1) and decay products running along the shore of the Northumberland Strait from Glasgow to Cape Tormentine, then apparently swinging westward past Moncton to the edge of the sample area. A second band of highs appears to cross the strait and just strike the northwestern edge of Prince Edward Island. This trend is exhibited by U (Fig. 1), Rn (Fig. 2), He (Fig. 3), F (Fig.4), conductivity, and alkalinity. Bearing in mind the distortion the data are subject to because of the variation in depth of wells and hence aquifers, this spatial association is quite remarkable and suggests the existence of a mineralized belt of regional dimensions or, at least, shows the presence of mineral waters in certain areas in the top 100 m or so. This sinuous trend suggests the possibility that U enrichment occurs in these rocks analogous to the so-called roll-front-type U deposits found in parts of the United States. It may well be a "roll front", but none of the actual values of U were high enough to suggest economic ore if one starts comparing ground-

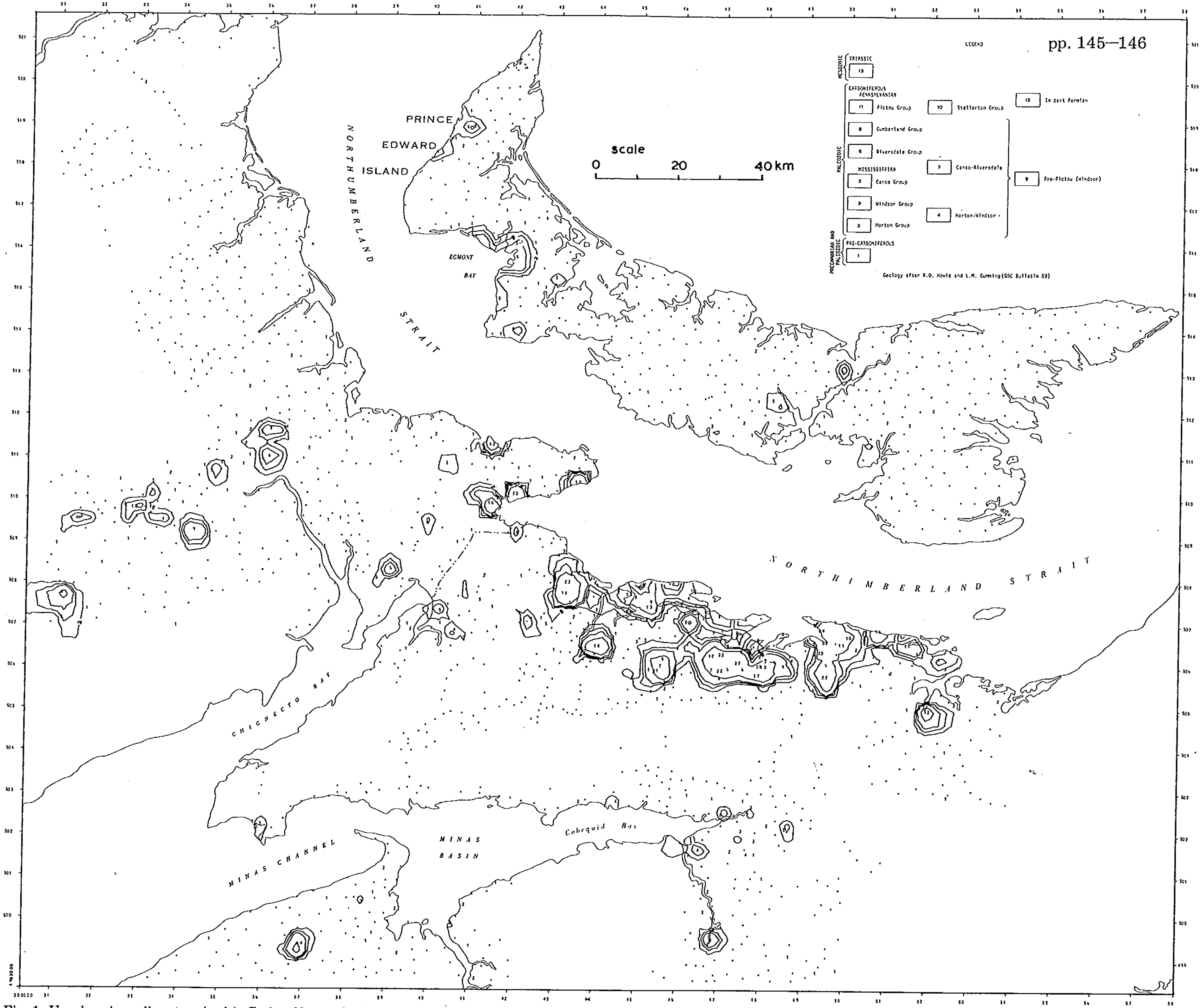


Fig. 1. Uranium in well waters (ppb), Carboniferous basin, eastern Canada. Contours: 1 = x + 0.25 s, 2 = x + 0.5 s, 3 = x + 1.0 s, 4 = x + 2 s. Scale 1 : 500,000 (Dyck et al., 1976a).

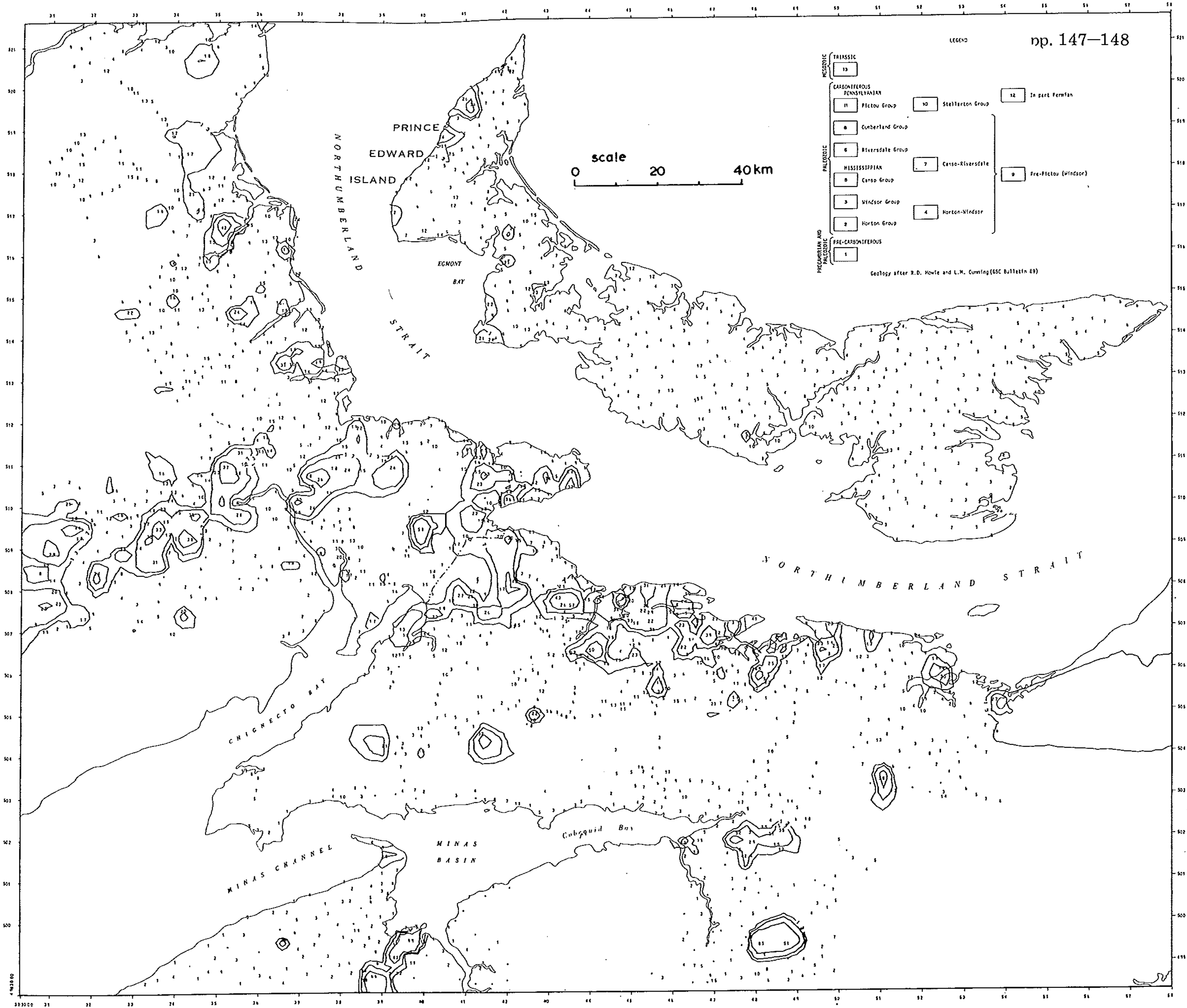


Fig. 2. Radon in well waters (pc/l x 10^{-2}), Carboniferous basin, eastern Canada (see also Fig. 1: Dyck et al., 1976a).

pp. 149—150

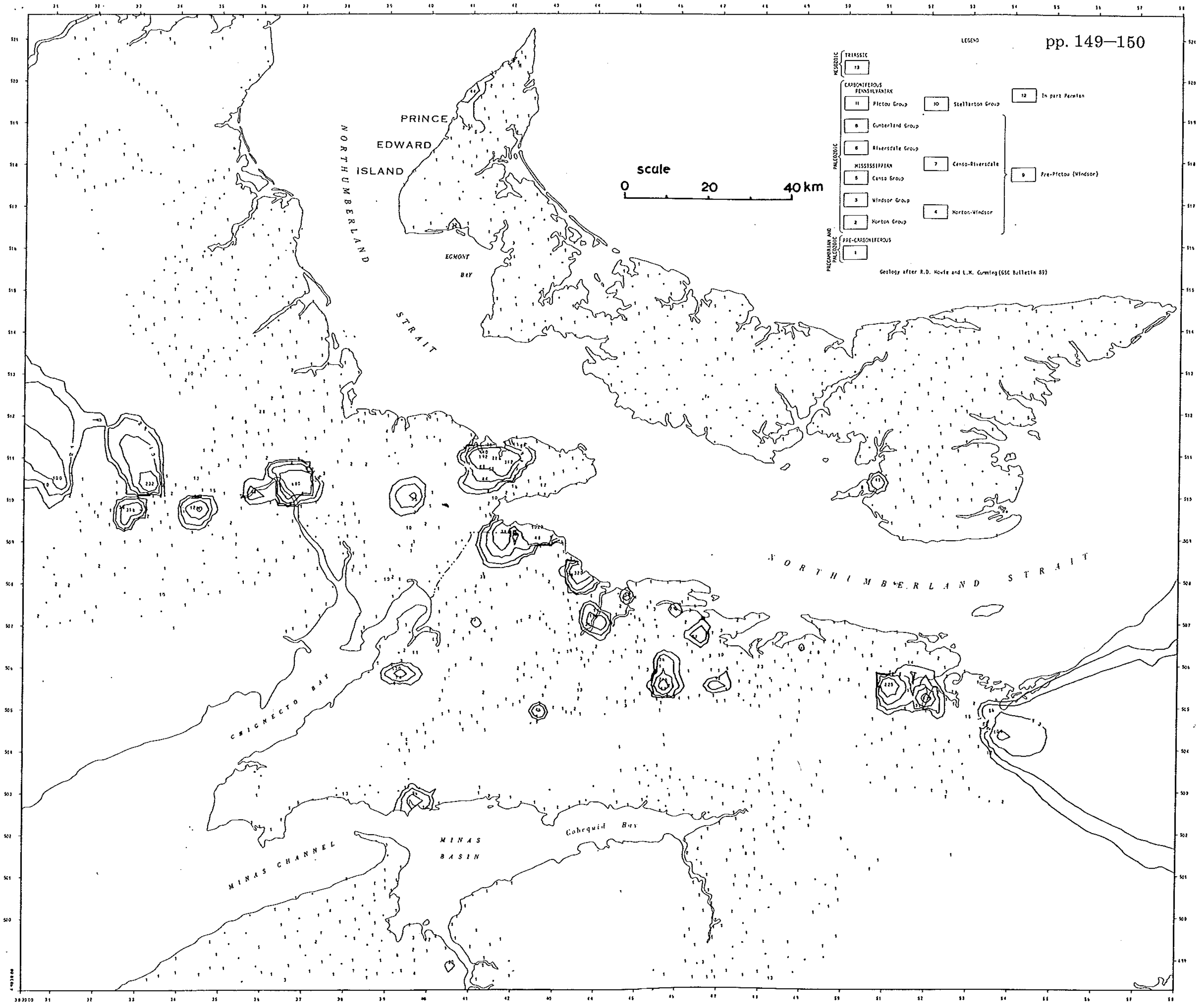


Fig. 3. Helium in well waters (std. $cm^3/l \times 10^5$), Carboniferous basin, eastern Canada (see also Fig. 1; Dyck et al., 1976a).

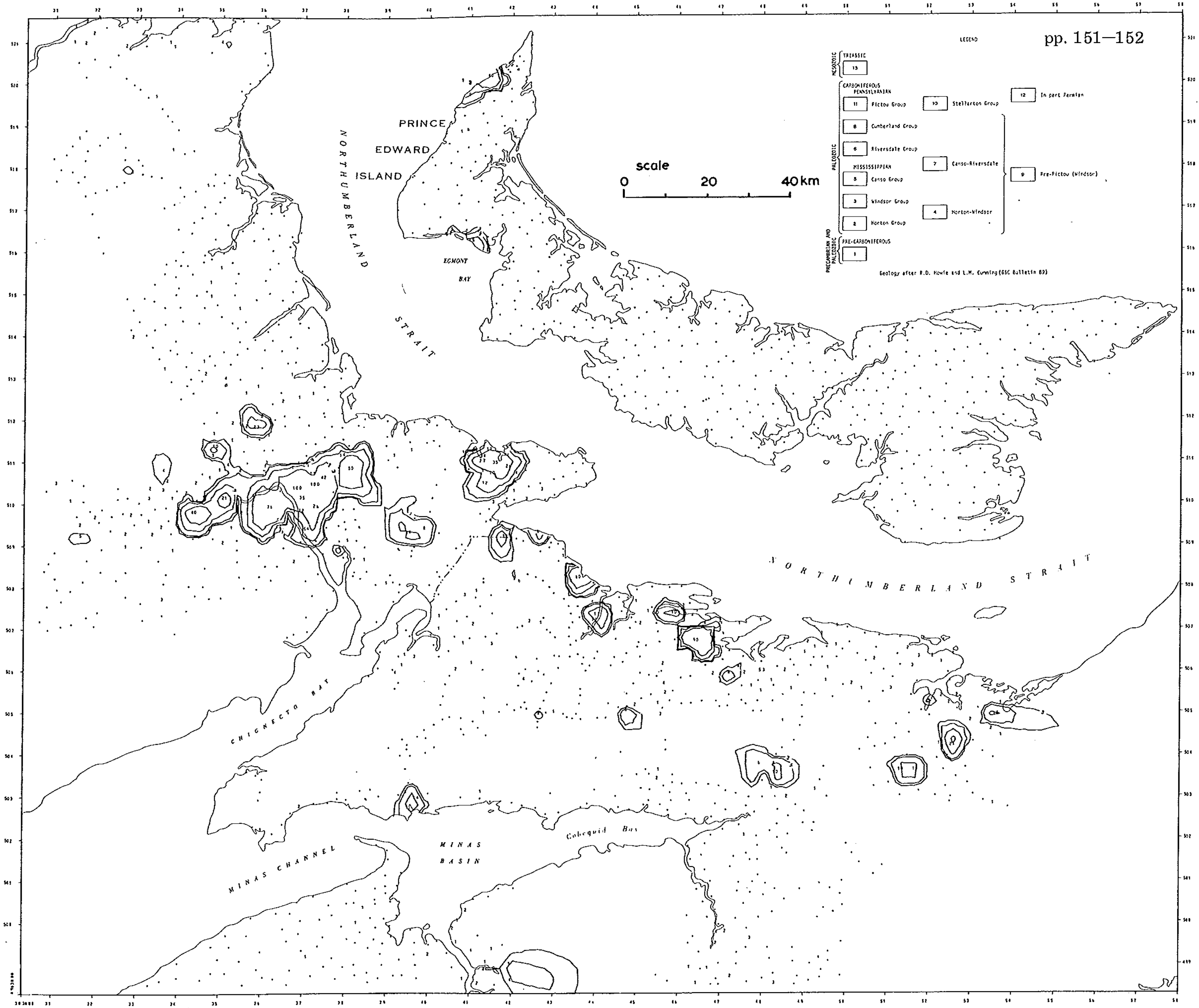


Fig. 4. Fluorine in well waters (ppm x 10), Carboniferous basin, eastern Canada (see also Fig. 1; Dyck et al., 1976a).

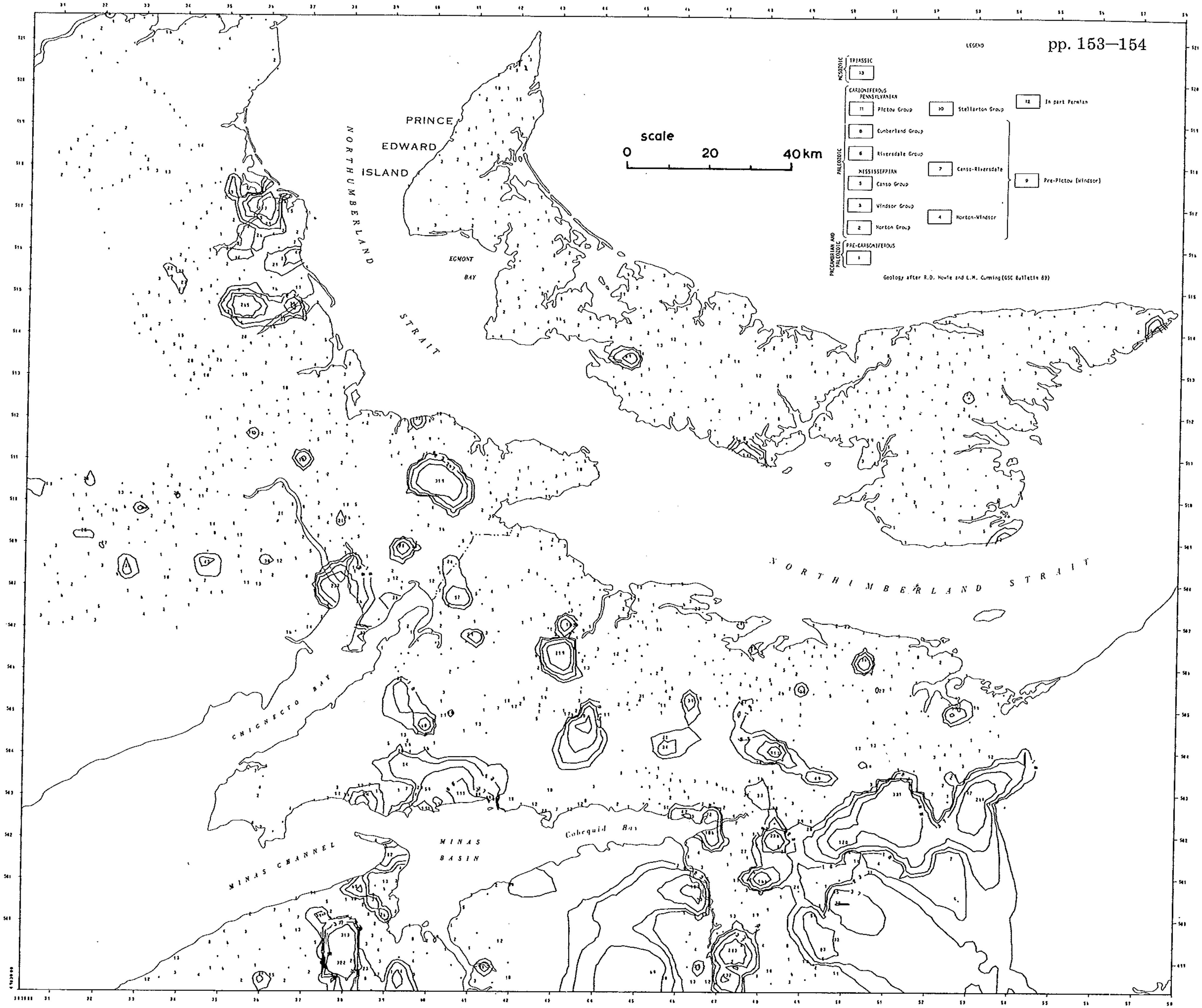


Fig. 5. Copper in well waters (ppb x 10^{-1}), Carboniferous basin, eastern Canada (see also Fig. 1; Dyck et al., 1976a).

pp. 155—156

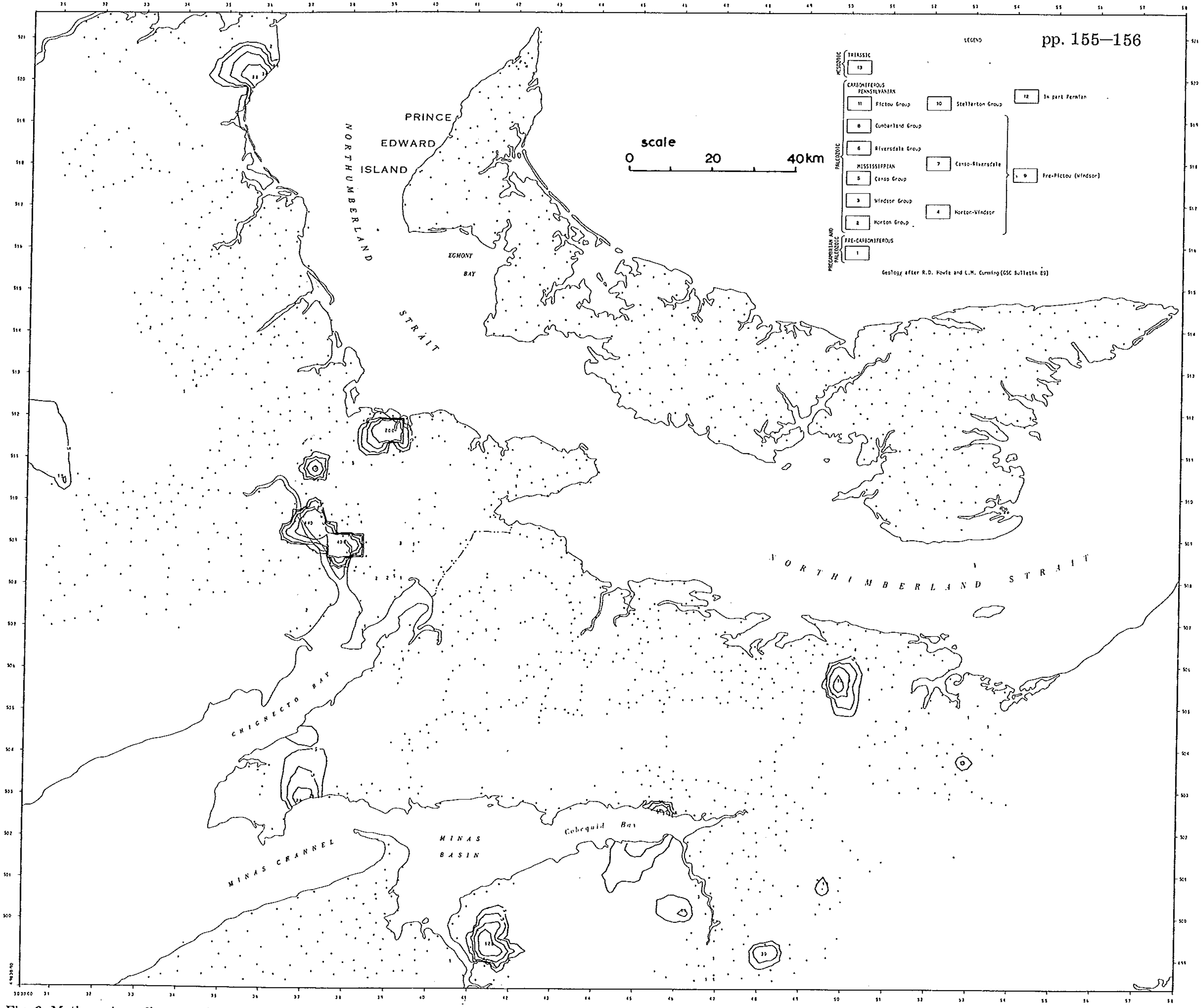
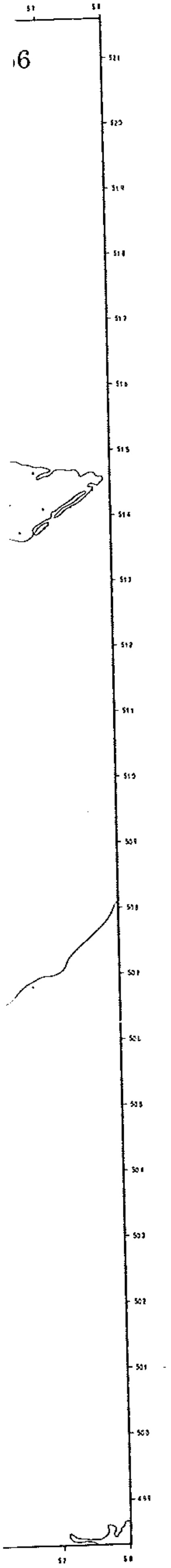


Fig. 6. Methane in well waters (std. $cm^3/\times 10$), Carboniferous basin, eastern Canada (see also Fig. 1; Dyck et al., 1976a).



water U contents. For example, groundwaters from the U ore-bearing Morrison Formation in the Colorado Plateau contained up to 18,000 ppb U (Phenix, 1960). Spring and well water samples in the U districts of Wyoming and South Dakota were found to contain up to 200 ppb U and a mean of 25 ppb U (Denson et al., 1956). Normal waters, by contrast are relatively low in U (White et al., 1963). In this study as Table I shows, the mode for U is actually below the detection limit of the method, i.e., 0.2 ppb, but in several areas the U level rises to several tens of ppb. Most of the anomalous areas are on or near known U occurences. All U anomalies on the northern edge of the Moncton Basin are in and around known occurrences, e.g., Jordan Mountain, Dee Brook, Havelock, Lutes Mountain, and Shediac. They are in Mississippian outcrop areas and overlap into areas of Pennsylvanian sandstone. It appears they are down-gradient from known occurrences. The three anomalies in the Baie Verte—Cape Tormentine area are new shows which were not previously known. They all appear to be in Pennsylvanian cover. Unpublished stream sediment results obtained by Smith (1968) also show U anomalies in this area.

The U anomalies indicated by the well water data along the coast of the Northumberland Strait are also known for the most part from Cu occurrence investigations (Brummer, 1958) and from stream sediment surveys (Little and Durahm, 1971) but the well water indicates much more widespread occurrence of U than was evident from stream sediment work. Also, the well water anomalies are more pronounced in this area relative to the anomalies in the Moncton Basin, whereas the stream sediment anomalies are more pronounced in the Moncton Basin (Dyck et al., 1976b).

Geologically the band of highs in northern Nova Scotia is confined mainly to the Pictou Group with the majority of U highs in the Lower Pictou (Geldsetzer, 1976). In New Brunswick similar rocks and highs extend into the Baie Verte—Cape Tormentine and Moncton areas. But in the Havelock area, rocks of somewhat older age of the Windsor and Horton Groups are exposed but still exhibit anomalies. Here there are in fact, porous limestone outcrops in the quarry areas which contain hydrocarbons and hence may explain some of the anomalies. He, in particular, may have found its way through these porous beds to the wells from the basement rocks.

The spatial association of U, Rn, He, F, and alkalinity is also evident in the correlation matrix in Table II. Evidently the maps give only a two-dimensional picture of a three-dimensional situation and more detailed investigations with close depth control are required to resolve the confusion caused by combining different aquifers together indiscriminantly. A clue to the significance of depth is also evident in the correlation matrix. The deeper wells all have higher U, Rn, He, F, conductivity, and alkalinity.

The existence of F in deep wells in the Moncton area has been known for some time and is believed to come from the thick volcanic ash unit identified in a few deep wells. F is also known to be associated with many kinds of U mineralization. U^{4+} apparently replaces Ca in the carbonate-fluorapatite mineral (Doi et al., 1975). During an erosion cycle alkaline-oxygenated groundwaters will dissolve U, F and other ions. The concentration of these ions in solution will depend on many factors, such as: distance between source and sample site, strength of source, rate of flow of water, volume of water, amount of carbonate and oxygen, etc. For example, average annual rainfall in the Maritimes is about 96 cm — in the Colorado Plateau only about 31 cm. This fact alone makes the U content comparison above somewhat suspect. An increase in the rate of circulation of groundwater may increase the rate of weathering but decrease the concentration of U in solution.

The coincidence of Rn and He with U should not be surprising since U is the parent of Rn and He. But there is ample proof in the literature that He can collect in reservoirs or move in aquifers in the ground completely dissociated from U occurrences. Its high mobility and total inertness are responsible for such separation under favourable conditions. While the main source of He reaching the atmosphere is granitic basement rock, one must not overlook the fact that it all originates from the decay of U and Th. Thus a U or Th deposit must have associated with it a He halo. Still, one cannot exclude the possibility of a fortuitous coincidence of He leakage from basement rocks through U accumulations in strata above, giving a misleading positive correlation.

Rn gas, because of its short half-life of 3.8 days, cannot move far from its immediate parent, Ra. Although Ra is quite immobile in the surficial environment, it is known to move considerable distances in underground water channels, particularly in saline waters, coating the walls of water channel material and emitting Rn into solution. By this mode the Rn range is extended considerably in groundwaters.

None of the Rn values encountered in this survey can be considered as exceptionally anomalous. In fact, the highest Rn values were observed in a few wells in the Halifax Formation near Wolfeville and Shubenacadie. Since only a few samples were taken in this formation it is not known whether these Rn values are characteristic of this rock type. The rocks consist of slates, schists, and minor quartzite and belong to the Au-bearing Maguma Group. The absence of U, He, F, and high alkalinity at these sites suggest a totally different environment from the anomalies along the Northumberland Strait and the Moncton Basin. By way of comparison, Rn levels of up to 200,000 picocuries per litre (pc/l) were encountered in the U district of Wyoming (Harshman, 1968).

In summary, the results of this well water survey suggest the existence of a roll front or chemical cells that were responsible for the deposition of U at some time in the past and now are being leached by circulating ground waters. Whether this deposition resulted in economic grade ore is unknown. It may well have been an intermediate phase in the cyclical enrichment process suggested for such epigenetic U ore deposits (Gruner; 1956; Doi et al., 1975).

Of the heavy metals Zn, Cu, Pb, Mn, and Fe, only the Cu map is shown here (Fig. 5), primarily to limit the length of the paper. Cu is shown to point out the contrast of the heavy metal distribution relative to U. As the results in Table I show, these five elements are also rather abundant in the Maritimes, except for Prince Edward Island, which is relatively and conspicuously void of all trace element anomalies when compared to the mainland. Most surprising of all is the lack of spatial correlation between U and Cu in the well waters. It is so surprising because there are, in fact, numerous Cu showings in northern Nova Scotia (Brummer, 1958) and in New Brunswick which have U associated with the Cu. In fact, the correlation coefficient is negative and significant. One might be tempted to conclude from this that the U found in the well waters is not due to the U in the Cu-U showings. But the more likely explanation is that the Cu is rather immobile at the higher pH and alkalinity exhibited by these waters; the U rather mobile. This is evident by comparing the correlation coefficients in Table II. This table also reveals the extremely close association of Fe and Mn and Zn confirming the widespread existence of pyrite. The generally negative correlation of these five elements with depth indicates lower mobility or lower concentration with depth. Many of the well water anomalies of these elements can be related to known occurrences or major lineaments (e.g., the old Cu workings near Dorchester, N.B., the native Cu occurrences in the Kentville, N.S., area, or the Cu ore deposit near Earlton, N.S.), but many are single-point anomalies. The regionally coherent trend of the U anomalies is not evident in these element maps, but generally Cu and Pb anomalies are more common in the southern portion of the sampled area. The positive correlation of suspended matter with Zn, Mn, and Fe deserves comment. Suspended matter was more common then anticipated in the sampled wells. In fact, 88 samples had sufficient suspended matter to be easily visible and therefore was recorded and given relative values of concentration. These 88 samples, when excluded from computations, caused a drop in the arithmetic means of roughly 10% in the case of Zn, Mn, and Fe and a large drop in the standard deviations. In the case of Cu and Pb no such shift in values occurred. Because these five elements were analyzed using an acidified sample it seems obvious that leaching of suspended matter caused this change in means. But since Cu and Pb did not show this change one can conclude that the suspended matter was rich in Fe and Mn oxides with absorbed Zn, but not Pb and Cu, or that the Pb and Cu were already leached out of the suspended matter by the natural water — not a likely event. In any event, to minimize the effect of the suspended matter on the anomaly maps, these 88 sites were excluded from Zn, Cu, Pb, Mn, and Fe maps and the calculation of contours and the results shown in Table I, but they were included in the correlation matrix. Table II reveals another rather unusual positive correlation, namely suspended matter with conductivity, pH, alkalinity, U, F, and He. Except for He, these measurements were made on an unacidified freshly collected sample. The most consistent but still speculative conclusion to be drawn from this observation is that there exist strong corosive and erosive groundwater flows which not only carry dissolved ions but also finely divided particles in suspension.

A number of heavy metal anomalies cannot be explained without more detailed follow-up. For example the high Pb value of nearly 800 ppb from near Salt Springs, N.S., was observed in a sample collected in a glass bottle as well as in the plastic bottle sample, virtually ruling out human and analytical error. This was a spring and not a well. There are a number of other wells in the area to the north that also contain higher than normal amounts of Pb. None of these sites contain abnormal amounts of any of the other elements which seems to rule out a Pb occurrence of the type found near Telford, some 50 km east of this Pb anomaly (the Telford occurrence contains Zn, Fe and Cu as well as Pb). Perhaps it is due to contamination from Pb pipes used at one time in some houses.

The CH_4 map (Fig. 6) has the fewest number of anomalies, but the CH_4 values have the largest contrast between background and anomaly (less than 0.01 and more than 40 std. cm^3/litre) of all the elements determined in the survey. The lack of correlation between He and CH_4 is at first disturbing, for it is a well known fact that most gas and oil deposits have associated with them much higher than background levels of He. The conclusion that one can draw from these facts is that the well methane is largely due to marsh gas produced in peat bogs and swamps. Hence, the positive correlation between Mn and CH_4. Certainly the CH_4 anomaly in the Point Escuminac area must be due to the surface gas generated in the large peat lands of the area. The large CH_4 anomaly on the eastern side of the Peticodiac River south of Moncton immediately overlies the original St. Josephs oil and gas field where some 20 wells were drilled to depths of 100—115 m and which produced oil, gas, and water. The proximity of this field to the larger and deeper Stony Creek oil and gas field on the west bank of the Peticodiac opposite the St. Josephs field, leads to speculation as to their possible relationship. Although there is no direct correlation between He and CH_4 in this area, the second highest He value encountered in the survey occurs in the same general area. The highest He value, 10,200 x 10^{-5} std. cm^3/1, was found in the Baie Verte area where there is no evidence of CH_4. There is, however, another anomalous CH_4 site south of Shediac, similar in magnitude to the ones south of Moncton. It is unexplained but seems to lie along a large basement lineament visible on aeromagnetic maps. Spotty, weak CH_4 highs appear unexplainably in various parts of Nova Scotia. In the Horn Point area a more pronounced anomaly, similar to the one near Point Escuminac is visible. Topographic maps do not indicate extensive swamp lands. Some follow-up is therefore indicated here. When this survey was planned it was hoped that CH_4 would give some indications of the coal fields in Nova Scotia. This obviously did not happen. Either the sample density was too low or the coal fields in the area are too well sealed from the aquifers used for domestic wells.

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CONCLUSIONS

Well water surveys at a sample density of one sample per 13 km^2 are useful and informative in delineating regional anomalies of trace elements.

The contrast between background and anomalous trace element values is greater in well waters than in stream sediments. This is particularly evident in the case of U in areas of higher than normal alkalinity.

The results of the well water survey invite considerably more detailed follow-up and interpretation.

The U, Rn, He, and F results of this well water survey suggests the existence of a roll front of chemical cells that were responsible for the deposition of U at some time in the past and now are being leached by circulating groundwaters. Whether this deposition resulted in economic grade ore is not known. It may well have been an intermediate phase in the cyclical enrichment process suggested for such epigenetic U ore deposits.

The heavy metals Zn, Cu, Pb, Mn, and Fe appear in anomalous amounts near several known deposits of their kind and a number of places where such deposits are not known at the present time.

The CH_4 content in well waters revealed the existence of a known unproductive gas and oil field as well as CH_4 generated by peat and swamp lands.

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