

HELIUM ISOTOPE DATING OF PORE WATER
IN THE ST. CLAIR BASIN

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Abstract

An age of approximately 55K years was found for the St. Clair basin clays using helium isotope dating. This is about 5 times larger than the date obtained from the more accepted carbon-14 method and from other geological evidence. Diffusion of helium from crustal rocks against a flow of approximately $0.03-0.05 \text{ cm a}^{-1}$ is the primary reason for this discrepancy. Mixing of the groundwater with a meteoric component has an opposite effect tending to lower the helium age.

INTRODUCTION

A safe supply of drinking water is a basic necessity for any community. For the proper management of waste disposal it is vital to understand the movement and age of groundwater. It is common practice to establish disposal sites on glacial clays since they are accessible and groundwater movement within them is typically slow. The St. Clair basin located in southern Ontario contains an extensive clay plane which may provide many potential dump sites.

The radioactive decay of uranium and thorium produces helium which is released from the solid phase if the escape path is short enough. If the production rate of helium is known and the concentration of helium produced in situ can be measured, then the age of the pore water can be found. To accurately date the water the degree of contamination of helium from other sources must be known.

If a high concentration of dissolved material is released into a porous media then both dispersion and convection of molecules takes place. The transport of material depends on porosity, diffusion coefficient, hydraulic conductivity and hydraulic gradient. If the boundary conditions of the system are known at the time of implacement of the solute material, than a theoretical concentration profile can be generated. From the time of implacement, the St. Clair basin clays may have undergone contamination from mantle sources which can be described by a theoretical concentration profile.

THE STUDY SITE

The St. Clair basin glaciolacustrine clay and tills which are bordered by the lakes Erie, St. Clair and Huron are generally up to 40 meters thick. The site investigated was near Sarnia along the western edge of the basin. The clayey till consisted of ground-up Devonian limestones on which the section unconformably lies. The sediment grain size is generally fine with 40-60% clay, 30-40% silt, 5-10% sand and <5% gravel size particles. The mineralogical composition of the tills is mainly, carbonates, quartz, feldspars and shale fragments. The stratigraphic section can be divided into two main units with the St. Joseph till overlying the Black Shale till.

The upper unit has a total carbonate content of approximately 40 to 50% with a calcite-dolomite ratio between 0.5 and 1.0. Lithic fragments which make up a portion of the rock are from igneous, metamorphic and carbonate provenances. The lower unit has a decreased carbonate content of approximately 30-40% but a higher calcite-dolomite ratio between 1.1 and 1.5. Rock fragments which appear in this unit are restricted generally to black shale clasts. The dominant clay minerals of the sections include illite, chlorite and minor amounts of kaolinite.

The top 4 meters of the clay plain is characterized by a weathered zone. Oxidation and desiccation of the soil has taken place and minor amounts of the clay minerals smectite and vermiculite have formed in this area. Secondary gypsum which occurs in fissures have been reported to a depth of 10 m. (Desaulniers and authors within, 1980).

Sampling of water and stratigraphy was done by drilling a series of holes to various depths at regular intervals of 3 meters. Sediment samples were taken at the bottom of each hole using Shelby tubes. Sections of core for study were therefore only available at certain heights which were at approximately 6 meter intervals.

Piezometers were installed at the bottom of each hole in order to measure the hydraulic conductivity and hydraulic head. The piezometers also collected ground-water for subsequent water chemistry and isotope studies. To insure the proper determinations were made of the concentrations of ^{18}O , ^2H , ^3H , major ions, and carbon and helium isotopes specialized procedures were used to sample the pore waters. The water samples taken for helium isotope analysis were sealed in a copper tube with pinch-off clamps. The contamination of helium in the tubes from the atmosphere is less than 0.1% over a storage time of 10,000 years. (Clarke and Kugler, 1973). The analysis of the pore water chemistry and carbon-14 dating was done by Desaulniers (1980).

AGE AND PALEOCLIMATE IMPLICATIONS OF ^3H , OXYGEN AND CARBON-14 DATA

The ^3H level in precipitation was increased from 5-20 tritium units to several hundred T.U. during the advent of atmospheric nuclear testing in the early 1950's. This drastic jump in tritium can be used to map the progress of meteoric water over the last thirty years. Desaulniers (1980) has shown that the increased amount of tritium has penetrated the St. Clair basin clays to a depth of 3-4 meters. The rate of meteoric influx, about 12 cm/g, through the fractured soil zone is probably a great deal faster than water movement in the deeper clays.

A plot made of $\delta^{18}O$ content with 2H content measured in precipitation defines a so called meteoric water line. The measurements for the groundwater samples plotted on the graph fit within an acceptable 95% confidence limit for the meteoric water line. (Desaulniers 1980). This indicates that the original pore waters did not undergo either evaporation or condensation. With the $\delta^{18}O$ signature of the water paleotemperature at the time of emplacement can be found. Due to the influx of modern meteoric water shown by tritium results the upper few meters the $\delta^{18}O$ values which exist here are typical for present-day precipitation. As you go deeper in the section the $\delta^{18}O$ signature approaches a value which is similar to those found for modern waters in the Arctic.

Evidence which supports the hypothesis that the tills were formed in a colder climate comes from shell and mollusk data. Fritz et al (1975) has guessed that $\delta^{18}O$ values which range between -18 and -20‰ (SNOW) taken from fossils in the basal till represent the Port Bruce advance of the Erie lobe during the last period of glaciation about 13,200 years ago. A similar $\delta^{18}O$ range was obtained by Desaulniers (1980) through the theoretical calculations using a temperature regime between 4-17 c. If the prediction of formation of the tills at the end of the last period of glaciation is correct then this would represent the maximum possible age of the pore waters. The paleoclimatic data given above provides vague information on the time of till deposition, groundwater emplacement and the original composition of the pore water.

The depositional history of the St. Clair basin clays has been studied by several authors and is also important in giving clues to the time of original deposition and condition of the groundwater. It has been

hypothesised by Gass et al (1961) that due to the lack of characteristic till features, the environment of depositions was sub-aqueous. Variation in this environment at the time of deposition, creating dessication at various stages may have caused differences in the moisture content, shear strength and preconsolidation pressures observed over the height of the section.

Palynological data and the appearance of overconsolidation in the upper layers has led some authors to believe that after deposition the groundwater levels have dropped. This corresponds to the dry climate which prevailed about 9000-11000 years ago. The lowering of the groundwater probably didn't greatly affect the isotopic composition of the water.

From the evidence collected by several authors it is generally believed that the clays were deposited during the last glaciation period about 10,000-13,000 years ago (Desaulniers and authors within, 1980). The paleotemperature data from $\delta^{18}O$ values suggests that the deep pore waters in the clay were isolated during a much colder climate. Therefore it is reasonable to suggest that the pore waters were trapped during the sub-aqueous deposition of the clays or soon thereafter. A more absolute age of the pore water can be obtained from carbon-14 dating.

The carbon-14 ages of groundwater samples were found through analysis of total dissolved inorganic carbon by Desaulniers (1980). The corrected ages were calculated by a specialized computer program which simulates the chemical evolution of the groundwater in a closed system. The main source of error in the ages would arise from the presence of CO_2 . The decay of organic material in an anerobic environment produces biogenic methane and CO_2 as a by-product. An area which is high in biogenic methane can be

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predicted from the diagnostic delta C value which it gives. CO₂ could also be produced in the system by other processes such as oxidation of methane which are not well studied. The diffusion of CO₂ from outside the system is another possible source of excess carbon. The presence of organic carbon tends to increase the estimation of groundwater age. The carbon-14 ages of the groundwater given on table #1 therefore would probably represent maximum values. This of course is assuming that there has been no meteoric recharge at depth.

DETERMINATION OF GROUNDWATER VELOCITY

The velocity of the groundwater can be found using Darcy's eqn.

$$V = Ki/n \quad (1)$$

where K = hydraulic conductivity
 i = hydraulic gradient
 n = porosity

The values for K, i and n were measured by Desaulniers (1980). Triaxial cell and time consolidometer tests were used in the lab to find a value for K. The tests agreed within 20% which represents a reasonably accurate determination of intergranular hydraulic conductivity. The values for the samples of clay range from 0.83-7.5 (10⁻⁸ cm/s) with a geometric mean of 2.8 (10⁻⁸ cm/s). The value for K as measured in the field was determined from the rate of water level rise in piezometers using the method of Hvorslev (1951). The agreement between the field and laboratory results are reasonable with the range and geometric mean of the field being 1.0-6.2 (10⁻⁸ cm/s) and 1.4 (10⁻⁸ cm/s) respectively.

The porosity of the clays ranged from 0.29 to 0.41.

Agreement between the field and lab results for the hydraulic conductivity indicates that there is not extensive water transport due to

fracturing. There were no fractures observed at depth and it is possible that expandable clay minerals may have partially sealed fissures which occur in the upper 6-10 meters.

The hydraulic gradient was found by measuring the average hydraulic head at each piezometer level and finding the change in water pressure with depth. The downward vertical gradient for the clay section ranged from 0.02 to 0.17.

The linear average groundwater velocity found using eqn #1 has a range of 0.04-0.46 cm/a with a geometric mean of 0.16 cm/a downward. The geometric mean may not be a fair representation of the true velocity since the hydraulic conductivity value cannot be averaged over the section. If the value for K falls on the lower end of the range for one part of the stratigraphy it will lower the groundwater velocity for the entire section.

HELIUM AND URANIUM-THORIUM ANALYSIS

The water samples were sealed in copper tubes at the time of sampling in order to prevent contamination by atmospheric helium. Using a vacuum line as described by Clarke and Kugler (1973) the water samples were degassed, removing the inert gases from solution. Trapping some of these gases in activated charcoal cooled to liquid nitrogen temperatures allowed the separation of helium and neon. The He-Ne sample was then divided and sealed into two sample tubes made of very low permeability pyrex 1720 glass. The A-Kr-Xe component of the gas was trapped in a separate tube after purification of the sample by a heated titanium sponge.

During the mass spectrometric analysis the degassed helium samples were filtered again in a similar manner. The dual collection (³He,

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He), 10 inch radiums spectrometer operated in the static mode was specially designed for the high sensitivity measurement of helium isotopes. The spectrometric analysis involved the measurement of ^4He and the $^3\text{He}/^4\text{He}$ ratio. Absolute values were found by correcting the original measurements with values found from air standards. These standards were run at regular intervals in order to check the performance of the machine. The background radiation taken periodically during each run was averaged and subtracted from the ^4He count.

Neon which was sealed in the sample tubes with the He can be used to check for air contamination and to cross-check the He ages. With a similar method that is used for He, Ne dates can be found through the production of radiogenic ^{21}Ne and ^{22}Ne . In the case due to the relatively young age of the groundwater there is not enough radiogenic Ne to be accurately measured.

The values for the $^3\text{He}/^4\text{He}$ and the absolute measurements of ^4He and He excess are summarized on table #2. The excess values were calculated by removing the atmospheric component that was in the groundwater at the time of deposition. The size of the original meteoric component may be over-estimated slightly, since a value for 20°C was used when the true deposition temperature was likely between $4^\circ - 17^\circ\text{C}$ as previously mentioned. It can be seen from table #2 that the ^4He excess value increases with depth.

The uranium and thorium concentrations were found using the method of delayed neutron reaction in the nuclear reactor, by nuclear activation services at McMaster University. Preparation for U-Th analysis involved grinding up small quantities of the clay unit, sampled at several heights. This was done to ensure that the non-homogenous particle size of

the clays did not effect the consistency of the U and Th analysis. Two runs were made for each level of the section and agreement between the duplicates was good. Some variations in the U and Th concentrations existed but there were no trends that could be recognized. The values for U and Th are listed on table #3. The concentrations of U and Th are relatively close and the Th/U ration varies from 1.1 to 2.3.

The lithium content of the clays was measured but unfortunately the attempt provided unreliable results. The values for the lithium content ranged from 26 to 48 ppm. Due to the nature of the procedure used for measurement, the true values for lithium are probably higher. The value for lithium of 60 ppm as suggested by Andrews (1983) for a typical clay seems reasonable.

The measurement of the concentrations of other elements, such as boron, which may be important in the production of helium was not made.

RADIOGENIC HELIUM PRODUCTION

Atmospheric helium if supplied solely by diffusion from the crust would have a ${}^3\text{He}/{}^4\text{He}$ ratio similar to the production ratio for crustal rocks. Since the ratio for atmospheric helium (1.38×10^{-6}) is several times to orders larger than typical production rates for lithospheric material there must be an alternative source for ${}^3\text{He}$ since ${}^4\text{He}$ is not lost preferentially through the atmosphere. Libby (Andrews and authors within 1984) has explained the excess ${}^3\text{He}$ to be due to cosmic ray produced neutrons which react with nitrogen in the atmosphere. Meteoritic material and cosmic dust also adds to the ${}^3\text{He}$ component. Spallation reactions in meteorites would raise the ${}^3\text{He}/{}^4\text{He}$ ratio since the internal production rate is approximately 0.3. The direct influx of ${}^3\text{He}$

in cosmic rays and solar winds is also significant. The concentration of helium is kept low (4.7×10^{-8} cc STP)/g H_2O) by loss of helium through the atmosphere. The rate of input of helium from atmospheric and crustal sources and loss due to escape from the earth's gravitational field are constant, therefore it can be assumed that the equilibrium concentration of helium has also remained constant over time.

The radiogenic production of 3He on a rock is due mainly to the reaction ${}^6Li(n, \alpha){}^3He$, with the production rate of 3He being equal to that of 3H . The production rate is given by

$$P = nF_{Li} \quad (2)$$

where F_{Li} is the fraction of neutrons captured by 6Li and n is the number of neutrons. F_{Li} is dependant on the neutron capture cross-section of Li , the number of Li atoms, as well as the number of neutrons captured by other elements in the matrix. Due to their large neutron absorption cross-sections B and Gd contents can greatly affect the number of neutrons captured by Li .

Neutrons involved in the reactions are created mainly by (α, n) reactions on light nuclei. The α particles are produced primarily through U and Th decay. Therefore the neutron production can be estimated by the relationship

$$n = f(R, Na, Mg, Al, Si, Ca) [U]$$

$$\text{where } R = Th/U$$

and using eqn #2 it is evident the 3He production rate is given by

$$P = f(R, Na, Mg, Al, Si, Ca) \cdot [U] \cdot F_{Li} \quad \text{atoms a}^{-1} \text{g}^{-1}$$

The production rate of 3He depends only on the concentrations of U and Th and is given by;

$$P = 3.2108 \times 10^6 [U] + 7.7632 \times 10^5 \cdot R \cdot [U] \quad \text{atoms a}^{-1} \text{g}^{-1}$$

The production ratio is then

$$P/P = \frac{f(R, Na, Mg, Al, Si, Ca)FLi}{3.2108 \times 10^3 + 7.7633 \times 10^4 \cdot R}$$

The production ratio for a rock is therefore not greatly influenced by the Th/U ratio but is strongly dependant on F_{Li} . Since reasonable U and Th contents have been ascertained and F_{Li} can be predicted for a typical day the production ratio for the section can be estimated. With [U] and [Th] being 7.3 and 10.4 ppm respectively, the calculated He production rate is 1.176×10^{-12} cm a. Using the predicted value of 60 ppm for Li and typical concentrations for the light elements and those with high neutron absorption cross-sections the estimated He^3/He^4 production ratio is 2×10^{-8} . This gives a He production rate of 2.353×10^{-20} cm a. If all the helium produced in-situ was released, then the production rates for the rock would be the radiogenic He^3/He^4 rates. Similarly if He^3 and He^4 are released at the same rate, the production ratio of the rock will equal the radiogenic production ratio.

The St. Clair Basin clays lie unconformably on limestones of Devonian age. Under this extensive carbonate layer is the granitic craton. The production ratio of a granitic rock is approximately 2×10^{-8} . The concentration of helium is high in craton pore waters due to in part to their age and also to accumulation of excess helium through uranium enrichment and/or primordial helium from the mantle. The diffusion rate of helium through solid granite is low so the predominant mechanism for the transport of helium would be through fissures in the craton.

A typical limestone has a production ratio of approximately 0.2×10^{-8} . The concentration of helium in the limestone would also be high

due to in-situ production and diffusion from the craton. The effect that the helium derived from lower layers would have on the helium concentrations of the clay section would depend on the rates of diffusion. Considering the high helium concentrations found by Bottomley et al (1984) in fissures through the Canadian Precambrian shield and the probability that the limestone layer is similarly fractured also with high helium concentrations it is reasonable to assume that there would be diffusion from these lower units. It is also likely that the diffusive influx would have a $^3\text{He}/^4\text{He}$ signature which is dominated by that of the limestone unit.

CALCULATION OF AGE FROM HELIUM DATA

To calculate the residency time of the pore water from helium measurements, certain criteria must first be met. The helium that is produced in the grains must all be released. Since the clays are predominantly made up of material with clay and silt size grains (<2 μm) and the porosity is high (approx. 40%) it is reasonable to assume that most of the helium produced radiogenically is released into the liquid phase. It must also be assumed that there has been no contamination from meteoric waters or from helium produced in other layers. Release of helium by dissolution of minerals must also be zero. Therefore all the helium in the system should be only the original meteoric component and that which is produced in situ by radiogenic decay. Examination of the validity of the above assumptions will follow.

The production of helium in a rock is proportional to the porosity of the matrix and inversely proportional to its density. The expression for residency time is

$$t = \frac{H (R_3 - R_4 (1-R_3))}{(R_4 P_3 - P_4)}$$

which can be simplified (since $(1-R_3)$ approx equals zero) to

$$t = \frac{H_A}{R_4 P_3 - P_4} \frac{R_3 - R_4}{R_4 P_3 - P_4} \quad (3)$$

- where ρ = porosity
- ρ_A = density
- $P_3 - P_4$ = production rates of He_3, He_4
- $R_3 = He_3 / He$ measured
- $R_4 = He_4 / He$ atmospheric
- H_A = solubility of atmospheric helium of 20 c

The values of P_3, P_4 for the clays have been previously calculated. The porosity and density used are 0.4×10^6 cc/m and 2×10^3 g/m respectively, the first obtained by direct measurement, the second typical for a clay.

The calculated ages for the groundwater given by eqn #3 are listed on table #1 with the corrected C^{14} values. The trend of increasing age with depth is followed by both carbon and helium methods but at depth the helium ages range from 4 to 6 times higher than carbon ages. It has been found by several authors that helium dating overestimates the age when compared to simpler measurements by C^{14} . (Andrews and Lee, 1979; Andrews et al., 1982; Bottomley et al, 1984). The C^{14} dates, paleoclimatic and geological history strongly suggest that the age of the groundwater is between 10,000 and 13,000 years. This means that there are alternate source(s) of helium and some of the assumptions made in order to do the calculations are incorrect.

One source of excess helium may be from dissolution of clay material and release of trapped He . The amount of total dissolved solids reaches a peak about 5m below the surface, falls off quickly and reaches a constant

low value at depth. Although the information involving this problem is vague, there doesn't appear to be a dramatic increase in helium with increase in TDS. Therefore the helium derived from dissolution can be considered negligible.

The source of excess helium is most likely diffusion from below. Since the helium concentration in the original meteoric water was low, a concentration gradient would immediately cause the upward diffusion of helium. In order to understand the movement of the helium in the matrix a theoretical concentration profile must be developed.

THE TRANSPORT AND MIXING OF HELIUM

Where both a concentration and hydraulic gradient exist the movement of solute material in pore water involves both convection and dispersion. This complex problem requires that some assumptions be made in order to simplify calculations. First the concentration of the atoms in the pore water must be small enough to assure that dispersive velocity is instant. The convective velocity must also be constant which requires that the hydraulic gradient is constant and the media is homogeneous.

The flow of solute material through saturated porous media is given by the eqn (Al-Niami, 1977).

$$\frac{dc}{dt} = D \frac{d^2c}{dx^2} - V \frac{dc}{dx}$$

where c = concentration of dispersing material
x = distance and direction of flow
V = flow velocity
D = dispersion coefficient

The dispersion coefficient in a porous media is given by the expression

$$D = D_w n$$

where n = porosity
D_w = dispersion coefficient in H₂O

With the use of boundary conditions the solution of the above differential eqn and theoretical curves were found by Al Niami.

In order to test the validity of the assumptions made the theoretical concentration profile of ^{37}Cl was checked with actual measured values. The late Silurian bedrocks, below the clay section have a characteristically high content of ^{37}Cl . Therefore the migration of ^{37}Cl from below affected only by diffusion and convection is the only major source of the atom. It was found by Desaulniers (1980) that the theoretical and real concentration profiles corresponded closely when a flow velocity of 0.03 cm^{-1} was used. The profile and boundary conditions used are shown on fig #1. The theoretical profile shows the steady state condition which would exist after approximately 10,000 years. Discrepancies which exist near the surface are due to quick meteoric infiltration through the weathered and fractured upper zone.

The dispersion coefficients of ^{37}Cl and ^4He are equal and the boundary conditions at the time of emplacement of the groundwater are also similar. Therefore the theoretical concentration profile for helium will be similar to that of ^{37}Cl . The concentration of helium in the clays has the added complication of in-situ production of a radiogenic component. This excess radiogenic He can be removed by finding the amount produced over the residency time (given by carbon dating) and subtracting it from the total helium concentration.

As with the ^{37}Cl profile the measured helium points generally correspond with the theoretical profile for flow against dispersion. The uppermost sample falls below the curve due to the lowering of the helium concentration due to meteoric influx. Points which fall far off the curve all occur between a depth of 18 to 27 meters below the surface. Samples

in this area all have excess helium values larger than that predicted by the theoretical concentration profile.

Possible explanations for the discrepancy involve the production and movement of helium in the clay. Increasing the U and Th concentrations of the clays would increase the helium which is radiogenically produced. The amount of the radiogenic atoms that would have to be added would be large and the measurement of U and Th revealed no significant change in their concentrations with depth.

Dissolution of clay minerals causing the release of trapped helium may have caused the aberration in the concentration profile. The measurement of total dissolved solids did not show any increase in the area of high helium concentration.

The nature of the clay matrix may also be the cause of the helium anomaly. Inspection of core samples at different heights revealed variations in the consolidation, density and composition of the clays. The production and release of helium which relies on porosity and density might be affected by changes in either the environment of deposition or degree of consolidation. A decrease in the grain size of the clays may cause a slight increase in helium by allowing the quick release of the radiogenic atoms. It is also possible that a heterogeneity in the sediment may restrict the passage of helium. It was shown before that the diffusion of helium upward is strongly dependent on porosity.

The actual mechanism which has maintained a large helium component in the mid-section of the clays, may include one or more of the above possibilities. In order to obtain a more accurate reason for the source, a more detailed study of the stratigraphy must be made. Changes of the porosity density and hydraulic conductivity with depth must be ascertained to more completely solve this problem.

The mixing of the in-situ radiogenic, allocthonous radiogenic and recent meteoric helium with the original meteoric component of helium are shown on fig #2. The graph of helium content is $\frac{^3\text{He}}{^4\text{He}}$ examines the effect of mixing increasing amounts of a specific $\frac{^3\text{He}}{^4\text{He}}$ ratio to an atmospheric component. The curves on the graph represent the production ratio for clay (2×10^{-8}), limestone (0.2×10^{-8}) and an infinitely small ratio. Below the infinitesimal line lies a forbidden region in which the $\frac{^3\text{He}}{^4\text{He}}$ ratio is impossible since ^3He production always accompanies ^4He production. The majority of the points fall between the clay and limestone lines which is what one would expect with mixing of the two. If you removed the ^3He concentration due to the influx of allocthonous helium, the points would be shifted from their present positions diagonally downward to a point on the production curve for clay at a lower concentration level.

The three samples closest to the surface lie above the clay line which signifies they have been mixed with a meteoric component with a higher $\frac{^3\text{He}}{^4\text{He}}$ ratio. The sample taken 6 meters below the surface has a $\frac{^3\text{He}}{^4\text{He}}$ ratio which is almost totally dominated by meteoric water, but the concentration of helium is much higher than that of atmospheric. This means that helium produced in the limestone or carbon has greatly affected the groundwater concentration even this close to the surface. Samples taken at a depth of 18m show the effects of meteoric influx but not to a great extent as is found in the weathered zone.

The lowest two points in the section fall into the forbidden region on the graph. This cannot be explained physically and the discrepancy is probably due to errors in measurement of helium.

The flow velocity which allowed the closest correlation of measured and theoretical concentration profiles falls between 0.03 and 0.05 cm^{-1} . This is in agreement within the range of velocities given by the Darcy equation but is well below the geometric mean calculation of .16 cm^{-1} . The calculated mean velocity would produce meteoric contamination up to 30m below the surface and since atmospheric influx only reaches to approximately 20m the Darcy calculation overestimates the value. This error could be due to incorrect determinations of the hydraulic conductivity and gradients.

The hydraulic conductivity of a layer of the bed could be reduced by overconsolidation. There are layers within the section which are slightly overconsolidated possibly due to lowering of the groundwater level or change in depositional environment (Adam, 1970). Such a layer may be the cause of the anomalously high helium concentrations in the clays from 18 to 27 meters below the surface.

It is also a possibility that the groundwater was moving faster in the past than it is now. Post glacial uplift may have produced an increasing hydraulic gradient over time (Desaulniers and authors within 1980). Due to the closeness of fit for the theoretical profile with the real concentration profile and the depth of penetration of meteoric water, the increase in hydraulic gradient would of had to have happened relatively recently and quickly.

CONCLUSION

In the case of the St. Clair basin clays near Sarnia, helium dating gives ages which are larger than those given by carbon-14. Considering other evidence about the age of the pore waters it is quite possible that

the carbon dates are correct or at least represent a maximum value. The excess helium cannot be explained by errors in either the values used for porosity or uranium and thorium content since these quantities were carefully determined. The helium content also doesn't correlate well with the amount of total dissolved solids so dissolution of minerals probably is not a major source of helium. The measured $^3\text{He}/^4\text{He}$ ratio of the pore water indicates mixing of in-situ and allocthonous components of radiogenic helium. The excess helium is therefore probably derived from a crustal source.

In order to use helium effectively as a dating technique, its accumulation from crustal sources must first be found. This depends on the production and diffusion rates of the underlying rocks. The transport of helium is difficult to ascertain since the presence of fissures can greatly affect the speed of flow and diffusion. Through increased understanding of the whole earth flux of helium and the affect of fissures on diffusion perhaps eventually corrections for crustal contamination may become useful in the calculation of helium dates.

At the present time care must be taken in calculating the age of porewater using helium methods since it is likely that the age may be overestimated. It is important that a true estimation of residency time is made when dealing with the burial of toxic material.

The transport mechanism of solute material is also very important when dealing with waste disposal. With the example of helium in the clays it was shown that dispersion and not convection was the dominate mode of transport. It is therefore vital to consider both even when they are in opposite directions.

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TABLE #1

Depth (M)	¹⁴ C (a) Mean adjusted age	He (a)	He/C
6	3,250	205	.06
12	4,179	15,138	3.6
18	4,390	26,786	6.1
24	<u>a</u> — <u>b</u> 9,129	<u>a</u> 44,842 <u>b</u> 41,207	<u>a</u> — <u>b</u> 4.5
27	—	55,000	—
31	8,186	45,289	5.5
37	13,191	55,148	4.2
44	—	110,758	—

TABLE #2

Depth (m)	$^3\text{He}/^4\text{He}$ ($\times 10^6$)	^4He ($\times 10^8$)	ccS-P/gH O ₂	excess ^4H ($\times 10^8$) cc STP/gH O ₂
6	1.350	6.91		2.41
12	.492	15.81		11.31
18	.334	25.29		20.79
24a	.214	19.66		15.16
24b	.242	27.42		22.92
27	.177	38.04		33.54
31	.222	31.04		26.54
37	.193	33.33		28.83
44a	.112	46.31		41.81
44b	.113	43.54		39.04
	errors 1-2%			

TABLE 3

Depth (m)	[U] ppm	[Th] ppm	Th/U
6	6.9, 6.8	10.7, 10.7	1.6
12	7.0, 6.6	11.0, 10.7	1.6
18	6.8, 7.1	10.3, 10.4	1.5
21	8.2, 7.2	10.2, 10.4	1.4
24	4.9, 4.9	11.2, 11.4	2.3
27	8.7, 8.8	9.4, 9.1	1.1
37	7.1, 7.3	10.3, 10.4	1.4

Figure #1

Theoretical concentration profile of Cl and helium for upward diffusion against downward flow. The solid line represents calculated values and points represent measured values of the concentration.

Boundry Conditions

$$C(0,t)=0 \quad \text{always}$$

$$C(x,0)=0 \quad \text{for all } x \text{ from the surface to a depth } L$$

$$C(L,t)=C_0 \quad \text{always}$$

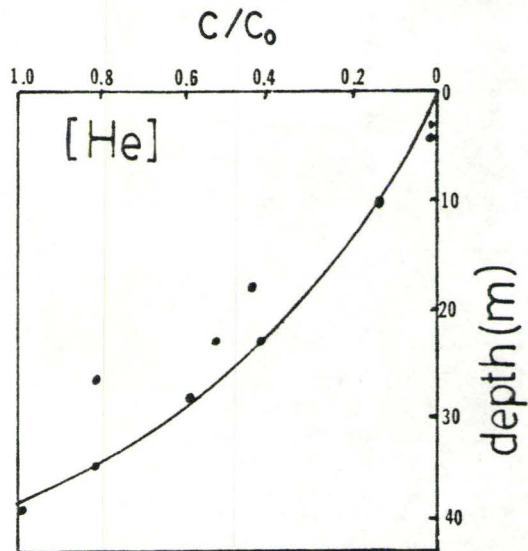
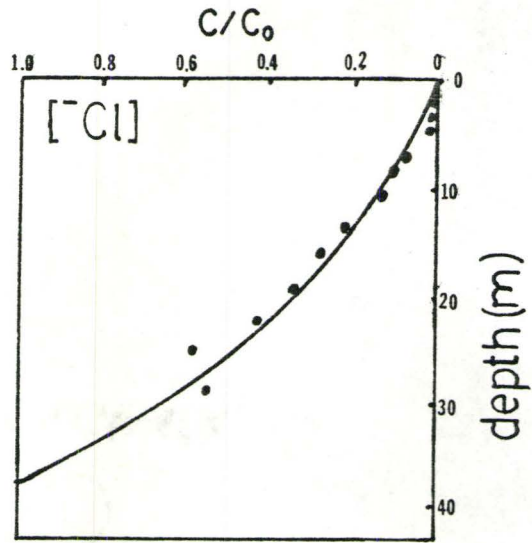
where C =concentration
 C_0 =concentration at depth L
 t =time
 L =maximum depth

For the generation of the theoretical concentration profile the following quantities were used for both Cl and helium.

$$D_w=1 \times 10^{-5} \text{ cm}^2 \text{ s}^{-1}$$

$$D_e=3 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$$

$$V=0.03-0.05 \text{ cm a}^{-1}$$



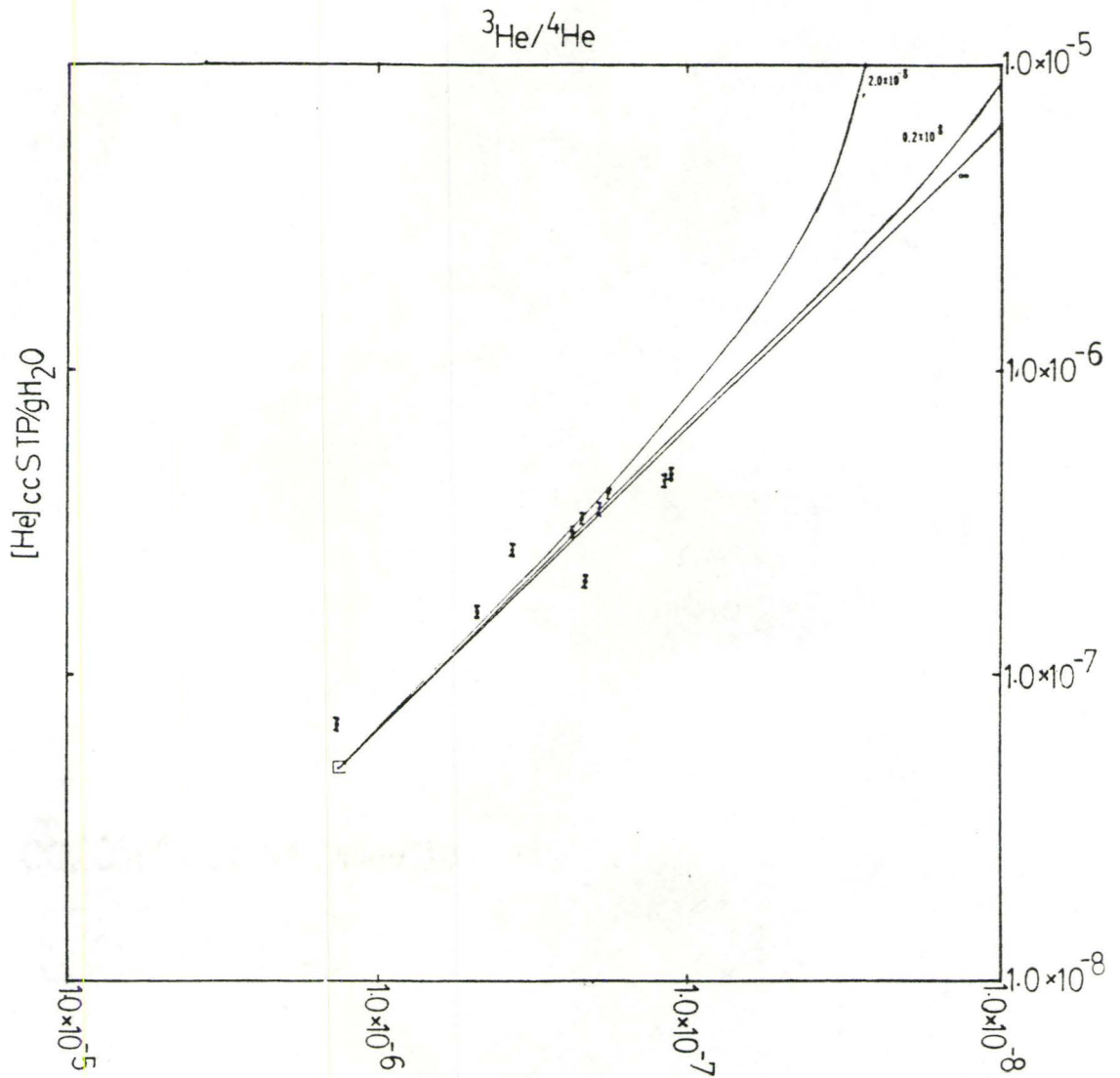


figure #2

Plot of helium concentration vrs. ${}^3\text{He}/{}^4\text{He}$ ratio.
 The solid lines represent mixing of a component
 with a specific ratio to a meteoric component.