A MINERALOGICAL AND CHEMICAL STUDY

OF THE LOWER FRASER RIVER ALLUVIAL SEDIMENTS

by

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ABSTRACT

A mineralogical and chemical study was conducted on the
clay fractions of lower Fraser River alluvial sediments. The
major objectives of the study were to characterize the mineralogy
of these sediments and to evaluate the influence of a marine
environment and sedimentary phases of deposition on their
mineralogical content.

Twenty-one sampling sites representing the four major soil
series developed on these sediments and six sea bottom samples
were collected. Surface and subsurface samples were taken for
the soil series.

X-ray diffraction analyses were conducted on the coarse
and fine clay fractions of all samples and the total K, Mg and
Ca contents of the clay fractions were also investigated.

With the exception of samples from the Pitt Meadows area,
there was a marked similarity in the clay mineral suite present
in these sediments. The major clay mineral components of the
coarse clay fraction were montmorillonoid and chlorite. Lesser
amounts of micaceous material and several interstratified clay
minerals were also present. The interstratified clay minerals
identified included a randomly interstratified chlorite-
montmorillonoid and chlorite-mica and in a limited number of
cases regularly interstratified chlorite-montmorillonoid. The
identification of a regularly interstratified chlorite-mica
was quite questionable.

Positive identification of kaolin was prevented in most instances by a heat unstable chlorite. However, kaolin was identified in a sample from the Pitt Meadows area and there was strong evidence to suggest its presence in other samples.

Quartz, feldspars and amphiboles were the only non-phyllosilicates identified.

The fine clay fractions were dominated by montmorillonoid and much lesser amounts of chlorite. Micaceous material, inter-stratified clay minerals and quartz were present in only questionable amounts and in some instances appeared to be absent.

The chlorite was identified as an iron rich variety possessing thermally unstable higher order reflections. A progressive decrease in the relative intensity of these reflections was observed on heating from 400 to 450°C. Furthur heating to 500°C resulted in the disappearance of the peaks.

The montmorillonoid component identified appeared to be of two types: An octahedrally substituted member and a tetrahedrally substituted member. The presence of the latter mineral prevented identification of vermiculite.

The results support the findings of other workers that marine deposited sediments are highly detrital in nature, dominantly reflect their source area and are influenced by sea water to only a minor extent. Diagenesis of 14 A° material of the marine sediments was indicated by X-ray diffraction analyses. Chemical analyses were also indicative of the minor influence of a marine environment.

Mineralogical variations within and among soil series were largely quantitative in nature. These variations tended to be minimized within a particular soil series. Mineralogical differences between the two clay fractions were observed, however, these were to be expected.

The variations noted in the mineralogy of the clay fractions of these sediments were attributed to sedimentary processes, seasonal variations in the detrital components carried by rivers, yearly variations in particular source areas and the local influence of sediments carried by several tributaries of the lower Fraser River that flow out of the Coast Mountains.

The X-ray and chemical analyses indicated that there was a valid basis for continued mapping of the Pitt soil series separate from the Monroe and Fairfield series. The two sampling sites from the Pitt Meadows were considerably higher in randomly interstratified chlorite-montmorillonoid and lower in micaceous material than those of the other sediments. Chemical analyses were also indicative of these differences.

The variability noted in soils from the Pitt Meadows area may be related to the influence of sediments carried by the Alouette River.

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INTRODUCTION

The recent advancements in X-ray diffraction techniques have resulted in the development of clay mineralogy to a point, where it now finds application in numerous fields of the applied sciences. In soil science, it has proved to be useful in the study and characterization of soils in relation to their formations, classification and utilization.

Up to the present, only a limited amount of mineralogical work has been conducted on the soils of British Columbia. Therefore, it was decided to undertake furthur studies using these techniques.

Preliminary work was carried out on several soils in the spring of 1963 and from this, it was decided to conduct furthur work on some of the alluvial sediments found in the lower Fraser Valley of British Columbia. These sediments are of considerable geological interest and provide the parent material of some of the most productive soils of the region.

The present study is largely devoted to X-ray diffraction analyses of the clay fractions of several of these sediments. The major objectives were to characterize their mineralogy and to evaluate the effect that such factors as a marine environment and sedimentary phases of deposition have on their mineralogical content.

LITERATURE REVIEW

(i) Description of the area

The lower Fraser Valley is located in the extreme south
west corner of the British Columbia mainland. It is a triangular
shaped area bordered by the Strait of Georgia on the west, the
Coast Mountains on the north and the Canada-U.S.A. border on the
south. The Cascade Mountains which form the apex of the triangle
are located approximately 80 miles to the east of the Strait of
Georgia (Figure 1). This area forms one of the largest blocks
of arable agricultural land in British Columbia.

The major physiographic feature of the lower Fraser Valley
is the Fraser River whose basin lies almost entirely within the
province of British Columbia and has its source in the Yellowhead
Pass in the Rocky Mountains (48). It attains a length of approx-
imately 850 miles and drains an estimated 90,000 sq. mi. area
(54). Within the lower Fraser Valley, the Fraser River exhibits
a braided channel pattern (50) and terminates in a growing delta
at the Strait of Georgia.

The physiography of the land mass of the lower mainland,
described herein, consists of four major divisions:

- recent delta

- recent floodplain

- raised delta

- upland area associated with the Pleistocene Age.

The recent delta begins where the first distributary is given
off at New Westminster and extends approximately 19 miles to the
Strait of Georgia (3). Tidal flats extend an additional 3 miles

seaward from the edge of the dyked areas of the delta. The
delta is reported to be growing at the rate of 28 feet per year
at 50 fathom contour and at a somewhat lesser rate in shallower
waters (54). For the most part, the delta area is below the
high tide mark and the region is dyked to exclude flood tides.
The majority of the soils in the delta area are mapped within
the Ladner soil series (68).

Recent floodplain deposits occupy an area adjacent to the
Fraser River from New Westminster to Agassiz. The width of
the floodplain in this region is quite variable, reaching a
maximum in the Chilliwack region and being of more limited extent
from Chilliwack to New Westminster due to the adjacent uplands.
The elevation of these sediments ranges up to 45 feet above the
sea level (20). Dykes are located adjacent to the river flanks
to prevent flooding during the freshet months of May, June and
July. The floodplain deposits appear to be typical of those
reported in other areas (83). Extensive areas of lateral
accretion deposits[1] occur adjacent to the river banks. These
deposits are generally charaterized by gentle ridge and swale
topography and are largely mapped within the Monroe and Fairfield

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[1]
Lateral accretion deposits are formed on the inside of a river
bend due to the existance of circulatory motion associated with
the channel bend. Material for their formation is derived from
lateral cutting of the drainage channel or directly from the
drainage basin itself (83). Happ et al (33) attributes their
formation to bed load, however, Wolman & Leopold (83) indicate
that the texture of lateral accretion deposits need not be
coarser than the associated vertical accretion deposits.

soil series (20).

The lateral accretion and channel fill deposits in the southwestern Chilliwack area are blanketed by varying depths of vertical accretion deposits.[2] Soils developed on these particular deposits are largley mapped within the Grigg soil series (20).

The formation of vertical accretion deposits at present is minimized due to the extensive dyking practices.

The raised delta is considered to have similar origin and composition to the recent delta but is of greater age having been deposited when the land was 50 - 150 feet lower than it is at the present time (48).

The upland areas are usually associated with glacial deposits of the Pleistocene age. These vary in elevation from 50 to 1100 feet above sea level (4, 5).

The regions south of the Fraser River, between New Westminster and the Cascade Mountains, are for a large part occupied by the raised delta and glacial deposits.

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[2]Vertical accretion deposits are formed when water overflows the banks of its channel and spreads out on the adjacent lands. As the water spreads out and reduction in velocity occurs, the coarser sediments are dropped forming natural levees along the border of the channel. The finer sediments are carried further and deposited as thin layers over the entire floodplain surface (33, 83). According to Happ et al (33) these deposits are composed almost entirely of sediments carried as suspended load. Doeglas (22) describes the suspended load of a river as consisting of particles less than 50 microns (silt size). Wolman & Leopold (83) report that in many cases vertical accretion deposits are only minor in extent, however, the particular physiography of the Chilliwack region would favor formation of extensive vertical accretion deposits.

The present study is limited to the areas described as the recent delta and recent floodplain of the Fraser River.

(ii) X-ray identification of clay minerals

Due to the complexity of clay mineral identification herein, it is felt that this particular section warrants a more detailed discussion than ordinarily would be presented.

Interpretation of X-ray analyses of soils and sediments has become increasingly complex as furthur refinements in X-ray equipment and techniques have been made. Problems in clay mineral identification are to a large part inherent in the clay minerals themselves. The fact that most clay minerals, especially montmorillonoids,[3] vermiculites and chlorites exhibit varying degrees of isomorphous substitution results in their specific chemical, physical and crystallographic properties varying accordingly.

The fact that extensive isomorphous substitution occurs in clay minerals has led a number of workers to believe that continuous isomorphous series exist between certain clay mineral types (74, 75, 79). Several isomorphous series have been established in the montmorillonoid group (51) and one of these, the montmorillonite-biedellite series is now considered to extend to include vermiculite, thus forming a continuous series from a high octahedrally substituted end member to a high tetrahedrally

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[3]The term montmorillonoid, herein, designates a group of 2:1 lattice type clay minerals that expand to approximately 17.65 A° on Ca saturation and glyceration. Montmorillonite is recognized as a member of this group exhibiting octahedral substitution.

substituted end member (73, 74, 75, 79).

If such a series exists between montmorillonoids and vermiculites, than distinction between the two groups becomes one of definition. Weiss (74) has suggested a critical value of 0.55 equivalents of tetrahedral substitution per $O_{10}(OH)_2$ units of structure for separation of the two groups. Minerals which approach this arbitrary value, may therefore, exhibit properties of both groups, namely, expansion on solvation and contraction to 10 A° on K saturation at room temperature.

The identification of vermiculite in the presence of the above described minerals becomes very confusing and in some instances almost impossible. Walker (73) found, using Mg saturation and glyceration, that vermiculites and montmorillonoids approaching the value designated by Weiss could be separated. In many cases, the use of Mg saturation and glyceration may be sufficient to distinguish the two, however, the presence of large amounts of chlorite may prevent their distinction even with the above criterion. Chlorites which have a 001 reflection in the vicinity of 13.80 - 14.80 A° (10, 53) may coincide with the similar reflection of vermiculite at 14.30 - 14.40 A° (74).

Greene-Kelley (74) using Li saturation and glyceration successfully distinguished between high and low tetrahedrally substituted montmorillonoids. The use of this method would determine if an intermediate clay mineral[4] was present, however,

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[4]The term "intermediate clay mineral" designates a clay mineral exhibiting properties of both the montmorillonoid and vermiculite

this would still not allow identification of an ordinary
vermiculite.

Differentiation of kaolin[5] from chlorite is somewhat
complicated by the fact that the OOL reflections of kaolin
coincide with those of chlorite. The 001 and 002 reflections of
kaolin at 7.13 and 3.57 A° approximate the 002 and 004 chlorite
peaks at 7.07 and 3.53 A°. Normally, kaolin clay minerals are
differentiated from chlorites by heating to temperatures in the
vicinity of 500 - 550°C. The kaolin reflections are reported as
being destroyed by temperatures of this order while the chlorite
reflections remain relatively unchanged. However, numerous cases
have been reported (14, 27, 45, 72, 80) where the higher order
reflections of chlorite are thermally unstable at temperatures
of 500°C and lower. This generally prevents distinction of the
two groups by heat treatments and other criterion must be used.

Several treatments have been proposed in order to differ-
entiate between kaolin and chlorite (2, 8, 9, 10, 21, 41, 53)
however, none appear to be universally accepted (72). Due to the
great variability of chlorites (10, 13, 21, 36, 45, 53, 57, 65,
69) it is unlikely that a universal criterion for distinction
between the two groups will be attained for sometime. Procedures

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groups. Such a clay mineral would characteristically show
tetrahedral substitution approaching the value assigned by
Weiss (74) for separation of the two groups.

[5]Kaolin is used to designate a group of 1:1 lattice type
alumino-silicates with a OOL sequence of peaks in the neigbor-
hood of 7.13 and 3.57 A°. Kaolinite is recognized as a member
of this group.

for their identification will therefore, depend on the particular type of chlorite under study.

Certain reflections however, are indicative of the presence of kaolin. Weaver (78) reports the formation of a doublet peak or a broading of the peak at 3.53 - 3.57 A° as a good indication of its presence, since when both kaolin and chlorite are present their respective peaks are slightly offset. This is also supported by Murray (57), Griffin (26) and Taggart et al (71).

The presence of a peak at 2.38 A° corresponding to the 003 kaolin reflection is also usually indicative of kaolin, since the 006 chlorite reflection is absent or very weak due to a structural factor (8, 10, 26, 43, 57, 78).

(iii) <u>Diagenesis[6] of clay minerals in a marine environment</u>

The mineralogical content of transported terrestrial materials varies considerably in extent and kind. Deposition of this material has resulted in significant contributions to the composition of marine sediments and in many cases, as with the Fraser River, results in the formation of large deltas.

The fine fractions of these transported materials have often been classified as alumino-silicates (81). The influence of a marine environment on such material has resulted in considerable

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[6]The term "diagenesis" utilized herein, includes all modifications that the basic clay mineral lattices undergo between deposition and lithification under conditions that are normal to the surface or outer part of the crust. This definition is more consistent with the views of Weaver (77) and excludes secondary factors such as cation adsorption reactions.

controversy in recent years.

Essentially, two extreme views have developed on the subject of diagenesis; the detritus school and the diagenesis school.

The detritus school ardently supported by Weaver (77) and Rivière (66), the latter as discussed by Whitehouse (81), favor marine deposited sediments as being highly detrital in nature, dominantly reflecting their source area and only being slightly modified by the depositional environment.

Although Weaver is considered to be a strong supporter of the detritus school, one must remember that his basic concept of diagenesis differs from that of other workers. Weaver (78) considers the basic clay mineral lattice, which is inherited from the source material, as being the significant parameter of clay minerals and modifications caused by the adsorbed cations are secondary, derived parameters reflecting the character of the depositional environment. He considers that, from a geologists point of view, the term diagenesis, when applied to clays should be restricted to changes in the basic clay mineral lattice and should not include cation adsorption reactions which comprise a good number of the diagenetic changes reported.

The second school, which includes such workers as Grim et al (29, 31, 32) Nelson (60 and Powers (63, 64) strongly supports diagenesis as the major or dominant process determining the distribution of clay minerals in a marine environment.

Other workers (25, 46, 47, 55, 62) prefer to adapt a more moderate view and utilize both concepts to explain the nature of

clay minerals in marine sediments.

Whitehouse (81, 82) has provided evidence, based on laboratory work, to support both contentions.

The evidence suggests a variable response of clay minerals to a marine environment. This is to be expected, however, as diagenesis is nothing more than the response of unstable mineral material to attain equilibrium with the new environment. Therefore, considerable variation in diagenetic modifications may be expected depending on the stability or susceptibility of the source material to alteration and on the environment itself (30). Length of time of exposure and differential settling tendencies appear to be the main factors affecting clay mineral distribution in the environment itself (30, 55, 62, 81).

Work in the Chesapeake Bay area (60, 63, 64), the North Carolina coast (27) and the Gulf of Mexico (32) appears to have established that montmorillonite undergoes transformations to chlorite and illite in a marine environment. Such transformations are also supported by the laboratory work of Whitehouse (82).

Caillère et al (15) and Slaughter & Milne (67) both successfully formed a chlorite-like structure from montmorillonite in the laboratory by precipatiting a $Mg(OH)_2$ layer in the interlayer positions. Bradley (8) thereby concludes that the Mg content and high pH of sea water would cause a similar reaction.

In addition Powers (64) has proposed an illite to chlorite transformation and Grim (28) a kaolinite to illite or chlorite modification. However, Weaver (78) and Whitehouse (82) have

cited strong evidence to disprove such alterations.

Weaver (76, 78) also contends that complete transformations of montmorillonite to chlorite and illite are highly unlikely and that mixed-layered clay minerals are the more probable products of diagenesis.

The probability of the reconstitution of degraded sediments, such as degraded chlorite or illite, in marine waters resulting in improved crystallinity has received support from most workers (8, 28, 58, 59, 78, 80).

Murray et al (58, 59) favors diagenetic changes as appearing in the form of changes in the crystallinity of the clay minerals rather than changes in the basic clay mineral type.

Most workers agree that alterations of clay minerals do occur in a marine environment. However, these changes are generally of a minor nature in quantitative terms and for the most part, marine sediments are usually reported as being highly detrital in nature (25, 26, 46, 55, 56, 58, 59, 62, 71, 77, 78, 80).

(iv) Review of the mineralogy of Fraser River sediments

Only a limited amount of mineralogical analyses have been conducted on the soils of the Fraser River floodplain and these have been restricted to the delta region.

Clark et al (17) analyzed one site from the Ladner soil series and reported montmorillonite, chlorite, interstratified montmorillonite-chlorite, illite, quartz and feldspar as being present in the clay fraction.

Comar (19) described the mineralogy of two sites within

the delta; a Ladner and a Nicomekl soil series. He reported
montmorillonite, chlorite, micaceous minerals, feldspar and
quartz as being present, but indicated that the presence of
vermiculite and kaolinite could not be established.

Clark et al (18) also reported kaolin in the yellow mottles
found in soils of the Nicomekl area.

METHODS AND MATERIALS

(i) X-ray analyses

Mineralogical analyses were conducted using a Philips X-ray diffraction unit equipped with a proportional counter and Philips recorder. $CuK\alpha$ radiation was employed with a tube potential and current of 40 kilovolts and 20 milliamps. $1°$ divergance, 0.1 mm receiving and $1°$ scatter slits were used in all determinations. Low angle reflections ($2°-5°$) were rerun using $\frac{1}{4}°$ divergance and scatter slits and a 0.1 mm receiving slit.

(a) sample preparation.

A 10 gm. air dried soil sample was utilized for separating the sand, silt and clay fractions for X-ray analyses. PH was adjusted to 3.5 using HCl and organic matter was then oxidized with H_2O_2 (49). Free iron oxides were removed with $Na_2S_2O_4$ employing Mackenzies method "a" (52). The samples were dispersed in calgon (40) and the sand fraction was removed using a 300 mesh sieve. Separation of the silt and two clay[1] fractions was accomplished by centrifugation.

(b) preparation and treatments of slide specimens

The oriented glass slide technique was employed for X-ray analyses throughout the study. Clay suspensions were placed on precleaned 26 x 47 mm petrographic glass slides and allowed to dry

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[1]The clay was separated into coarse and fine fractions which correspond to 2-0.2 and <0.2 microns, respectively.

(16). Drying was accomplished with a heat lamp (35°C).[2]

Ca and K saturated specimens were employed for the X-ray analyses. Saturated specimens were obtained by washing the desired aliquot of clay suspension three times in a 1N chloride solution of the particular element, followed by two washings in distilled water.

Solvation of Ca saturated specimens was carried out utilizing glycerol and heating to 100°C for 2 hours (51). Initially, solvation was conducted in moisture tins. However, this resulted in imcomplete expansion of material. Rubber sealed glass jars were, therefore, employed. Samples were heated for periods of 1, 2 and 3 hours. Complete expansion of material was observed with the 2 hour heating period. Prior to the X-ray analyses the solvated samples were held in a dessicator for 12 - 16 hours.

A series of heat treatments (100, 200, 300, 400, 450, 500 and 550°C) were run on K saturated specimens of eight different samples. Heat treatments were conducted in a muffle furnace, heating at the appropriate temperature for 1 hour. Temperatures of 300, 400 and 550°C were selected for the final heat treatments of K saturated specimens, along with the 35°C temperature. The 35, 300 and 550°C temperatures are those normally used in the identification of vermiculite, montmorillonoid and kaolin,

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[2] Normally, saturated clay suspensions are dried at room temperatures (25°C). Several checks were run on 25 and 35°C specimens to determine any affect the latter temperature may have on K saturated slides. X-ray patterns were identical. In order to speed up operations, the heat lamp was utilized for drying specimens.

respectively. An additional heat treatment at 400°C was necessary in order to characterize the chlorite present.

(c) slide peeling

The problem of peeling of 2-0.2 micron clay on the glass slides when heated to greater than 400°C appeared to be largley affected by the amount of clay dispensed onto the slide. Initially, 15 mgms of clay per sq. in. of slide was used. Such a concentration gave excellent results for Ca saturated specimens and K saturated specimens up to 400°C. However, cooling of slides heated to temperatures greater than 400°C resulted in peeling and flaking of the clay in practically all cases. Several methods of cooling and various types of slides, including stainless steel slides, were employed to prevent peeling. None of these proved satisfactory. Finally, reduction of the suspension concentration to 7 mgms per sq. in. of slide prevented furthur peeling. This concentration of clay gave satisfactory X-ray patterns.

Peeling was not a problem with the $<$0.2 micron fraction.

(ii) Sample preparation for mechanical & chemical analyses

The clay fraction obtained from mechanical analyses was also employed for the chemical determinations. Samples were air dryed and passed through a 2 mm sieve. A 20 gm sample was used. Organic matter was destroyed with H_2O_2 (49) however, pH was not adjusted for these samples. Several samples were run to determine the effect on Fe removal on the mechanical analyses. Results (Appendix I) indicate that the presence of free iron

oxides in these soils had little effect on the mechanical analyses. $Na_2S_2O_4$ treatment was, therefore, omitted.

The samples were dispersed in calgon (40). The sand was removed using a 300 mesh sieve, dried at 110°C, weighed and stored. The silt and clay fractions were determined by the pipette method of Kilmer & Alexander (49).

The silt plus clay suspension remaining after mechanical analyses was centrifuged to separate the two respective fractions. The clay fraction was washed three times in 1N Ammonium acetate, followed by two washings in distilled water. The samples were dryed at 110°C, ground in an agate motar and stored for chemical analyses.

(iii) Determination of total K, Ca and Mg.

Jackson's method (39) for semimicrochemical silicate analyses was employed in determining total K, Ca and Mg. Dissolution of the samples was accomplished using the hydrofluoric-perchlorate acid method.

K was estimated with a Perkin-Elmer model 146 flame spectrophotometer using lithium as an internal standard and Ca and Mg were determined by the versene method. Erroneous results were obtained when Ca and Ca plus Mg were determined on the same aliquot as suggested by Jackson. Ca and Ca plus Mg were, therefore, determined on separate aliquots. Ca plus Mg was determined using duplicate and in some cases triplicate samples.

(iv) Descriptions and locations of sampling sites

Twenty-one sampling sites, representing the four major soil series developed on Fraser River alluvium, along with six sea

bottom samples were collected. Figure I indicates their locations with the exception of S-7.[3]

Samples of the various soil series were generally taken along fence lines to minimize the affects of liming, fertilization and other management factors. Surface and subsurface samples of each soil profile were taken. In all cases the surface samples represented the Aa or Ah horizon. The subsurface samples, depending on the soil series are B or C horizons.

(a) Sea samples

Samples S-1, 2 & 8 represent sediments taken from the littoral[4] environment. With the exception of sample, S-2, these are highly gleyed sediments and generally emitt H_2S gas.

Samples S-3, 5 & 7 were taken from the bottom of the Strait of Georgia in 930, 540 and 1362 feet of water, respectively. According to Mathews[5] these samples represent Fraser River alluvium that has been in contact with sea water for no more than 3 - 5 years.

Sample S-7, which is not shown in Figure I, is located to the northwest of the map area off Ballenas Island at 49° 12' 55" N latitude and 123° 17' 35" W longitude.

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[3]Symbols used in Figure I and hereafter denote the following: S - sea sediments, L - Ladner soil series, G - Grigg soil series, F - Fairfield soil series and M - Monroe soil series. Numbers designate the particular sampling sites within each of the above groupings.

[4]The littoral environment is described as that area which extends from mean high tide to mean low tide (61).

[5]Dr. W. H. Mathews - personal communication.
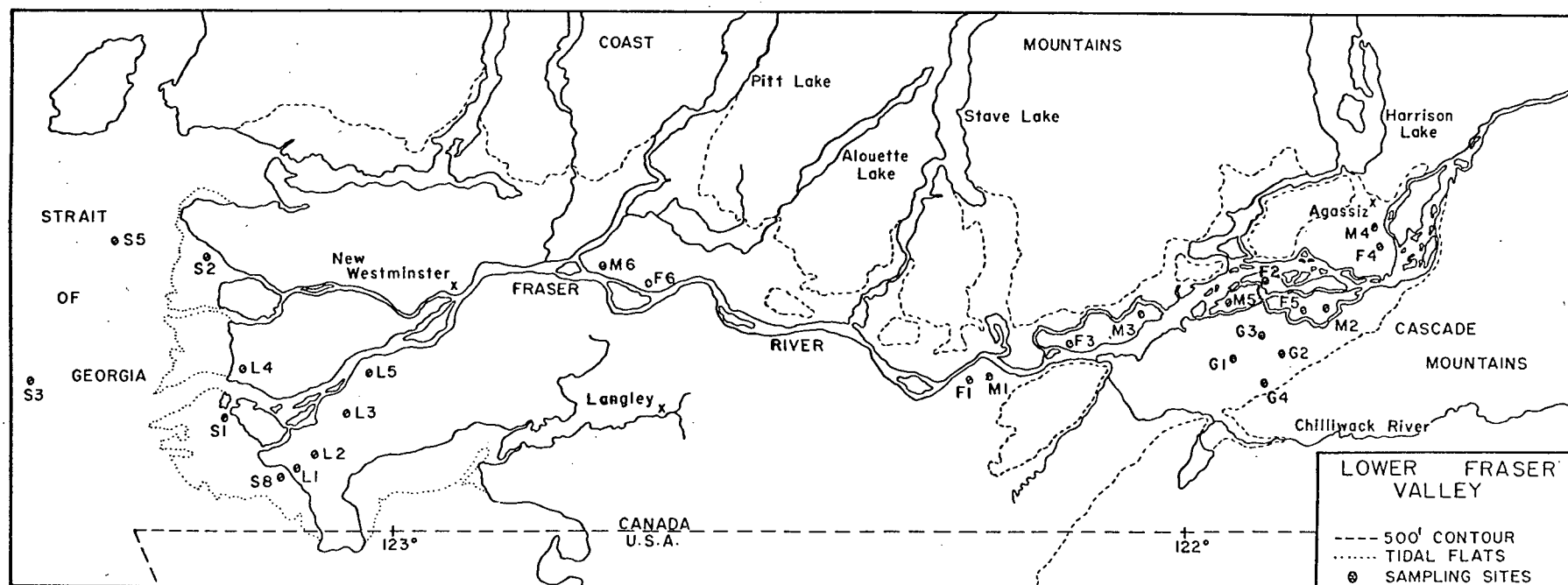
Figure I Map of lower Fraser Valley indicating sampling sites

(b) Ladner soil series

The Ladner soil series which is classified as an orthic
to degraded dark gray gleysol, is the most extensive series
mapped in the present delta region (68). The material from
which these soils are derived belong to the Salish Group and
represents a mixture of marine and non-marine sediments deposited
by the Fraser River (68).

Topography of the areas sampled was level to gently undulating,
with the exception of L - 3 which was gentle ridge and swale. In
the latest soil survey of the delta area (68), L - 3 has been
mapped within the Crescent series, however, in the present study
it has been included in the Ladner soil series.

Internal drainage of soils of the Ladner series is poor due
to the heavy massive structure and during most months, the soils
are influenced by a high water table. As a result, the subsoils
are often highly mottled.

A total of five sites were sampled.

(c) Grigg soil series

Four sites in this series were sampled. The Grigg soil
series has developed on vertical accretion deposits in the eastern
end of the Fraser Valley. It has been classified as an orthic
dark gray gleysol (20). Topography is level to gently undulating.
Drainage is poor and consequently the B and C horizons are mottled.

(d) Monroe soil series

The Monroe soil series has developed on lateral accretion
deposits adjacent to the Fraser River. They are well drained

soils which have been classified as mull regosols (20).
Topography is characterized by ridges and swales. Six sites
were sampled from this series.

Sample M - 6 at present is mapped within the Pitt series
(37). However according to Runka,[6] on remapping of the Pitt
Meadows area, this site will be mapped as a member of the Monroe
series.

(e) Fairfield soil series

The Fairfield soil series are separated from the Monroe
series on the basis of drainage and are classified as gleyed mull
regosols developed on lateral accretion deposits (20). Generally,
the Fairfield series occupies the lower positions and the Monroe
series, the somewhat higher positions on the ridge and swale
topography. Six sites were sampled in the Fairfield series.

F - 6 is mapped as a poorly drained member of the Pitt
series (37). On remapping however, it will be included in the
Fairfield series.[7]

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6 & 7 Mr. G. Runka - personal communication

I Interpretation of X-ray diffraction analyses

X-ray diffraction analyses of the clay fractions of these soils and sediments indicated them to be mineralogically similar, however, the mineralogy of the coarse and fine clay fractions from the same sampling sites were different.

Results of the X-ray analyses of the coarse and fine clay fractions are presented in Table I.

(i) 2-0.2 micron fraction

To illustrate interpretation of X-ray patterns for the coarse clay fraction, a Fairfield subsoil sample (F - 4) was chosen. Figure II depicts the X-ray diffraction tracing of this sample.

The relatively strong peak at 14.71 A° which expanded to 17.65 A° on glyceration was attributed to montmorillonoid. Subsequent K saturation and heat treatments were necessary in order to contract the 14.71 A° peak to 9.95 A°. The residual peak remaining at 14.20 A° after K saturation and glyceration, along with an integral sequence of higher order reflections at 7.07, 4.69, 3.53 and 2.82 A° were attributed to chlorite. The possibility of vermiculite contributing to the 14 A° peak is discussed in a later section.

The presence of micaceous material[1] was confirmed by a

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[1] The term micaceous material herein, designates a mineral or minerals with a 001 reflection close to 10 A° which is unaffected by glyceration, K saturation or heat.

Figure II X-ray diffraction tracing of

FAIRFIELD-4
11-25 INCHES
2-0.2 MICRONS

Ca Saturated

Ca + Glyceration

K⁺ Saturated (35°C)

K Saturated (300°C)

K Saturated (400°C)

K Saturated (550°C)

2.82 A° 3.17 A° 3.34 A° 3.53 A° 3.68 A° 3.89 A° 4.23 A° 4.69 A° 4.98 A° 5.51 A° 7.07 A° 7.82 A° 9.95 A° 11.04 A° 14.39 A° 14.71 A° 17.65 A°

DEGREES 2θ
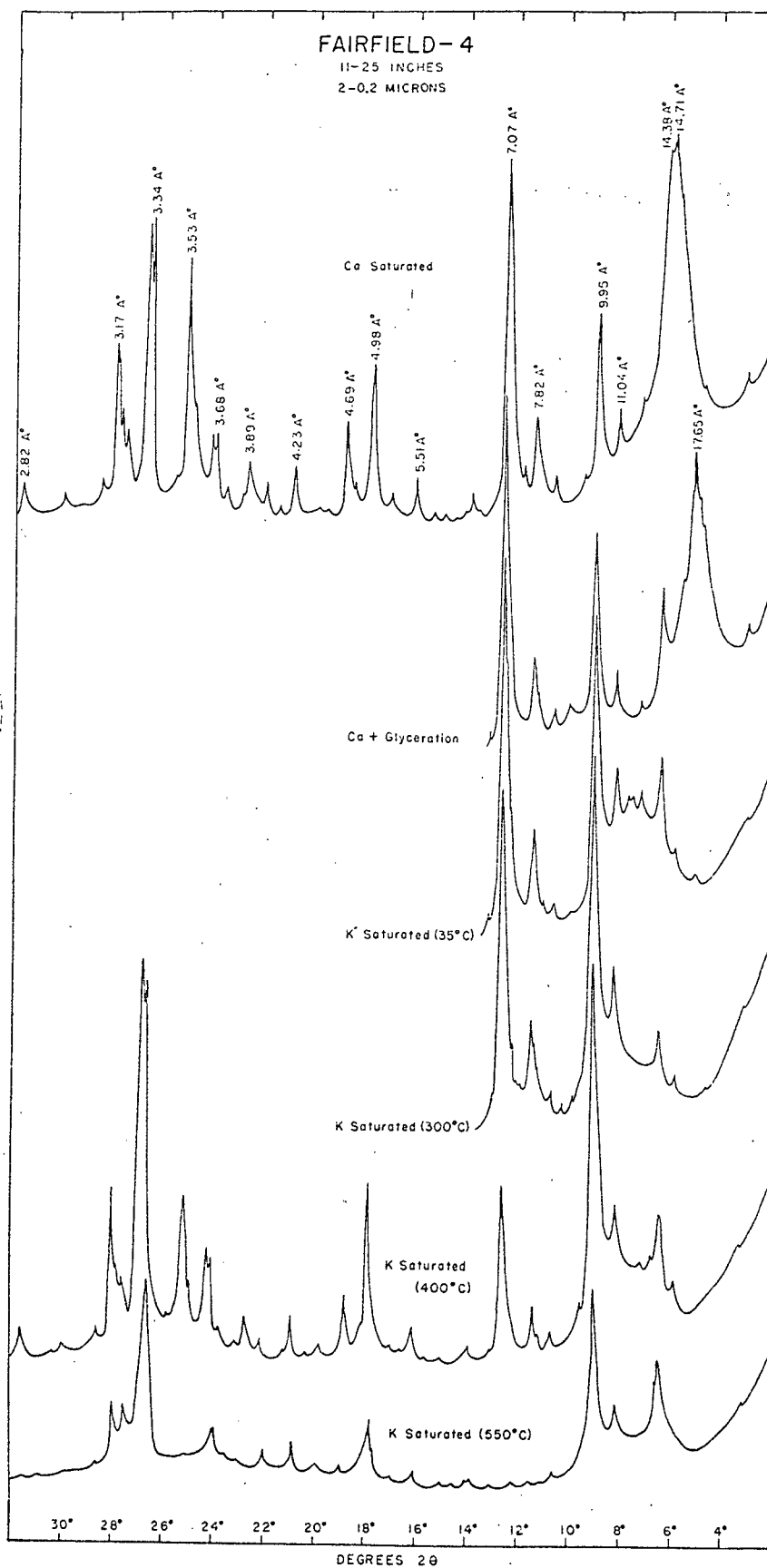
Table I X-ray diffraction properties of soils and sediments[2]

Samples	Depth (inches)	Size fraction[3]											
		2-0.2 microns						less than 0.2 microns					
		M	C	M/C	I	V	K	M	C	M/C	I	V	K
Sea sediments													
1	0-10	3	3	?	2	?	?	4	2	1	1	?	?
2	0-8	3	3	?	2	?	-	4	1	1	1	?	-
3	-	2	3	?	2	?	-	4	2	1	1	?	-
5	-	2	3	1	2	?	-	4	2	1	1	?	-
7	-	1	3	1	2	?	-	4	1	1	1	?	-
8	0-12	2	3	1	2	?	-	4	2	1	1	?	-
Ladner series													
1	0-10	3	4	1	2	?	?	4	2	1	1	?	?
	10-25	3	3	1	2	?	?	4	2	1	1	?	?
2	0-10	3	3	1	2	?	?	4	2	1	1	?	?
	10-24	3	3	1	2	?	?	4	2	1	1	?	?
3	0-7	1	3	1	1	?	?	4	2	1	1	?	?
	7-24	2	3	1	2	?	?	4	2	1	1	?	?
4	0-10	3	3	1	2	?	?	4	2	1	1	?	?
	10-24	4	4	1	3	?	?	4	2	1	1	?	?
5	0-8	2	3	1	1	?	-	4	2	1	1	?	-
	8-24	2	3	1	1	?	-	4	2	1	1	?	-

Table I cont'd

Samples	Depth (inches)	Size fraction											
		2-0.2 microns						less than 0.2 microns					
		M	C	M/C	I	V	K	M	C	M/C	I	V	K
Grigg series													
1	0-11	3	3	1	1	?	-	4	2	1	1	?	-
	11-20	3	3	1	2	?	?	4	2	1	1	?	?
2	0-10	3	3	1	2	?	?	4	2	1	1	?	?
	10-22	3	4	1	2	?	?	4	2	1	1	?	?
3	0-10	3	4	1	2	?	-	4	2	1	1	?	-
	10-24	3	4	1	2	?	?	4	2	1	1	?	?
4	0-9	1	3	1	1	?	?	4	2	1	1	?	?
	9-20	2	4	1	1	?	-	4	3	1	1	?	-
Monroe series													
1	0-9	3	4	1	2	?	-	4	2	1	1	?	-
	9-20	3	3	1	2	?	?	4	2	1	1	?	?
2	0-11	3	3	1	2	?	?	4	1	1	1	?	?
	11-26	4	3	1	2	?	?	4	1	1	1	?	?
3	0-6	4	4	1	2	?	?	4	1	1	1	?	?
	6-18	4	3	1	2	?	?	4	1	1	1	?	?
4	0-9	4	4	1	2	?	?	4	1	1	1	?	?
	9-24	4	3	1	2	?	?	4	1	1	?	?	?

Table I cont'd

Samples	Depth (inches)	Size fraction											
		2-0.2 microns						less than 0.2 microns					
		M	C	M/C	I	V	K	M	C	M/C	I	V	K
Monroe cont'd													
5	0-9	3	3	1	2	?	-	4	1	1	1	?	-
	9-23	3	3	1	2	?	?	4	1	1	?	?	?
6	0-7	1	3	2	1	-	1	1	1	3	?	-	?
	7-20	2	3	2	1	-	?	1	1	3	?	-	?
Fairfield series													
1	0-8	3	3	1	2	?	?	4	2	1	1	?	?
	8-18	3	3	?	2	?	?	4	2	1	1	?	?
2	0-8	3	4	1	2	?	?	4	2	1	1	?	?
	8-20	3	3	?	2	?	?	4	2	1	1	?	?
3	0-5	3	3	1	2	?	-	4	1	1	1	?	-
	5-18	4	3	1	2	?	?	4	2	1	1	?	?
4	0-11	4	3	1	2	?	?	4	1	1	1	?	?
	11-25	4	4	1	2	?	-	4	1	1	1	?	-
5	0-10	3	3	?	2	?	?	4	2	1	?	?	?
	10-24	3	3	?	2	?	?	4	2	1	1	?	?
6	0-6	1	3	2	1	-	?	2	2	3	?	-	?
	6-24	1	3	2	1	?	?	2	2	3	?	?	?

Table I cont'd

[2]Semiquantitative estimations of clay mineral contents are made on the basis of comparisons of areas within the strongest peak.

[3]Meaning of symbols: M – montmorillonoid; C – chlorite; M/C – randomly interstratified montmorillonoid-chlorite; I – micaceous material; V – vermiculite; K – kaolin; ? – probably a slight amount present; 1 – small amount present; 2 – low-moderate amount present; 3 – moderate amount present; 4 – large amount present.

moderate peak at 9.95 A° along with a integral sequence of higher order reflections at 4.98, 3.32, 2.50 and 1.99 A°. The basal spacings of the micaceous component persisted during glyceration, K saturation and the heat treatments, however, the relatively intensity of the 9.95 A° peak increased on K saturation and heat due to contraction of montmorillonite and possibly vermiculite.

Identification of kaolin and especially vermiculite are somewhat questionable in many instances. Interpretation of their particular patterns, along with those of mixed-layered minerals will be discussed in more detail in a following section.

Considerable quantities of non-phyllosilicate minerals were identified in the coarse clay fraction of these sediments. A relatively strong peak at 3.34 A° and a somewhat weaker peak 4.23 A° was attributed to quartz (1).

A variety of feldspars appeared to be present indicated by a series of peaks at 3.17, 3.20, 3.24, 3.66, 3.68 and 4.02 A° (1). The reflections are indicative of both potash and plagioclase feldspars. However, without the aid of camera techniques, ascribing a particular peak to a specific feldspar is very difficult.

A relatively weak peak at 8.42 A° was attributed to amphiboles (38).

(a) characterization of chlorite and indentification of kaolin

The identification of kaolin in many instances depends on fortuitous resolution of its reflections from those of chlorite or on the chlorite content being so small that chlorite reflections
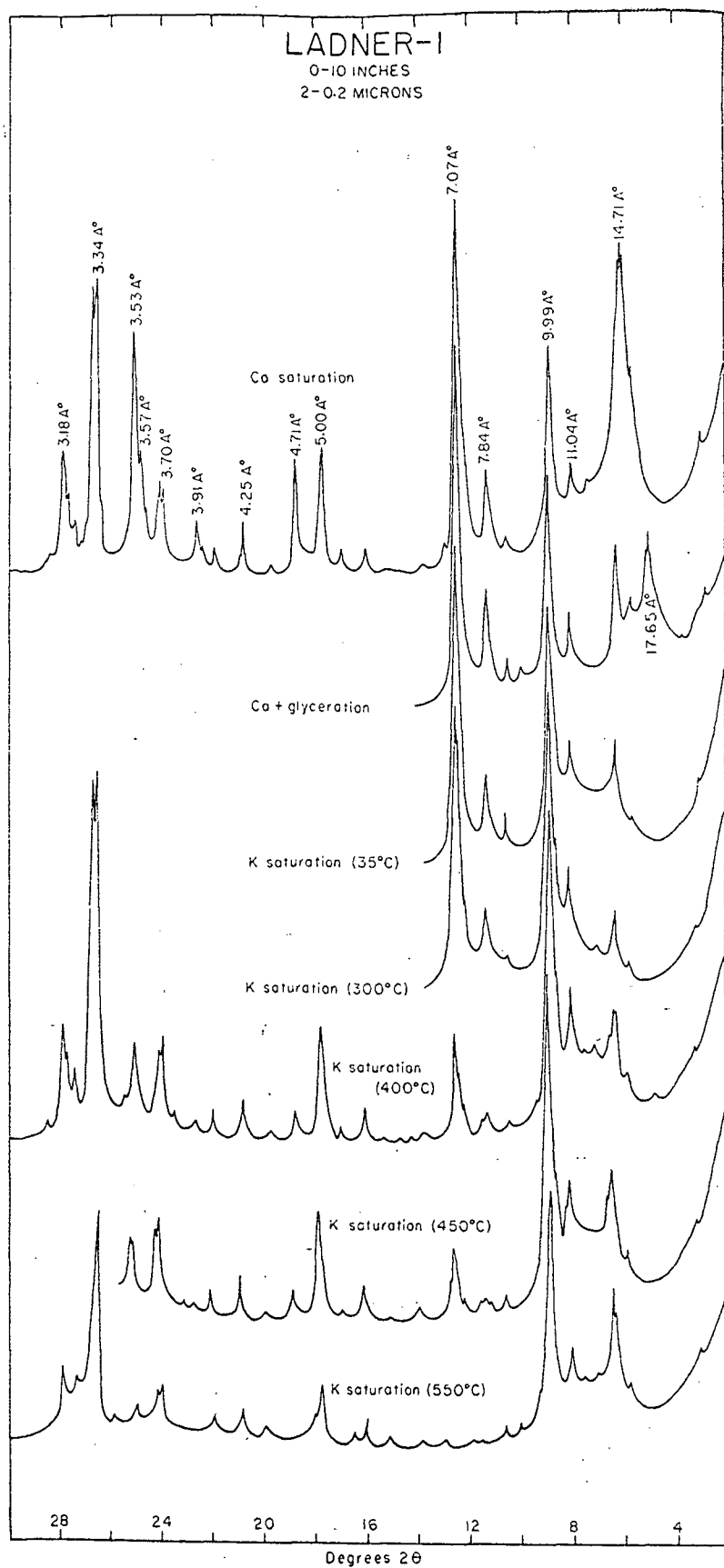
do not mask those of kaolins.

The identification of kaolin, herein, proved to be difficult for two reasons. Firstly, the presence of relatively large amounts of heat unstable chlorite tended to mask the kaolin peaks. Normally, kaolin can be identified by heat (9). However, since the higher order reflections of chlorite were thermally unstable, this prevented the use of heat treatments for positive identification.

Secondly, if kaolin minerals are present they are in minor quantities. Normally, if kaolin and chlorite are present in somewhat similar amounts, identification of the two components can be made. The 001 and 002 kaolin reflections at 7.13 and 3.57 A°, respectively, are slightly offset from the chlorite 002 and 004 reflections at 7.07 and 3.53 A° thus forming twin peaks. However when one is present in much smaller amounts, this is not the case (71).

Figures II, III, or IV indicate the diffraction properties of the chlorite in these soils and sediments. Relatively strong 002 and 004 reflections at 7.07 and 3.53 A° respectively, as compared to much weaker peaks at 14.20, 4.71 and 2.82 A° which correspond to the 001, 003 and 005 chlorite reflections are supposedly characteristic of an iron rich chlorite (10). Comar also reports an iron rich chlorite in these soils (19).

K saturated specimens heated to 300°C resulted in the 001 reflection at 14.20 A° shifting to 13.80 A°. The higher order reflections remained unchanged at this temperature. Further

Figure III X-ray diffraction tracing of

LADNER-1
0-10 INCHES
2-0.2 MICRONS

3.18 A°   3.34 A°   3.53 A°   3.57 A°   3.70 A°   3.91 A°   4.25 A°   4.71 A°   5.00 A°   7.074°   7.84 A°   9.99 A°   11.04 A°   14.71 A°   17.65 A°

Ca saturation

Ca + glyceration

K saturation (35°C)

K saturation (300°C)

K saturation (400°C)

K saturation (450°C)

K saturation (550°C)

28   24   20   16   12   8   4

Degrees 2θ

heat treatments to 400 and 450°C resulted in a progressive descrease in the relative intensity of the high order chlorite reflections until at 500°C[4] no evidence of these peaks were left. Weaver (75) reports this to be characteristic of many chlorites.

The fact that the 002 and 004 chlorite reflection progressively diminish on heat treatments make the identification of kaolin difficult since the 00L reflections of kaolin also disappear at 500°C (38).

Pinsak and Murray (62) attributed any residual peak remaining at 7 A° after heat treatment to 450°C to kaolinite. However, due to the wide variability noted in chlorites it is felt that such a criterion should not be used for the present identification. Kaolin is given a question mark in Table I, if a 2.38 A° peak is present in combination with a doublet or shoulder on the low angle side of the 004 chlorite reflection at 3.53 A°. This indicates that there is probably a light amount present.[5]

Only in one case, Figure IV is kaolin postively identified. A twin peak at 7.07 and 7.13 A° along with a doublet occuring at 3.53 and 3.57 A° and a weak peak at 2.38 A° is taken as conclusive evidence for the presence of kaolin.

---

[4]X-ray tracings of the 500°C heat treatment are not shown, however they are very similar to the 550°C treatment. Figure III contains a 450°C heat treatment.

[5]The various treatments proposed (2, 9, 21) for identifying kaolin have not been attempted in the present study. However an attempt will be made to distinquish kaolin by one of these test and the results will be made available at a later date.

(b) vermiculite identification

Problems in distinguishing between vermiculite and mont-morillonoid have been discussed in detail in the literature section.

Normally, any contraction to 10 A° upon K saturation at room temperature is attributed to vermiculite. In the present study however, there appears to be evidence to suggest that an intermediate clay mineral is present which exhibits properties of both the above groups. The present of such a mineral, of course, makes the identification of vermiculite difficult.

Figures II, III, IV or VI indicate the response of the 14 A° peak to the K saturation and heat treatments. The contraction to 10 A° that occurs at 35°C would normally be attributed to vermiculite. However, when one considers the extent of expansion of the 14 A° peak and compares this to the contraction to 10 A° on K saturation, plus the ease with which the peak collapses, it appears that a portion of the expanded material contracted to 10 A°.

This also supported by the results of the ⟨0.2 micron fraction (Figure V). The ⟨0.2 micron fractions are characterized by a relatively intense 14 A° peak which on solvation almost completely expands to 17.65 A°. Usually a weak peak or a slight shoulder at 14 A° was observed after solvation. Peaks at 7 A°, 4.70 and 3.53 A° which reacted to heat treatments in a similar fashion to those in the 2-0.2 micron fraction were attributed to chlorite. On this basis, part or all of the 14 A°

peak remaining after solvation must be due to chlorite. However, on K saturation (35°C) a substantial increase in intensity of the 10 A° peak was observed in many cases. The extent of this increase appeared to be too great to compensate for the 14 A° peak left after solvation. Therefore, one can only conclude that a portion of the expandable material is contributing to the 10 A° peak on K saturation (35°C).

Assuming the previous interpretation correct and considering the definition of a montmorillonoid herein, one concludes that the montmorillonoids identified in these soils and sediments consists of two types, an octahedrally substituted member and a tetrahedrally substituted member. The latter being designated as a intermediate type clay mineral approaching in charge, the value indicated by Weiss (74) for separation of the vermiculite and montmorillonoid groups.

Weaver (79) reported a somewhat similar case with a Womble clay. He attributed the fact that the clay mineral expanded to 17 A° on solvation and readily contracted to 10 A° on K saturation (room temperature) to a high interlayer charge, probably due mainly to tetrahedral substitution. Weaver considers such minerals to have been derived from mica type material.

Walker (73) used Mg saturation and glyceration to distinguish between vermiculites and montmorillonites. However, the identification of vermiculite in the soils under study would still be difficult in many cases due to the relatively large quantities of chlorite that appears to be present in B. C. soils

(13, 17, 72).

Vermiculite is indicated as probably being present in Table I.

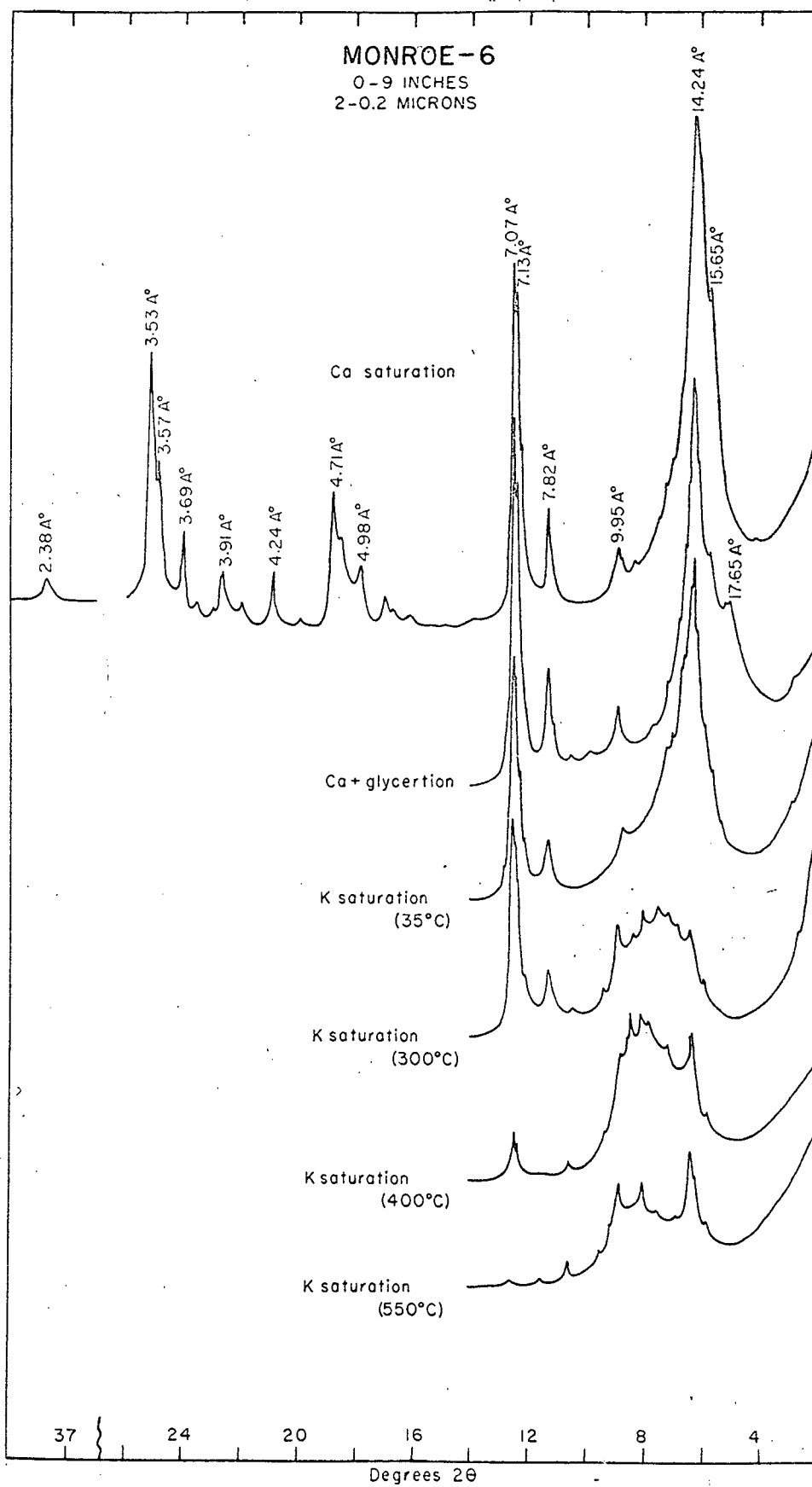(c) interstratified clay minerals

Recent work has shown interstratified clay minerals to be quite abundant in soils and sediments. Both regular and randomly interstratified minerals are common. They generally involve an expandable and a non-expandable component such as montmorillonite and illite, although other combinations of clay minerals appear to be possible (76).

Interpretation of mixed-layered clay minerals was made according to Weaver (76).

Randomly interstratified chlorite-montmorillonoid was identified in practically all samples. Most samples appeared to contain relatively small quantities. An exception to this was noted with the Monroe and Fairfield sites #6. Both the coarse and fine clay fractions appear to contain relative large amounts of such a interstratified mineral in comparison to the remaining sites sampled.

Figure IV contains the X-ray diffraction tracing of a Monroe surface soil sample (M - 6). A relatively strong peak centered on 14.24 A° was attributed mainly to randomly inter-stratified chlorite-montmorillonoid. The montmorillonoid component was identified by partial expansion of the 14 A° peak on glyceration and the development of a broad band from 10 - 14.20 A° on K saturation and heat (550°C) indicated the presence of chlorite

Figure IV X-ray diffraction tracing of

MONROE-6
0-9 INCHES
2-0.2 MICRONS

14.24 A°

7.07 A°
7.13A°

3.53 A°
3.57 A°

Ca saturation

15.65 A°

3.69 A°
3.91 A°
4.24 A°
4.71A°
4.98 A°

7.82 A°

9.95 A°

2.38A°

17.65 A°

Ca+glycertion

K saturation
(35°C)

K saturation
(300°C)

K saturation
(400°C)

K saturation
(550°C)

37   24   20   16   12   8   4

Degrees 2θ

and also montmorillonoid.

In some instances, a regularly interstratified chlorite-
montmorillonoid, similar to that described by Earley (23) also
appeared to be present. A relatively weak peak at 29.42 A°
which expanded to approximately 32 A° on glyceration and con-
tracted to 23.8 A° on K saturation and heat (300°C) was attributed
to such a mineral (Figures II & III).

A review of literature indicates that interstratification
involving chlorite-mica components are relatively uncommon
(8, 47, 76). However, this was not the case with the present
sediments. A peak at 11.04 A° was attributed to a randomly inter-
layered chlorite-mica (Figures II & III). Stability of the peak
on solvation, K saturation and heat excluded the possibility of
a montmorillonoid, vermiculite or kaolin component, thereby
indicating a mixed-layered chlorite-mica. The fact that an
integral series of higher order peaks were not observed, in-
dicated the interstratification to be of a random nature.

Peak intensities of this mineral indicated it to be con-
centrated in the coarse clay and fine silt fractions and being
of lesser quantities or absent in the fine clay and coarse silt
fractions.[6] This coincides with the chlorite and mica components
of these fractions also.

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[6] X-ray analyses of the coarse and fine silt fractions of these
sediments are being conducted by Dr. E. H. Gardner, Dept. of
Soil Science and will be reported at a later date.

The identification of a series of reflections at 15.65, 7.84, 5.21 and 3.89 A° was uncertain (Figures II, III & IV). However, two possibilities existed involving a regularly interstratified chlorite-mica and a non-phyllosilicate, taranakite.

Although low angle reflections in the vicinity of 1 - 4° 2θ for the above series of peaks could not be distinguished, there was evidence to suggest the mineral was a regularly interstratified chlorite-mica. This was observed in the reaction of the peaks to heat treatments and also in the particular fractions in which the reflections were identified.

Heat treatment of the K saturated slides to 450°C caused the 7.84, 5.21 and 3.89 A° peaks to disappear. Since the chlorite identified herein, is thermally unstable, the disappearance of the above reflections would be anticipated.

As in the case of the randomly interstratified chlorite-mica, the content of this mineral in a particular size fraction appeared to coincide with the chlorite and mica contents of that fraction.

Taranakite, a hydrated potassium aluminum iron phosphate, is reported with hkl reflections at 15.5, 7.6, 5.8, 4.4 and 3.83 A° (1). These reflections differ somewhat from those observed and suggest that the mineral is probably not taranakite.

The possibility of the 7.84 A° and 3.89 A° peak being due to a partially dehydrated halloysite was ruled out. Both Brindley (9) and Grim (28) report d spacings of this order for meta-halloysite and similar temperatures (400 - 450°C) to completely

dehydrate it to 7.20 A°. Brindley et al (11, 12) reported a progressive shifting of the 001 reflection at 7.8 A° to 7.2 A° on dehydration. In the present study a progressive diminishing of the intensity of the two peaks were observed on heating to 450°C but the d spacings remained constant.

(ii) <u>< 0.2 micron fraction</u>

Interpretations of the diffraction patterns were made in a similar manner to the 2-0.2 micron fraction. Figure V contains the X-ray diffraction tracing of a Fairfield surface sample (F - 4) which is fairly typical of the fine clay samples. Results of X-ray analyses of this fraction are found in Table I.

The < 0.2 micron fractions, with the exceptions of the two Pitt Meadow sites (M - 6 & F - 6), were dominated by montmorillonoid. Chlorite is present in somewhat lesser amounts and micaceous material is present in very low or questionable amounts. The identification of kaolin and vermiculite was furthur complexed by the broader, more diffuse nature of the peaks that is characteristic of X-ray diffractograms of this fraction. No further attempts, therefore, were made in order to identify them. Their presence in Table I is indicated as questionable.

The content of non-phyllosilicate minerals in this fraction was very low. Feldspars and amphiboles appeared to be absent in most cases. The presence of quartz was indicated in several instances by a weak peak at 3.34 A°.

II <u>Nature of sediments</u>

X-ray analyses indicates the sediments are quite similar

Figure V X-ray diffraction tracing of

FAIRFIELD-4
0-11 INCHES
< 0.2 MICRONS
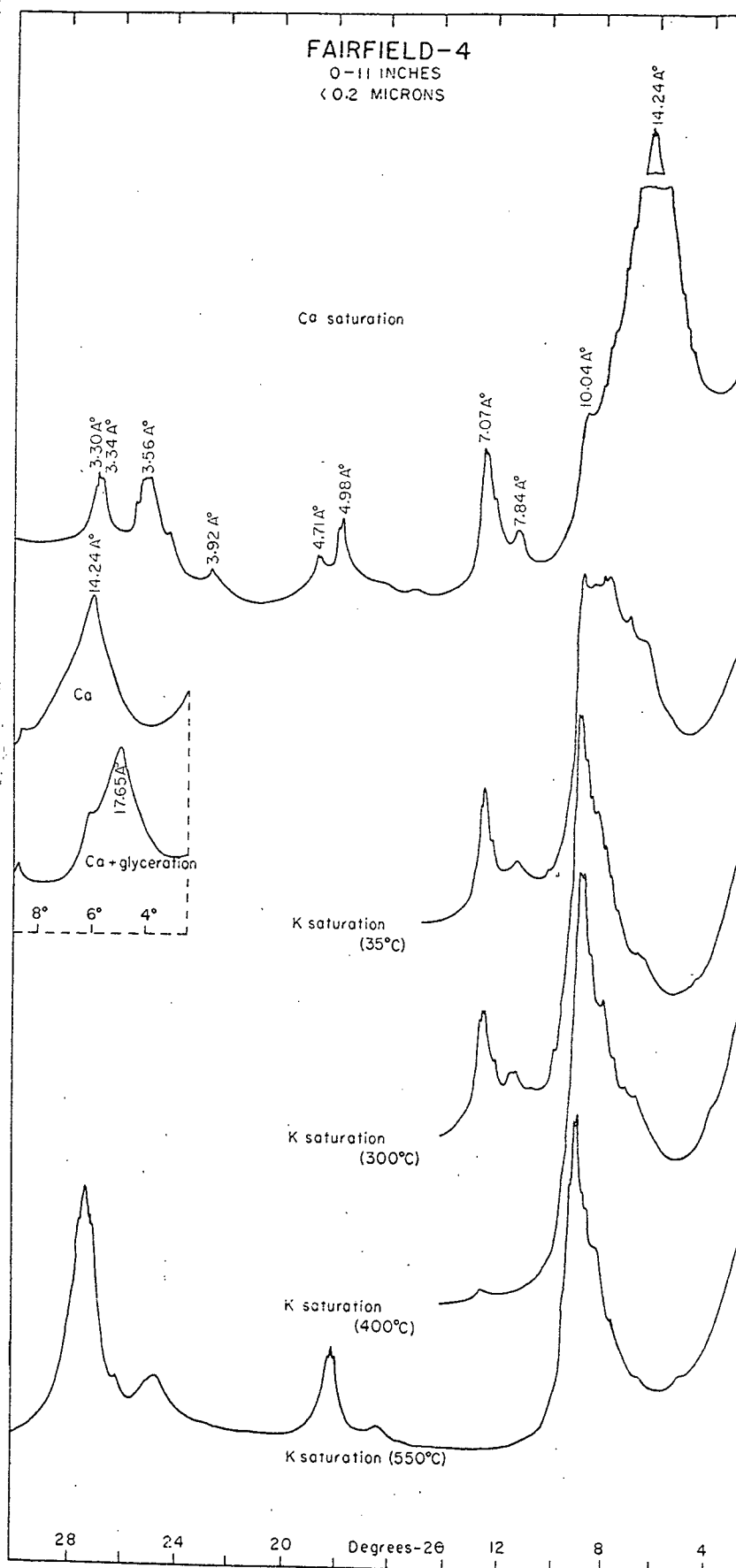
mineralogically. Variations in mineralogy however, were observed between the two clay fractions.

The mineralogical similarity of these sediments is to be expected. Doeglas (22) reported a mineralogical variation between the greater than 50 micron fraction and the less than 50 micron fraction due to mode of transporataion. Particles less than 50 microns were carried as suspended load and sand particles (>50 microns) were moved by saltation resulting in differentiation of the two fractions due to velocity. He furthur stated that such segregation was at a minimum in the clay fractions and would only account for quantitative variations in mineralogy.

Source area variations would be practically non-existant due to physical mixing during transportation.

On this basis, clay mineral assemblages would represent a sum total mineralogy of the specific source areas and qualitative variation would be non-existant or of a minor nature.

Quantitative variations observed can probably be accounted for by sedimentary processes, seasonal variation in the detrital components carried by rivers, variations in specific source areas from year to year and the local influence of sediments carried by several tributaries of the lower Fraser River.

(i) Detritus vs diagenesis

The mineralogical analyses supports the findings of many other workers (26, 55, 62, 71, 78) that marine deposited materials are mainly detrital in nature and dominantly reflect their source area. However, there appears to be evidence to suggest that

diagenesis is operative to a minor extent.

Evidence to support this contention is found in both the X-ray and chemical analyses.

Figures II and VI contain the X-ray diffraction tracings of typical samples from fresh water and sea water environments, respectively. In all cases, there is a distinct difference in the nature of the 14 A° peak of samples from these two particular environments. Samples from fresh water environment show characteristically sharp, relative strong, symmetrical 14 A° peaks. The comparable peaks of the marine samples on the other hand, are of considerably lower intensity, asymmetrical, being somewhat broader and more diffuse in nature, containing several shoulders on the low angle side. Solvation resulted in variable expansion of the 14 A° peak.

The more diffuse nature of the 14 A° peak, along with the shoulders on the low angle side are considered to be due to interlayer contamination of expandable material, such as montmorillonoid. The presence of interlayered contaminant plus the relative decrease in intensity of the 14 A° is considered to represent a diagenetic change.

Similar modifications were observed in bore hole samples from the Delta area taken at 100 - 200 feet depths.[7] These samples would represent Fraser River alluvium deposited in sea water hundreds of years ago.

Table II contains the total K, Ca and Mg of the clay fractions of these soils and sediments.

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[7]Dr. E. H. Gardner - personal communication
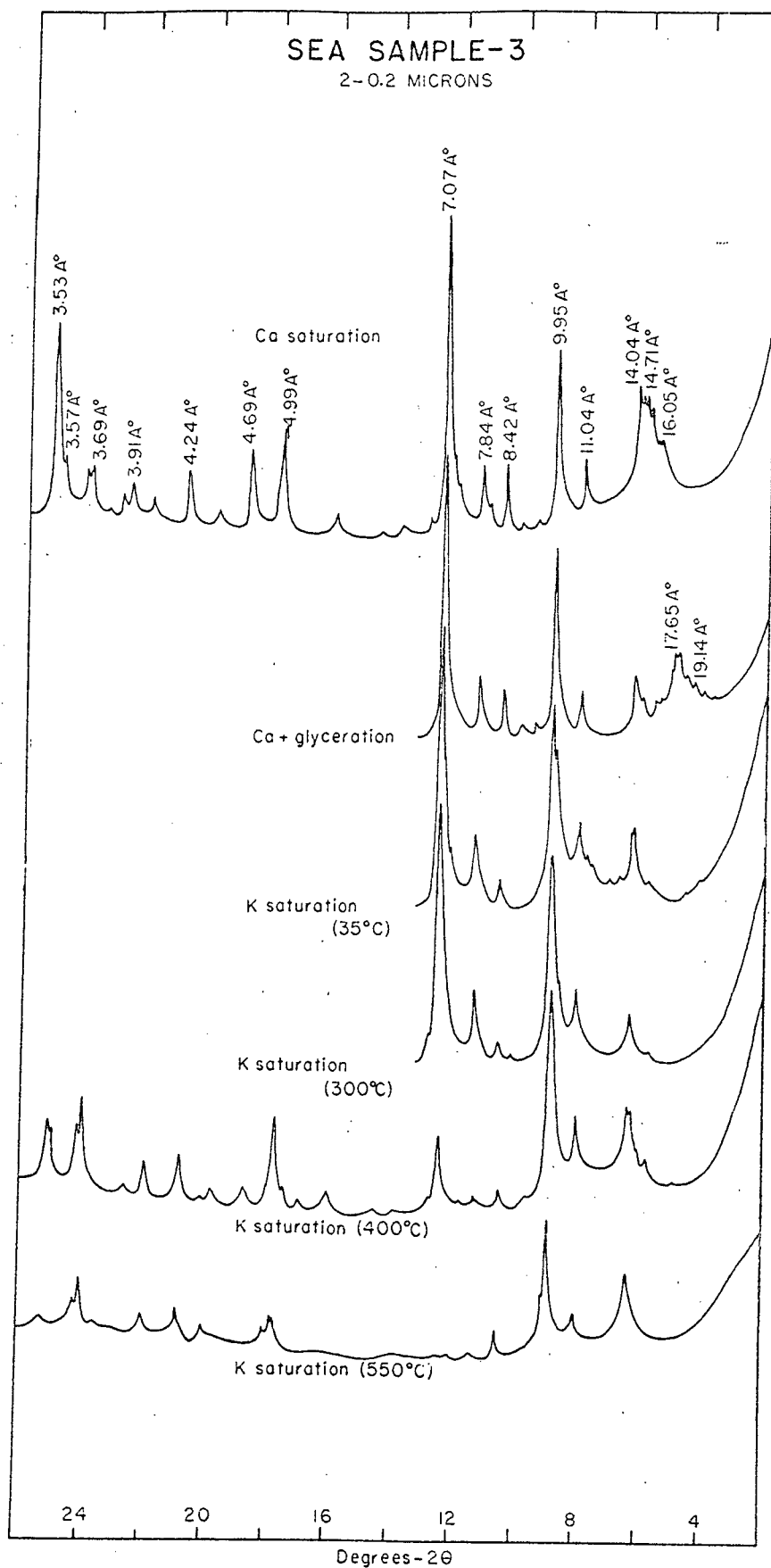
Figure VI X-ray diffraction tracing of

SEA SAMPLE-3
2-0.2 MICRONS

Ca saturation

Ca + glyceration

K saturation
(35°C)

K saturation
(300°C)

K saturation (400°C)

K saturation (550°C)

Degrees-2θ

Table II   Total K, Mg and Ca of the clay-sized fraction[8]

Samples	Depth (inches)	% K	% Mg	% Ca
Sea sediments				
1	0-10	2.05	1.56	0.54
2	0-8	2.10	1.49	0.43
3	-	1.99	1.40	0.49
5	-	1.91	1.41	0.56
7	-	1.55	1.82	0.65
8	0-12	1.77	1.55	0.40
Ladner series				
1	0-10	1.91	1.24	0.27
	10-25	1.80	1.26	0.32
2	0-10	1.97	1.26	0.31
	10-24	1.93	1.40	0.25
3	0-7	1.79	1.36	0.31
	7-24	1.85	1.40	0.28
4	0-10	1.64	1.31	0.31
	10-24	1.95	1.46	0.35
5	0-8	1.68	1.28	0.28
	8-24	1.61	1.48	0.28
Grigg series				
1	0-11	1.34	1.38	0.28
	11-20	1.26	1.34	0.31
2	0-10	1.40	1.25	0.25
	10-22	1.65	1.14	0.28
3	0-10	1.49	1.26	0.28
	10-24	1.46	1.28	0.28
4	0-9	1.14	1.54	0.34
	9-20	1.61	1.79	0.40
Monroe series				
1	0-9	1.65	1.41	0.31
	9-20	1.59	1.40	0.25
2	0-11	1.13	1.35	0.25
	11-26	1.43	0.88	0.14
3	0-6	1.46	1.40	0.31
	6-18	1.49	1.35	0.25

Table II cont'd

Samples	Depth (inches)	% K	% Mg	% Ca
Monroe (cont'd)				
4	0-9	1.34	1.32	0.28
	9-24	1.40	1.39	0.28
5	0-9	1.47	1.26	0.25
	9-23	1.40	1.28	0.22
6	0-7	0.92	1.03	0.14
	7-20	0.90	0.90	0.11
Fairfield series				
1	0-8	1.69	1.14	0.28
	8-18	1.60	1.03	0.25
2	0-8	1.72	1.50	0.28
	8-20	1.74	1.37	0.25
3	0-5	1.76	1.46	0.31
	5-18	1.73	1.52	0.28
4	0-11	1.52	1.52	0.28
	11-25	1.42	1.53	0.28
5	0-10	1.44	1.17	0.22
	10-24	1.46	1.26	0.20
6	0-6	1.10	0.80	0.12
	6-24	0.92	0.57	0.14

[8] Analyses reported on basis of oven-dry weight after NH_4^+ saturation of the exchange system.

In most cases, the sea samples and the Ladner soils, most
of which were originally deposited in sea water, are higher in
total K, Ca and Mg, especially K and Ca, than the sediments
deposited in fresh water environments.

Exchangeable cation data (20, 37, 68) also appears to re-
flect the influence of sea waters. Although exchangeable Mg is
relatively high in all Fraser River floodplain sediments, there
appears to be a general increase in the exchangeable Mg content
as the Strait of Georgia is approached. Expressing the ex-
changeable Mg of the subsoil as a percentage of the base exchange
capacity, the following results are obtained: Grigg - 36%,
Fairfield - 38%, Monroe - 22%, Pitt - 45% and Ladner - 50%.

On the basis of the present data, it appears that modifi-
cations of sediments after deposition in marine waters takes
the form of simple ion exchange reactions and additions of
materials to interlayer positions as advocated by Weaver (77)
and Grim (30).

Powers (64) reported the preferential adsorption of Mg over
K in a marine environment. Considering the relatively constant
ration of Mg:K in sea water approximately 3:1 (70), the prefer-
ential adsorption of Mg onto the exchange system could be predicted
according to the mass action law.

In only one case, S - 7, is there evidence to support pref-
erential absorption of Mg over K into interlattice positions.

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[9]Percentages represent averages of the following: Grigg - 1
profile, 6 subsamples; Fairfield - 1 profile, 3 subsamples;
Monroe - 1 profile, 4 subsamples; Pitt - 3 profiles, 11 sub-
samples; Ladner - 3 profiles, 9 subsamples.

In S - 7, the total K and Mg was 1.55 and 1.82%, respectively. The reverse in these contents was noted in all other marine deposited sediments. However, the particular nature of the sedimentary environment and possibly the clay minerals themselves help explain this.

Several workers (30, 55, 62) have stated that length of time of exposure to sea water is a major factor in diagenetic changes. Milne (55) reports that alteration of clay minerals can be expected in an area where the sedimentation rate is low and sufficient time is available for chemical equilibria between sea water and clay minerals, however, in an area of active deposition due to the blanketing effect of overlying clay material and insufficient time of exposure, diagenetic modification is at a minimum.

The specific area described herein, is one of active deposition. Therefore, absorption reactions would be at a minimum. However, the particular nature of S - 7 is such, that diagenesis would be expected to be the most pronounced of the marine sediments sampled. S - 7 occurs in 1362 feet of water, 40 - 50 miles northwest of the other sea samples. Mechanical analyses (Appendix II) indicates that 97% of the sample is less than 20 microns. This sample, therefore, represents a considerable greater period of exposure to sea water and a minimizing of the blanketing effect.

Bradley (8) states that much of the recent sediments transported by rivers into oceans is of a degraded nature. This does

not appear to be the case with Fraser River sediments. The relative sharp diffraction peaks of the micaceous and chloritic components would indicate they are not of a degraded nature. Since Grim (30) and Doeglas (22) report that no alteration or regrading of sediments occurs during transportation in fresh water, the present sediments reflect a source area of a relatively low weathering intensity.

This is also reflected in the presence of amphiboles which disappear relatively early in the weathering sequence (42).

No particular sequence in the distribution of mixed-layered clay minerals was observed to support Grims contention (32) that diagenesis proceeds via a randomly interstratified stage or Weavers theory (76) that mixed-layered clay minerals are the probable products of marine diagenesis.

(ii) <u>Content of rock flour</u>[10]

X-ray and mechanical analyses appear to support the contention of Armstrong (3, 4, 5), Johnston (44) and Mathews[11] that Fraser River alluvium is composed to a large extent of "rock flour".

X-ray analyses indicate the fine and coarse silt fractions are dominated by non-phyllosilicates, especially quartz and feldspars.[12] Chlorite and micaceous material appear to be

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[10]The term "rock flour" herein, designates rock-material formed by physical grinding processes and therefore is composed largely of unweathered mineral particles.

[11]Dr. W. H. Mathews - personal communication

[12]Dr. E. H. Gardner - personal communication

concentrated in the coarse clay and fine silt fractions. Both minerals are found in the sand fractions, however their content decreased quite markedly in the fine clay fraction, especially the mica. The particular size fractions in which the chlorite and mica are concentrated and the symmetry of their peaks on X-raying suggests they are relatively unweathered and have resulted largely from physical breakdown.

Mechanical analyses (Appendix II) are also indicative of a high content of "rock flour". In a majority of the cases, the silt content of these sediments range between 60 - 75% and the clay content is sually less than 30%. Fine silt usually accounts for 60 - 100% of the silt fraction. Pettijohn (61) reports silt to be the product of physical breakdown.

III <u>Relation of soil series</u>

Mineralogical variations of the clay fraction within and among soil series appears to be relatively small. Quantitative variations existed however, but these tended to be minimized within each specific soil series.

The largest quantitative variations in mineralogy within a particular soil series were found within the Fairfield and Monroe series. This is probably to be expected since they occupy the largest area in terms of distance.

X-ray diffractograms of Monroe and Fairfield samples from any one particular area are almost identical. Such similarities are probably reflected in the nature of the deposits. Both series are developed on lateral accretions deposits and are

separated merely on the basis of drainage. Although drainage
is considered to be a factor affecting the clay mineral content
of soils (7, 40, 46), when one considers the relative age of
these soils the effect of such a parameter would probably be
very small or neligible.

Sites 3 and 4 of the above two series are located on the
northern side of the Fraser River on Nicomen Island and at
Agassiz, respectively. On the basis of X-ray diffractograms,
samples from these particular areas appear to contain more mont-
morillonoid than the respective sites located on the southern
flanks of the Fraser River. Although sedimentary processes may
account for this difference, the possibility of the influence
of sediments from the Harrison River should not be overlooked.

The sampling sites from the Pitt Meadows area, M and F - 6,
distinctly differ both in mineralogy and chemistry from the
remaining Monroe and Fairfield samples and for that fact from the
rest of the soils and sediments sampled. Figure IV contains the
X-ray diffraction tracing of M - 6 (0-9").

The clay fraction, unlike other samples, appears to be
dominated by randomly interstratified chlorite-montmorillonoid.
This was true of both the coarse and fine clay fractions.
Other samples contained such a mixed-layer mineral but only in
minor or questionable amounts.

The micaceous mineral content was considerably lower in
these sites as compared to other soils. This was reflected both
in the X-ray and chemical analyses. The 10 A° peak was

considerably weaker in the 2-0.2 micron fraction than those of other areas. Chemical analyses (Table I) also indicate a much lower K content. Percent total K was in the neighborhood of 0.92% for soils in the Pitt Meadows area, while the other soils averaged 1.4% or higher. The Pitt Meadow soils also contained relatively low amounts of Ca and Mg.

Sampling sites in this area appeared to be on soils developed on typical lateral accretion deposits of the Fraser River flood-plain. Morphologically they were very similar to the other Monroe and Fairfield soils which were sampled.

The variation in mineralogy of the Pitt Meadows samples may possibly be accounted for by the influence of sediments carried by the Alouette River. Mathews (54) reported that very little sediment is being added to the Fraser River below Hope by tributaries, since nearly all the rivers pass through lakes in their lower courses. However, the Alouette River has developed a small floodplain and it is quite probable that sediments from this river have influenced the mineralogy of the surrounding soils to some degree.

The data suggests, that several of the rivers, such as the Harrison and Alouette, which flow out of the Coast Mountains have had a greater influence on the mineralogy of these sediments than was previously suspected. However, furthur mineralogical studies of the sediments of these particular rivers would be necessary to confirm this.

IV <u>Relation to previous work</u>

A suite of clay minerals somewhat similar to those reported

by Clark et al (17) and Comar (19) for the Ladner soil series
is indicated by the present work. Comar (19) reported diffi-
culties in identification of vermiculite and kaolinite. A
similar problem was confronted in the present work. However,
results strongly suggest small amounts of kaolin minerals are
present. In addition to the clay mineral suite reported by
Clark et al and Comar, a randomly interstratified chlorite-
mica was identified.

Comar (19) identified the chlorite in the Ladner soils as
an iron rich variety which differs from the iron chlorite,
described herein, in that its higher order reflections possessed
considerably more thermal stability. The variability in the
thermal stability of the chlorite higher order reflections noted
is probably attributable to pretreatment methods. Comar did
not remove iron prior to X-raying whereas, in the present study,
free iron was removed by the dithionite method (52). Harward
et al (34, 35) have reported similar discrepancies in X-ray
diffractograms due to pretreatment of samples.

V Potassium contents

Although the present study was not conducted in relation
to a K problem, it is felt this particular section warrants a
discussion as a possible basis for future work.

Considerable variation in response to K fertilization has
been noted in soils of the lower Fraser Valley, especially on
soils in the eastern sector of the Valley. X-ray and chemical
analyses (Table II) suggests that the K contents of these soils

are quite high. However, considerable amounts of the K appears to be tied up in the form of primary mica minerals (largley white mica) and feldspars. X-ray analyses indicates that both minerals are concentrated largely in the silt fraction. Both feldspars and white micas are reported to release comparatively small amounts of K on weathering (24).

Variable response may also be related to the type of clay mineral. As discussed in a previous section, results suggest the presence of a high tetrahedrally charged clay mineral having properties similar to a montmorillonoid. Montmorillonoids, such as beidellite, which exhibit a high interlayer charge are reported to fix greater quantities of K than are the octahedrally substituted members (24).

The data suggest that these soils are relatively high in reserve K and the variable response noted in K fertilization may well be correlated with the mineralogy of these soils.

CONCLUSION

X-ray analyses were conducted on Fraser River alluvial sediments deposited under fresh water and sea water environments. Results indicate that the sediments are highly detrital in nature and dominantly reflect their source area. Marine diagenesis appears to be operative to a minor extent. This is illustrated by the decreased intensity of the 14 A° peaks of marine samples and the existance of several shoulders on the low angle side of the 14 A° peak which are attributed to interlayer contamination of expandable clay minerals resulting from the influence of a marine environment. Although most of the soils of the Ladner series were originally deposited in sea water, their X-ray diffraction patterns are more characteristic of those sediments formed under a fresh water environment.

Chemical analyses were also indicative of the minor influence of a marine environment. The total K, Mg and Ca contents of the clay fractions of the marine sediments were somewhat higher than those found in the soil samples furthur up the Valley. The exchangeable Mg content also increased due to the effect of marine conditions, however in the present study, cation adsorption reactions are not considered to constitute a diagenetic reaction.

The soils and sediments are composed chiefly of "rock flour" consisting largley of quartz, feldspars and moderate amounts of mica minerals and chlorite. The high silt contents (60 - 75%) of these samples furthur supports this. The high content of

"rock flour" and the presence of relatively easily weathered minerals i.e. amphiboles is suggestive of a source area of a relatively low weathering intensity.

The major components identified in the 2-0.2 micron fraction were montmorillonoid and chlorite. Considerable amount of micaceous material, quartz and feldspar were also present. With the exception of regularly interstratified montmorillonoid-chlorite which was identified in a limited number of samples, minor amounts of randomly interstratified montmorillonoid-chlorite and chlorite-mica were found in all samples. The identification of a series of peaks at 15.65, 7.84, 5.21 and 3.89 A° as a regularly interstratified chlorite-mica was quite questionable.

Kaolin appeared to be present in minor amounts in most samples however, positive identification was prevented in most instances by the presence of a heat unstable chlorite. The particular nature of the montmorillonoid also prevented identification of vermiculite.

Quartz, feldspars and amphiboles were the only non-phyllosilicates identified in this fraction.

The $<$ 0.2 micron fractions were dominated by montmorillonoids and moderate amounts of chlorite. Micaceous material and inter-stratified clay minerals were present in very low or questionable amounts. With the exception of minor amounts of quartz, the non-phyllosilicates appeared to be absent from this fraction.

Evidence suggests that the montmorillonoid component

identified consisted of two types: An octahedrally substituted member and a tetrahedrally substituted member which exhibited properties of both the vermiculite and montmorillonite groups. The presence of the latter mineral prevented positive identification of a vermiculite mineral.

The chlorite was characterized as an iron rich variety possessing thermally unstable reflections at 7.07, 4.71, 3.53 and 2.82 A°. A progressive decrease in the relative intensity of the chlorite higher order reflections was observed on heating from 400 to 450°C and furthur heating to 500°C resulted in disappearance of the peaks. Discrepencies in the thermal stability of the chlorite peaks reported by Comar (19) and in the present study, are attributed to pretreatment methods.

Mineralogical variations within and among soil series were largely limited to a quantitative nature. Although mineralogical variations were noted, with reference to kaolin and regularly interstratified chlorite-montmorillonoid, these minerals were present in minor quantities and their identification in many instances was somewhat questionable. Assessment, therefore, of the mineralogical variation in these sediments is quite difficult and probably not too meaningful.

The quantitative variations noted in the mineralogy of these sediments is attributed to sedimentary processes, seasonal variations in the detrital components carried by rivers, yearly variations in particular source areas and the local influence of sediments carried by several tributaries of the lower Fraser

River that flow out of the Coast Mountains.

X-ray and chemical analyses indicated that there is a valid basis for continued mapping of the Pitt soil series separate from the Monroe and Fairfield series. X-ray diffraction properties of these soils indicated a much higher content of randomly interstratified chlorite-montmorillonoid and a considerably lower micaceous mineral content then the remainder of soils and sediments sampled. Total K, Ca and Mg contents of the clay fraction of soils from the Pitt Meadows area were also considerably lower than those of the remaining sites sampled.

The variability noted in soils from the Pitt Meadows area may be related to the influence of sediments carried by the Alouette River.

BIBLIOGRAPHY

1. American Society for Testing Materials. 1963. Index (inorganic) to the power diffraction file. Philadelphia. (Special Technical Publication (48-M2).

2. Andrew, R. W., M. L. Jackson & K. Wada. 1960. Intersalation as a technique for differentiation of kaolinite from chloritic minerals by X-ray diffraction. Soil Sc. Soc. Amer. Proc. 24:422-424.

3. Armstrong, J. E. 1956. Surfical geology of Vancouver area, British Columbia. Geol. Surv. Canada, Paper 55-40.

4. _____ 1957. Surfical geology of New Westminster British Columbia. Geol. Surv. Canada, Paper 57-5.

5. _____ 1960. Surfical geology of Sumas map-area, British Columbia. Geol. Surv. Canada, Paper 59-9.

6. _____ & W. L. Brown. 1954. Late Wisconsin marine drift and associated sediments of the Lower Fraser Valley, British Columbia. Bull. Geol. Soc. Amer. 65:349-364.

7. Barshad, I. 1959. Fractors affecting clay formation. Clays & Clay Minerals, 6th Conf., Pergamon Press, Los Angeles. pp 110-132.

8. Bradley, W. F. 1954. X-ray diffraction criteria for the characterization of chloritic material in sediments. Clays & clay Minerla, Nat. Acad. Science-Nat. Res. Counc., Pub. 327. pp 324-334.

9. Brindley, G. W. 1961. X-ray identification and crystal structures of clay minerals, Ch.II, pp 51-131 (G. Brown, editor). Mineralogical Society, London.

10. _____ 1961 X-ray identification and crystal structures of clay minerals. Ch.VI, pp 242-296. (G. Brown, editor). Mineralogical Society, London.

11. _____ & J. Goodyear. 1947-49. Part II Transition of halloysite to metahalloysite in relation to relative humidity. Mineralogical Mag. 28:407-422.

12. _____, K. Robinson & J. Goodyear. 1947-49. Part III. Effect of temperature & pressure on the transition from halloysite to metahalloysite. Mineralogical Mag. 28:423-428.

13. Brydon, J. E., J. S. Clark & V. Osborne. 1961. Dioctahedral chlorite. Can. Min. 6:595-609.

14. _____ & H. Heysten. 1958. A mineralogical and chemical study of the dikeland soils of Nova Scotia. Can. Jour. Soil Sc. 38:171-186.

15. Caillère, S. & S. Henin. 1947-49. Experimental formation of chlorites from montmorillonites. Mineralogical Mag. 28:612-620.

16. Carroll, D. & J. C. Hathaway. 1954. Clay minerals in a limestone profile. Clays & Clay Minerals, Nat. Acad. Sc.-Nat. Res. Coun., Pub. 327. pp 171-182.

17. Clark, J. S., J. E. Brydon & H. J. Hortie. 1962. Clay minerals in B. C. subsoils. Can. Jour. Soil Sc. 42:296-301.

18. _____, G. A. Gobin & P. N. Sprout. 1961. Yellow mottles in poorly drained soils of the lower Fraser Valley. Can. Jour. Soil Sc. 41:218-227.

19. Comar, V. K. 1960. Soil permability as affected by different clay minerals and exchangeable cations. Masters Thesis, Dept. Soil Science, U.B.C.

20. _____, P.N. Sprout & C. C. Kelley, 1962. Soil survey of Chilliwack map-area. Preliminary Report #4, B. C. Dept. of Agric., Kelowna, B. C.

21. Dixon, J. B. & M. L. Jackson. 1960. Mineralogical analyses of soil clays involving vermiculite-chlorite-kaolinite differentiation. Clays & Clay Minerals, 8th Conf., Pergamon Press, New York. pp 274-286.

22. Doeglas, D.J. 1960. Sedimentogical data for soil mineralogy. 7th International Cong. Soil Sc., Madison, Wisc. pp 534-547.

23. Earley, J. W. et al. 1956. Regularly interstratified montmorillonite-chlorite. Amer. Min. 41:258-267.

24. Gardner, E. H. 1960. Potassium release from several Western Oregon soils and its relationship to crop growth and soil mineralogy. Ph.D. Thesis, Oregon State College, Corvallis, Oregon.

25. Glass, H. D. 1958. Clay minerals of Pennsylvanian sediments in southern Illinois. Clays & Clay Minerals, 7th Conf., Pergamon Press, New York. pp 162-177.

26. Griffin, C. M. 1962. Regional clay-mineral facies-Products of weathering intensity and current distribution in the north eastern Gulf of Mexico. Bull. Geol. Soc. Amer. 73:737-768.

27. _____ & R. L. Ingram. 1955. Clay minerals of the Neuse River estuary. Jour. Sed. Petrology 25:194-200.

28. Grim, R. E. 1953. Clay mineralogy. McGraw-Hill Book Comp., Inc., New York.

29. _____ 1958. Concept of diagenesis in argillaceous sediments. Bull. Amer. Assoc. Petrol. Geol. 42:246-253.

30. _____ 1962. Clay mineralogy. Science 135:890-898.

31. _____ et al 1949. Clay mineral composition of some sediments from the Pacific Ocean of the California coast and the Gulf of California. Bull. Geol. Soc. Amer. 60:1785-1808.

32. _____ & W. D. Johns. 1954. Clay mineral investigations of sediments in the Northern Gulf of Mexico. Clays & Clay Minerals, Nat. Acad. Sc.-Nat. Res. Coun., Pub. 327. pp 81-103.

33. Happ, S. C. G. Rittenhouse & G. C. Dobson. 1940. Some principles of accelerated stream and valley sedimentation. U.S.D.A. Tech. Bull. 695, 133 pp.

34. Harward, M. E. et al. 1962. Effect of iron removal and dispersion methods on clay mineral identification by X-ray diffraction. Soil Sc. Soc. Amer. Proc. 26:535-541.

35. _____ & A. A. Theisen. 1962. Problems in clay mineral identification by X-ray diffraction. Soil Sc. Soc. Amer. Proc. 26:335-341.

36. Hey, M. H. 1954. A new review of chlorites. Mineralogical Mag. 30:277-292.

37. Holland, W. D., A. L. van Ryswyk & C. C. Kelley, 1957. Soil survey of Pitt Meadows Municipality. B. C. Dept. of Agric., Kelowna, B. C.

38. Jackson, M. L. 1956. Soil chemical analyses-advanced course. University of Wisconsin. Madison.

39. _____ 1958. Soil chemical analyses. Prentice-Hall, Inc., Englewood Cliffs., N. J.

40. _____ 1959. Frequency distribution of clay minerals in major soil groups as related to the factors of soil formation. Clays & Clay Minerals, 6th Conf., Pergamon Press, Los Angeles. pp 133-143.

41. _____ 1962. Significance of kaolinite intersalation in clay mineral analyses. Clays & Clay Minerals, 9th Conf., Pergamon Press, New York pp 424-430.

42. _____ et al. 1948 Weathering sequence of clay-size minerals in soils and sediments. Jour. Phys. & Colloid Chem. 52:1237-1260.

43. Johnson, L. J. et al. 1963. Clay mineral characterization of modal soil profiles in several Pennsylvania counties. Soil Sc. Soc. Amer. Proc. 27:568-572.

44. Johnston, W. A. 1921. Sedimentation of the Fraser River delta. Geol. Surv. Canada, Mem.-125.

45. Jones, L. H. P. et al. 1964. Dioctahedral vermiculite and chlorite in highly weathered red loams in Victoria, Australia. Soil Sc. Soc. Amer. Proc. 28:108-113.

46. Keller, W. D. 1956. Clay minerals as influenced by environment of their formation. Bull. Amer. Assoc. Petrol. Geol. 40:2689-2710.

47. _____ 1959. Clay minerals in the Morrison formation of the Colorado Plateau. Clays & Clay Minerals, 7th Conf., Pergamon Press, New York. pp 293-294.

48. Kelley, C. C. & R. H. Spilsbury. 1939. Soil Survey of the lower Fraser Valley. B. C. Dept. of Agric.

49. Kilmer, V. J. & L. T. Alexander. 1949. Methods of making mechanical analyses of soils. Soil Sc. 68:15-24.

50. Leopold, L. B. & M. G. Wolman. 1957. River channel patterns: braided, meandering and straight. U. S. Geol. Surv. Prof. Paper 282-B.

51. MacEwan, D. M. C. 1961. X-ray identification and crystal structures of clay minerals. Ch.IV, pp 143-207 (G. Brown, editor). Mineralogical Society, London.

52. Mackenzie, R. C. 1949. Free Iron oxide removal from soils Jour. Soil Sc. 5:167-172.

53. Martin, R. T. 1955. Reference chlorite characterization for chlorite identification in soil clays. Clays & Clay Minerals, Nat. Acad. Sc.-Nat. Res. Coun., Pub. #395. pp 117-145.

54. Mathews, W. H. & F. P. Shepard. 1962. Sedimentation of Fraser River delta, British Columbia. Bull. Amer. Assoc. Petrol. Geol. 46:1416-1443.

55. Milne, I. H. & J. W. Earley. 1958. Effect of source and environment on clay minerals. Bull. Amer. Assoc. Petrol. Geol. 42:328-338.

56. _____ & W. L. Schott. 1958. Clay mineralogy of recent sediments from the Mississippi Sound Area. Clays & Clay Minerals, Nat. Acad. Sc.-Nat. Res. Coun., Pub. 566. pp 253-265.

57. Murray, H. H. 1954. Genesis of clay minerals in some Pensylvanian shales of Indiana and Illinois. Clays & Clay Minerals, Nat. Acad. Sc-Nat. Res. Coun., Pub. #327. pp 47-67.

58. _____ & J. L. Harrison. 1956. Clay mineral composition of recent sediments from Sigsbee Deep. Jour. Sed. Petrology 26:363-368.

59. _____ & A. S. Sayyab. 1955. Clay mineral studies of some recent marine sediments of the North Carolina Coast. Clays & Clay minerals. Nat. Acad. Sc.-Nat. Res. Coun., Pub. 395. pp 430-441.

60. Nelson, B. W. 1960. Clay mineralogy of the bottom sediments, Rappahannock River, Virginia. Clays & Clay Minerals, 7th Conf., Pergamon Press, New York. pp 135-147.

61. Pettijohn, F. J. 1949. Sedimentary rocks. Harper & Bros., New York.

62. Pinsak, A. P. & H. H. Murray. 1960. Regional clay mineral patterns in the Gulf of Mexico. Clays & Clay Minerals, 7th Conf., Pergamon Press New York. pp 162-177.

63. Powers, M. C. 1954. Clay diagenesis in the Chesapeake Bay area. Clays & Clay Minerals, Nat. Acad. Sc.-Nat. Res. Coun., Pub. 327. pp 68-80.

64. _____ 1959. Adjustment of clays to chemical change and the concept of the equivalence level. Clays & Clay Minerals, 6th Conf., Pergamon Press, New York. pp 309-326.

65. Quigley, R. M. & R. T. Martin. 1963. Chloritized weathering products of a New England glacial till. Clays & Clay minerals, 10th Conf., Macmillan Co., New York. pp 107-116.

66. Rivière, A. 1953. Sur l'origine des argiles sédimentaires. Congrès Géologique Internat. 1952, fascicule 18, pp 177-180.

67. Slaughter, M. & I. H. Milne. 1960. The formation of chlorite-like structures from montmorillonite. Clays & Clay Minerals, 7th Conf., Pergamon Press, New York. pp 114-124.

68. Sprout, P. N. & W. A. Holland, 1959. Soil survey of Delta Municipality. Preliminary Report #2, B. C. Dept. of Agric., Kelowna, B. C.

69. Sutherland, H. H. & D. M. C. MacEwan. 1962. A swelling chlorite mineral Clays & Clay Minerals, 9th Conf., Macmillan Co., New York. pp 451-458.

70. Sverdrup, H. U., M. W. Johnson & R. H. Fleming 1962. The oceans. Prentice-Hall, Inc., N. J.

71. Taggart, M. S. & A. D. Kaiser. 1960. Clay mineralogy of Mississippi River deltaic sediments. Bull. Amer. Geol. Soc. 71:521-530.

72. Theisen, A. A. & G. R. Webster & M. E. Harward. 1959. The occurrence of chlorite and vermiculite in the clay fraction of three British Columbia soils. Can. Jour. Soil Sc. 39:244-251.

73. Walker, G. F. 1958. Reactions of expanding-lattice clay minerals with glycerol and ethylene glycol. Clay Mineral Bull. 3:302-313.

74. _____ 1961. X-ray identification and crystal structures of clay minerals. Ch.VII, pp 297-325 (G. Brown, editor). Mineralogical Society, London.

75. Warshaw, C. M. & R. Roy. 1961. The classification and a scheme for the identification of layer silicates. Bull. Geol. Soc. Amer. 72:1455-1472.

76. Weaver, C. E. 1956. The distribution and identification of mixed-layer clays in sedimentary rocks. Amer. Min. 41:202-221.

77. _____ 1958. A discussion on the origin of clay minerals in sedimentary rocks. Clays & Clay Minerals, Nat. Acad. Sc.-Nat. Res. Coun., Pub. #566. pp 159-173.

78. _____ 1958. Geologic interpretation of argillaceous sediments. Bull. Amer. Assoc. Petrol. Geol. 42:254-309.

79. _____ 1958. The effects and geologic significance of potassium "fixation" by expandable clay minerals derived from muscovite, biotite, chlorite and volcanic material. Amer. Min. 43:839-861.

80. _____ 1959. The clay petrology of sediments. Clays & Clay Minerals, 6th Conf., Pergamon Press, New York pp 154-187.

81. Whitehouse, J. G., L. M. Jeffrey & J. D. Debbrecht. 1960. Differential settling tendencies of clay minerals in saline saters. Clays & Clay Minerals, 7th Conf., Pergamon Press, New York. pp 1-79.

82. _____ & R. S. McCarter, 1958. Diagenetic modification of clay mineral types in artifical sea water. Clays & Clay Minerals, Nat. Acad. Sc.-Nat. Res. Coun., Pub. #566. pp 81-119.

83. Wolman, M. G. & L. B. Leopold. 1957. River floodplains: Some observations on their formation. U.S. Geol. Surv. Prof. Paper 282-C.

APPENDIX

Appendix I Fe removal[*] vs Fe present for method of mechanical analyses

Samples	Depth (inches)	% sand		% silt		% clay	
		1	2	1	2	1	2
Sea sediments 8	0-12	11.70	10.50	68.40	70.80	19.90	18.71
Ladner series 1	10-25	14.00	15.60	67.10	65.90	18.90	18.50
4	0-10	1.90	2.20	71.30	72.80	26.80	25.00
Grigg series 3	10-24	3.20	4.40	67.50	69.20	29.30	26.40
Monroe series 2	0-11	30.10	30.00	48.20	52.00	21.70	18.00
Fairfield series 4	11-25	16.70	18.40	68.00	67.00	15.30	14.60
6	0-6	12.30	11.30	46.40	50.00	41.30	38.70

*1 - Fe removed by Na dithionite using Mackenizie's method "a" (52); 2 - Fe present.

Appendix II Mechanical analyses of soils and sediments

Samples	Depth (inches)	Sand (%)	Silt (%) 2-20μ	Silt (%) 20-50μ	Silt (%) total	Clay (%)	Textural class
Sea sediments							
1	0-10	1.07	64.01	10.31	74.32	24.60	SiL
2	0-8	11.67	48.09	21.21	69.30	19.03	SiL
3	-	17.95	41.26	20.28	61.54	20.51	SiL
5	-	28.31	32.57	20.14	52.71	18.91	SiL-L
7	-	-	48.60	3.02	51.62	48.02	SiC
8	0-12	10.50	43.05	27.75	70.80	18.71	SiL
Ladner series							
1	0-10	26.04	32.91	26.26	59.17	14.79	SiL
	10-25	15.60	29.25	36.65	65.90	18.50	SiL
2	0-10	2.23	54.68	15.46	70.14	27.63	SiCL-SiL
	10-24	5.88	51.06	16.48	67.52	26.60	SiCL-SiL
3	0-7	-	68.14	4.75	72.89	26.50	SiL-SiCL
	7-24	2.39	62.24	9.91	72.15	25.46	SiL-SiCL
4	0-10	2.20	55.94	16.86	72.80	25.00	SiL-SiCL
	10-24	17.38	23.73	38.74	62.47	20.15	SiL
5	0-8	-	63.68	4.22	67.90	31.83	SiCL
Grigg series							
1	0-11	7.56	49.25	12.28	61.53	30.90	SiCL
	11-20	5.64	49.88	23.45	73.33	21.02	SiL

Appendix II   cont'd

Samples	Depth (inches)	Sand (%)	Silt (%)			Clay (%)	Textural class
			2-20 μ	20-50 μ	total		
Grigg (cont'd)							
2	0-10	12.14	47.11	10.00	57.11	30.75	SiCL
	10-22	-	57.68	5.02	62.70	36.76	SiCL
3	0-10	4.03	49.48	13.82	63.30	32.67	SiCL
	10-24	4.40	53.19	16.01	69.20	26.40	SiL-SiCL
4	0-9	3.75	57.40	16.71	74.11	22.14	SiL
	9-20	3.84	50.48	26.44	76.92	19.23	SiL
Monroe series							
1	0-9	7.22	54.09	15.49	69.58	23.19	SiL
	9-20	4.68	53.48	24.26	77.74	17.57	SiL
2	0-11	30.00	30.61	21.39	52.00	18.00	SiL
	11-26	74.96	10.51	8.27	18.78	6.25	SL-LS
3	0-6	26.87	34.19	27.86	62.05	11.08	SiL
	6-18	43.41	20.40	25.13	45.53	11.06	L
4	0-9	21.70	40.05	27.37	67.42	10.87	SiL
	9-24	21.77	33.57	29.85	63.42	14.80	SiL
5	0-9	7.90	56.18	16.27	72.45	19.76	SiL
	9-23	15.25	44.62	24.76	69.38	15.36	SiL
6	0-7	16.05	35.95	26.98	62.93	20.97	SiL
	7-20	21.40	36.93	26.80	63.73	14.87	SiL

Samples	Depth (inches)	Sand (%)	Silt (%)			Clay (%)	Textural class
			2-20 μ	20-50 μ	total		
Fairfield series							
1	0-8	6.05	50.41	14.31	64.72	29.22	SiCL
	8-18	5.73	55.75	16.02	71.77	22.49	SiL
2	0-8	5.31	53.36	18.81	71.54	23.14	SiL
	8-20	1.13	63.02	6.94	69.96	28.81	SiCL-SiL
3	0-5	9.51	47.51	24.96	72.47	18.02	SiL
	5-18	9.71	46.16	29.43	75.59	14.70	SiL
4	0-11	12.41	41.54	24.52	66.06	21.31	SiL
	11-25	18.40	35.57	31.43	67.00	14.60	SiL
5	0-10	13.10	47.99	14.71	62.70	24.19	SiL-SiCL
	10-24	13.91	41.54	29.54	71.39	14.69	SiL
6	0-6	11.30	43.89	6.11	50.00	38.70	SiCL
	6-24	18.76	39.64	7.39	47.03	34.21	SiCL