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CLAY MINERALOGY OF RECENT SEDIMENTS OF THE BROAD SOUND AREA, QUEENSLAND

by

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ABSTRACT

Kaolinite, illite, and montmorillonite plus mixed layer montmorillonite - illite are present in approximately equal amounts in Holocene sediments from Broad Sound. Statistically significant quantitative differences between the marine, intertidal, and mangrove environments are few, but there are many small significant differences between these three and the supratidal mudflat and mangrove inlet environments. These minor variations in clay mineralogy may be explained by (i) the slow settling and flocculation rates of montmorillonite in saline water, (ii) the conversion of montmorillonite to illite to give irregularly stacked mixed layer montmorillonite - illite in the highly saline and often desiccated supratidal mudflat environment and (iii) the source of sediment in each environment.

Nine stream sediment and six soil samples form part of the Broad Sound catchment area were analysed, and it appears that montmorillonite is being partly converted to illite to give mixed layer montmorillonite - illite as sediment enters the saline water of Broad Sound.

INTRODUCTION

General

This study of the clay minerals of the Broad Sound area was undertaken as a contribution to the Estuary Study Project; it will be subsequently incorporated into a comprehensive Bulletin dealing with the project (Gibson in Cook & Mayo, 1972).

Broad Sound is a large shallow estuary on the central Queensland coast (Fig. 1). It is up to 18 km wide and has a maximum depth at low water of 20 m. Tidal ranges of 10 m are not uncommon, and the four major creeks draining into the estuary are tidal for up to half of their total length. It is possible that stream capture has vastly reduced the catchment area of Broad Sound to the present figure of about 5,000 km^2.

Climate

Broad Sound is situated on latitude 22°S and has a monsoonal climate (Table 1).

January mean daily maximum temperature	-	30°C
January mean daily minimum temperature	-	20 - 22°C
July mean daily maximum temperature	-	22 - 23°C
July mean daily minimum temperature	-	7 - 8°C

Average monthly rainfall at Mackay, 150 km north of Broad Sound:

Jan	29 8 mm	May	50 mm	Sept	40 mm
Feb	250	June	60	Oct	45
Mar	195	July	40	Nov	70
Apr	90	Aug	25	Dec	150

Yearly average = 1313 mm or about 52".

TABLE 1: Some Climate Statistics of the Broad Sound Area. (from Gentilli, 1971)

Rainfall at Broad Sound is probably lower than that given in Table 1, but follows the same seasonal pattern. The rainfall in the wet season is extremely variable, with little or no rain in some years and over 150 cm in others.

Hence the Broad Sound catchments have high runoff and sediment discharge associated with flooding for two or three months of most years and little runoff during the rest of the year.

The Catchment Areas

Four major creek systems (Herbert, Waverley, and St Lawrence Creeks and the Styx River) drain into Broad Sound. These catchments are bounded by ranges up to 500 m high which descend to coastal flats with an elevation of only 20 to 60 m. The generalized surface geology and approximate area of the four catchments are given in Table 2.

TABLE 2 PERCENTAGES OF AREAS OF RIVER CATCHMENTS UNDERLAIN BY GEOLOGICAL FORMATIONS SPECIFIED

	Herbert	Styx	Waverley	St Lawrence
Cainozoic sediments	70	37	42	46
Tertiary laterite	0	2	0	0
Cretaceous coal measures	0	3	9	2
Granite - mainly Upper Permian	15	3	1	0
Permian sediments and volcanics	7	43	38	48
Devonian - Carboniferous volcanics and sediments	0	12	10	4
Lower Palaeozoic sediments and hornfels	7	0	0	0
(?)Lower Palaeozoic serpentine	1	0	0	0
TOTALS	100	100	100	100
Catchment Area (km^2)	2610	1690	580	370

Depositional Environments of Broad Sound

Broad Sound has been divided into five main sedimentary environments and several sub-environments (Cook and Mayo, pers. comm.). These are shown in Figures 2 and 3.

1. The Supratidal Mudflat Environment. This environment is made up of those tidal flats and channels invaded only at the highest tides. Laminated silty and muddy sediments, commonly with a carbonate content of less than 1 percent and, bound by algal filaments, predominate.

2. The Mangrove Environment. This is the area between the supratidal and intertidal environments which has been colonized by mangrove. Brown oxidized muds, strongly bioturbated by crabs, shrimps, etc., predominate.

3. The Mangrove Inlet Environment. Mangrove inlets are the channels in mangrove deposits. Sediment appears to be supplied to them mainly from the slumping of mangrove deposits and erosion of the supratidal environment. Many channels have sandy or gravelly bottoms. Current velocities are high, and in some places the channels have cut through the mangrove deposits into indurated bedrock. Most of the mangrove inlets have a V-shaped cross section.

4. The Intertidal Environment. This is the area between lowest low water and the supratidal environment, excluding the mangrove and mangrove inlet environments. There is a clear distinction between intertidal sands and muds. The muds form a strip up to several hundred metres wide between the areas of mangrove and the intertidal sands, and are composed of sediment eroded from the mangrove muds. They are finely laminated and have a depositional dip of a few degrees seaward. The sands have a much wider distribution and form elongate bodies parallel to the tidal currents. Carbonate material may form up to 50 percent of these sands, and silt rarely makes up more than 4 percent, except in areas well back into the creeks flowing into the estuary (see Fig. 3) where the tidal influence is diminished. The tidal currents reach velocities of up to 4 knots in the main part of the estuary.

5. The Marine Environment. This is the part of the estuary not exposed at lowest low tide. The boundary of this environment is subject to change, as there is much movement of sediment between the intertidal and marine environments. The marine environment can also be subdivided by the different grainsizes of sediment present. Marine sands occur at an average depth of 4 m, whereas marine gravels and muds occur at an average depth of 6 m. It is thought that the gravels, which contain many nodules, and perhaps the muds, are parts of earlier deposits which are being covered by prograding sand. These three subenvironments are not shown on Figure 3, which shows facies in more detail.

ACKNOWLEDGEMENTS

I should like to acknowledge the guidance of P.J. Cook who originally suggested that I carry out this study, provided background information, and made useful suggestions and criticisms about my methods and interpretations.

I should also like to thank Mr George Berryman who prepared the diffractometer charts, Mr Ken Armostrong who mounted most of the clay samples, and Mr Wayne Mayo who ran some computer programs. Thanks are also due to other workers who collected and prepared the samples prior to my joining the Bureau.

ANALYTICAL PROCEDURES

Samples and Sample Preparation

Samples used in this study were the less than 2-micron fraction of sediment samples collected from Broad Sound and its catchment during 1970. This fraction was separated from the rest of the sediment by settling and decantation. A veneer of clay material was mounted on to small ceramic tiles using a suction method similar to that of Kinter & Diamond (1955) to give maximum orientation of the clay particles.

X-ray diffractograms were made of each tile after it was:

(i) dried at room temperature;

(ii) placed in a glycol atmosphere at 60°C for at least 24 hours, and

(iii) heated at 300°C for at least two hours.

Some tiles were also x-rayed after being heated at 600°C for at least two hours. All heated tiles were x-rayed to 15° 2θ, the glycolated tiles to between 15° and 30° 2θ, and the untreated tiles to between 15° and 40° 2θ.

The clay samples were not treated to remove organic matter, calcium carbonate, amorphous iron, etc., nor were they saturated with any ions (calcium, magnesium, etc.) in the laboratory.

Mineral Indentification

The clay mineral groups dealt with in this record were recognized by their characteristic basal spacings corresponding to x-ray diffraction maxima, and the behaviour of these maxima after glycolation and heating. Nickel filtered copper Ka radiation with a stabilized power supply was used. Minerals of the kaolinite, illite, and montmorillonite groups and mixed layer clays were identified, and quartz was detected in all samples x-rayed beyond 25° 2θ. No attempt was made to identify the individual mineral or minerals in each group. The identification scheme set out below is similar to that of Carroll (1970) and Grim (1968).

Kaolinite. Members of the kaolinite group have a basal spacing of 7°A followed by a rational sequence of secondary diffractions. None of these are affected by glycolation or heating to 300°C.

Illite. Members of the illite group have a basal spacing of 10°A followed by a rational sequence of secondary diffractions. None of these are affected by glycolation or heating to 300°C.

Montmorillonite. Clays which have a basal spacing of between 12.4°A and 15°A when untreated and of 17°A and 18°A after glycolation belong to the montmorillonite group. The basal spacing collapses to 10oA after being heated at 300°C.

Mixed layer clays. In this study the only mixed layer clays identified were irregularly interstratified montmorillonite-illite. These are identified by their basal spacing of between 10°A and 15°A when untreated and between 10°A and 16°A when glycolated. They collapse to 10°A when heated at 300°C.

Chlorite. Chlorite was identified only in soil samples from the Styx River Catchment. The 14°A basal spacing is unaffected by glycolation or heating at 600°C, and the second order diffraction at 7°A is not affected at 300oC.

Other Minerals. Quartz was identified by a diffraction peak corresponding to a spacing of 4.26°A. In many charts, a small peak corresponding to a spacing of 13.6°A was encountered. A chart made of a blank tile also showed this diffraction maximum, and it was concluded that it was due to the material in the tile itself or a misalignment of the diffractometer. The characteristic shape and position of this peak made it easily recognizable in most charts (see Fig. 5 - this peak is at about 6° 2θ).

QUANTITATIVE ASPECTS

Useful comparisons of clay mineralogy may be made by comparing the areas under the basal diffraction peaks of the different clay groups. Many authors have devised empirical correction factors for peak areas; a popular method seems to be that of Biscaye (1965), which was a development of the method of Johns, Grim, & Bradley (1954), and was subsequently used by Rateev et al., (1969). The weighting factors of this method were: the area of the 17°A glycolated peak for montmorillonite; four times the 10°A peak (glycolated trace) for illite and twice the 7°A peak area for kaolinite. However, in the charts obtained in this study, it was impracticable to measure the area of the 17°A peak on the glycolated chart as the trace in the 2-4° 2θ region was very poor.

Consequently the method suggested by Schultz (1960) was used for all estuary and creek samples. In this method, the collapsed montmorillonite peak and the illite peak areas have the same weighting, and the weighting of the kaolinite peak with respect to these two varies according to the crystallinity of the kaolinite. Schultz's chart shows that the 80% confidence interval for the kaolinite weighting factor for the kaolinite of Broad Sound is from 1.2 to 1.6. Rather than use a non-integral factor, it was decided to not apply any correction factors. Hence the areas under the 7A and 10A peaks on the glycolated chart were used as measured of kaolinite and illite, and the increase of the 10A peak after the sample had been heated to 300°C was used as a measure of the montmorillonite and mixed layer clays, referred to hereafter as "montmorillonite (plus m.l.)". The three areas were summed to 100% to give percent clay mineralogy.

No attempt was made to determine quantitatively the clay mineralogy of the soil samples as they either contained chlorite or gave traces too poor to measure accurately. Biscaye (1964) suggested that the areas under the 3.5°A doublet (kaolin 002 and chlorite 004) are proportional to the amounts of each present, but this method was not attempted. A semi-quantitive mineralogy is given for the soil samples.

RESULTS AND DISCUSSION

Clay Minerals of the Estuary

The percentage clay mineralogy for the estuary samples shown in Appendix 1 indicate that kaolinite, illite, and montmorillonite (plus m.l.)

are present in approximately equal amounts. Figure 5 shows three typical diffractometer charts of Broad Sound clays. The localities of the sampling points are given on figure 8. A similar assemblage (kaolinite, illite, and montmorillonite) has been reported in recent sediments by many workers, including Grim, Dietz & Bradley (1949) in the Gulf of California and off the Californian coast, and Oinuma et al. (1959) in the western Pacific. Prior & Glass (1961) found a similar assemblage in Cretaceous and Tertiary sediments deposited in an inner neritic environment in the Mississippi Embayment.

Rateev et al. (1969) do not give data for most of the eastern coast of Australia and the area for several hundred kilometers to seaward in their maps of the worldwide distribution of clay minerals, but it is evident that kaolinite, illite, and montmorillonite are each generally between 20% and 40% of the clay fraction at latitudes around 20°S. Hence it appears that the assemblage encountered in Broad Sound is not at all unusual by worldwide standards.

Table 3 gives the means and unbiased standard deviations of the mineralogy of samples from each depositional environment and Figure 6 shows the statistically significant differences in mineralogy between the five main environments. The student's t-test shows there is no significant difference in the clay mineralogy between the intertidal sands and muds or between the marine muds, sands and gravels.

Environment	Number of Samples	Kaolinite mean	Kaolinite s.d.	Illite mean	Illite s.d.	Montmorillonite (plus m.l.) mean	Montmorillonite (plus m.l.) s.d.
Supratidal	27	36.11	3.21	34.74	4.74	29.22	6.22
Mangrove	20	32.00	3.24	31.40	2.46	36.65	4.03
Mangrove Inlet	20	36.20	2.86	30.55	2.98	33.35	4.45
Intertidal	27	31.78	4.16	32.70	3.71	35.63	5.44
Marine	26	31.96	4.86	30.08	3.40	38.04	5.51
All Environments	120	33.57	4.28	32.02	3.97	34.50	6.12

TABLE 3: Mean and unbiased standard deviations of the mineralogy of samples from the five depositional environments.

To be able to provide reasons for the variation in clay mineralogy between the environments, the sources of the sediment in each environment (as well as the interchange of sediment between environments) should be known. Information supplied to the author suggests that:

1. Mangrove muds are being both deposited and eroded at the present time. The mangrove deposits seem to be a temporary store of fine sediment.

2. Much sediment is exchanged between the marine and intertidal environments.

3. Intertidal muds are derived mainly from erosion of mangrove deposits.

4. Both supratidal and mangrove sediments are eroded to supply the detritus in the mangrove inlets.

5. High spring tides supply most of the sediment to the supratidal environment. During the wet season sediment is also supplied from the land, generally from nearby soils. Ponding occurs in this environment as in places it is slightly lower than the mangrove muds, which prevents total drainage. This ponding causes high salinities in the supratidal environment. Coastal grasslands flanking the supratidal environment have been eroded in places.

There appears to be a continual interchange of sediment between the marine, intertidal, and mangrove environments; the supratidal and mangrove inlet environments receive sediment from these three and to a lesser extent from the surrounding land.

In an attempt to ascertain interrelationships between various clay fractions, scattergrams of the percentages of the three minerals analysed were plotted by computer (GESTAT program by Garrett, 1967). These are shown in Figure 7. There are good inverse relationships between the amount of montmorillonite (plus m.l.) and the amounts of kaolinite and illite in the estuary as a whole; there is no correlation between kaolinite and illite.

These relationships are in fact more apparent than real, for if the absolute amount of the clay minerals (expressed as a percentage of the total sediment) is considered, the amount of montmorillonite being deposited is varying independently of kaolinite and illite, thus altering the amount by which they are diluted. A small random variation in the ratio of the amount of kaolinite/illite being deposited would account for the lack of correlation between the kaolinite and illite. This variation would also account for the absence of perfect straight line relationships between montmorillonite (plus m.l.) and either kaolinite or illite when the clay mineralogy is given as a percentage of the clay fraction.

Whitehouse, Jeffrey, & Debrecht (1960) found that in water of a chlorinity of 18 ppt, kaolinite and illite settle at a rate of about 10 m per day, which is about ten times as fast as montmorillonite. Whitehouse (1952) and Whitehouse & Heffrey (1955) also report a much slower settling rate of montmorillonite. Montmorillonite settles more slowly because it usually has a smaller grainsize, flocculates more slowly, and forms smaller floccules.

The slower settling rate of montmorillonite (and no doubt mixed layer montmorillonite-illite) would result in varying amounts of these minerals settling in different environments as well as within one environment, according to the depth and movement of water and other conditions of deposition.

Figure 7b shows scattergrams of the supratidal samples only. It is clear that the inverse relationship between kaolinite and montmorillonite (plus m.l.) is far less pronounced than before, while the inverse relationship between illite and mixed layer clays is retained.

Since much of the water entering the supratidal environment cannot escape because of ponding, the supratidal deposits should generally reflect the mineralogy of the suspended clay load of the water of Broad Sound mixed with a little clay from nearby soils. However, the variability of mineralogy (17 to 40% montmorillonite (plus m.l.)) and the inverse relationship between illite and montmorillonite (plus m.l.) indicate that another process is occurring in the supratidal environment.

Examination of the diffractometer traces of supratidal clays shows that these sediments usually contain more mixed-layer clays than montmorillonite. The relative amounts of these two minerals could not be measured, but, as a guide, 21 of the 27 samples from the supratidal environment give a glycolated chart on which the basal peak of the expanding mineral(s) is so close to the 10°A illite peak that there is little or no 'valley' between the two (see sample 003 in fig. 5). The curve must be corrected to a horizontal background to see how much of a drop in X-ray intensity there is between the two peaks.

Hence it appears that either less montmorillonite is reaching the supratidal environment (which is very unlikely), or that montmorillonite is being transformed to mixed layer montmorillonite-illite, or the montmorillonite content of the mixed layer clays is being decreased. The high salinities and desiccation which occur in the supratidal environment could easily have a drastic effect on the montmorillonite and could convert some of it to illite, forming mixed layer montmorillonite-illite.

The conversion of montmorillonite to illite in saline conditions has been noted by several clay mineralogists and sedimentologists: Dietz (1941) and Milne & Earley (1958) have reported a transformation of montmorillonite to illite, and Grim & Vernet (1961) reported a change from montmorillonite through mixed layer montmorillonite-illite to illite in the Mediterranean. Braitch (1971) does not mention montmorillonite as a clay found in salt deposits. It is assumed in this record that montmorillonite has been supplied to at least some salt deposits, and it is concluded that montmorillonite cannot exist in equilibrium with a high salinity.

A single sample of suspended load from near the mouth of St Lawrence Creek was examined by X-ray diffraction. The specimen was composed predominantly of quartz with minor kaolinite, illite, and montmorillonite (in decreasing order). Because of the limited nature of a single sample no conclusions can be drawn at this stage.

<u>Clays from the Catchment of the Styx River</u>

Six soil samples and nine of alluvium from the banks of creeks in the Styx River catchment were analysed for clay minerals. As four of the soil samples gave very poor traces (probably due to poor crystallinity of the clay minerals present) and the other two contained chlorite (which could not be quantitatively measured), no accurate quantitative data are given. Qualitative mineralogy of these six samples and the mineralogy of the streambank sediments are given in Appendix 1. The localities of the samples are shown in Figure 4.

The soils have widely varying clay compositions, and many more analyses would be needed to carry out a full study of them.

Although the mean clay mineralogy of the stream sediments is statistically different from the mineralogy of the marine sediments of Broad Sound, no conclusions may be drawn as these streams drain only about 12% of the total catchment of Broad Sound. However, the presence of montmorillonite is interesting. Prior & Glass (1961) report that montmorillonite is absent in the Cretaceous and Tertiary fluvial sediments of the Upper Mississippi Embayment, but forms from 20% to 80% of the clay from the inner neritic zone. They attribute this variation to the fine grainsize of montmorillonite, which prevents it from settling in fluviatile conditions. Clearly, some (unknown) factor allows montmorillonite to settle in at least some of the creeks draining into Broad Sound.

The expanding mineral present in the alluvium appears to be pure montmorillonite, whereas there is commonly appreciable mixed layer montmorillonite-illite in sediments from all environments of Broad Sound. If the samples studied are typical of the sediment coming into Broad Sound, slow conversion of some of the montmorillonite to illite to give irregularly stacked mixed layer montmorillonite-illite may be occurring as the sediment enters saline water.

Conclusions

1. The general assemblage of clay minerals in Broad Sound (kaolinite, illite, montmorillonite, and mixed layer montmorillonite-illite) is not unusual when compared with assemblages in ocean sediments at a similar latitude to Broad Sound.

2. Generally speaking, the sediment of supratidal mudflat and mangrove inlet environments have less montmorillonite plus mixed layer clays and more kaolinite and illite than does sediment of the marine, mangrove, and intertidal environments. This may be explained by the conversion of montmorillonite to illite via irregularly stacked mixed layer montmorillonite-illite in the highly saline and commonly desiccated supratidal mudflat environment, and the erosion of this sediment into mangrove inlets.

3. Minor variations in clay mineralogy between the marine, intertidal, and mangrove environments may be explained by the slow settling rate of montmorillonite when compared with kaolinite and illite.

4. There may be some conversion of montmorillonite to illite via irregularly stacked mixed layer montmorillonite-illite as sediment from the catchments enters the saline water of Broad Sound. This process would be much slower than the conversion taking place in the supratidal mudflat environment.

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REFERENCES

BISCAYE, P.E., 1964 - Distribution between kaolinite and chlorite in recent sediments by x-ray diffraction. Amer. Miner., 49, 1281-9.

BISCAYE, P.E., 1965 - Mineralogy and sedimentation of Recent deep-sea clay in the Atlantic Ocean and adjacent seas and oceans. Bull. geol. Soc. Amer., 76, 803-31.

BRAITCH, O., 1971 - SALT DEPOSITS; THEIR ORIGIN AND COMPOSITION, Tr. by P.J. Burek and A.E.M. Nairn in consultation with A.G. Herrmann and R. Evans. Springer Verlag, Berlin, New York.

CARROLL, D., 1970 - Clay minerals: a guide to their x-ray identification, Geol. Soc. Amer., Spec. Pap. 126.

COOK, P.J., & MAYO, W., 1972 (in prep) - Sedimentation in a tropical estuary (Broad Sound, Queensland). Bur. Miner. Resour. Aust. Bull.

DIETZ, R.S., 1941 - Clay minerals in recent marine sediments. PhD Thesis, University of Illinois.

GARRETT, R.G., 1967 - A program for the rapid screening of multivariate data from the earth sciences and remote sensing. Northwestern University Rep. 11.

GRIM, R.E., 1968 - Clay Mineralogy (2nd ed). N.Y. McGraw-Hill.

GRIM, R.E., DIETZ, R.S., & BRADLEY, W.F., 1949 - Clay composition of some sediments from the Pacific Ocean off the California coast and the Gulf of California. Bull. geol. Soc. Amer., 60, 1785-803.

GRIM, R.E., VERNET, J.P., 1961 - Etude par diffraction des mineraux argileux de vases Mediterraneenes. Bull. Suisse Mineral. Petrog., 41, 65-70.

JOHNS, W.D., GRIM, R.E., & BRADLEY, W.F., 1954 - Quantitative estimations of clay minerals by diffraction methods. J. Sediment. Petrol., 24, 242-51.

KINTER, E.B., & DESMOND, A.S., 1955 - A new method for preparation and treatment of orientated-aggregate specimens of soil clays for x-ray diffraction analyses. Proc. 5th Conf. Clays, Clay Min., 318-44.

MILNE, I.H., & EARLEY, J.W., 1958 - Effect of source and environment on clay minerals. Bull. Amer. Ass. Petrol. Geol., 24, 328-38.

OINUMA, K., KOBAYASHI, K., & SUDO, T., 1959 - Clay mineral composition of some recent marine sediments. J. Sediment. Petrol., 29, 56-63.

PRIOR, W.A., & GLASS, H.D., 1961 - Cretaceous-Tertiary clay mineralogy of the upper Mississippi Embayment. J. Sediment. Petrol. 31, 38-51.

RATEEV, M.A., GORBUNOVA, Z.N., LISITZYN, A.P., & NOSOV, G.L., 1969 - The distribution of clay minerals in the ocean. Sedimentology, 13, 21-44.

SCHULTZ, L.G., 1960 - Quantitative x-ray determinations of some aluminous clay minerals in rocks. Proc. 7th Conf. Clays, Clay Min. 216-44.

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WHITEHOUSE, U.G., 1952 - Chemistry of marine sedimentation: in Study of nearshore Recent sediments and their environs in the northern Gulf of Mexico. A.P.I. Proj. 51, Prog. Reps. 5, 6, 7 Texas A & M Research fund Project 34A 89p.

WHITEHOUSE, U.G., & JEFFREY, L.M., 1955 - Peptization resistance of selected samples of kaolinite, montmorillonite and illitic clay materials. Clays & Clay Mins., Nat. Acad. Sci - Nat. Research Council Pub., 395, 260-81.

WHITEHOUSE, U.G., JEFFREY, L.M., & DEBBRECHT, J.D., 1960 - Differential settling tendencies of clay minerals in saline waters, Proc. 6th Conf. Clays, Clay Min., 1-79.

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APPENDIX 1: Clay mineralogy of samples from Broad Sound and its catchment.

Clay Mineralogy and Environments of Estuary Samples Studied

Sample No.	Kaolinite %	Illite %	Montmorillonite plus Mixed-layer %	Depositional Environment
70636-002	27	32	40	Supratidal
014	37	36	27	Supratidal
015	36	40	24	Intertidal
019	39	44	17	Supratidal
022	39	37	24	Supratidal
030	35	32	34	Intertidal
032	39	39	22	Supratidal
033	40	37	23	Supratidal
034	38	43	19	Supratidal
035	34	30	36	Mangrove
036	34	34	32	Intertidal
039	36	42	21	Supratidal
042	32	32	35	Marine
043	30	33	38	Mangrove
044	39	26	36	Supratidal
045	25	34	41	Intertidal
052	40	30	30	Supratidal
056	25	31	44	Mangrove
070	33	34	33	Supratidal
071	31	34	35	Intertidal
076	35	32	33	Intertidal
077	39	29	32	Supratidal
080	36	29	34	Marine
084	33	31	36	Mangrove
090	37	34	29	Intertidal
094	32	41	27	Supratidal
097	35	34	31	Marine
098	26	35	39	Intertidal
102	29	30	40	Mangrove
107	34	35	32	Supratidal
108	29	32	39	Intertidal
112	31	33	36	Supratidal
120	32	35	34	Supratidal
122	30	28	41	Intertidal
123	26	36	38	Mangrove
128	27	31	42	Mangrove
130	38	35	27	Supratidal
138	28	28	43	Mangrove
139	35	32	33	Supratidal
140	32	29	39	Mangrove
141	37	31	33	Intertidal
143	32	33	35	Mangrove
146	35	35	30	Mangrove
147	31	28	41	Mangrove
150	30	33	37	Intertidal
152	28	30	41	Intertidal
153	36	35	29	Supratidal
166	38	36	26	Supratidal
174	35	35	31	Mangrove
175	37	32	32	Supratidal

APPENDIX 1: Continued

Sample No.	Kaolinite %	Illite %	Montmorillonite plus Mixed-layer %	Depositional Environment
70636-183	40	34	26	Supratidal
193	34	27	39	Supratidal
194	32	36	32	Intertidal
196	31	30	39	Marine
198	35	33	33	Marine
201	22	29	48	Marine
205	37	39	24	Supratidal
212	38	35	27	Mangrove
213	29	32	39	Intertidal
215	35	31	35	Marine
219	24	33	43	Marine
221	29	32	39	Marine
224	34	30	36	Mangrove
227	33	30	37	Mangrove
229	32	40	28	Intertidal
234	35	29	36	Supratidal
235	36	29	36	Mangrove
236	36	28	37	Intertidal
237	32	26	42	Marine
242	39	24	37	Marine
247	29	24	47	Intertidal
251	37	32	32	Intertidal
253	34	29	38	Supratidal
255	30	30	40	Marine
262	27	28	45	Marine
264	30	28	43	Marine
266	27	30	43	Marine
270	29	36	35	Marine
271	35	27	38	Marine
273	32	36	42	Marine
276	29	32	39	Mangrove
285	35	34	31	Marine
287	38	32	30	Marine
292	31	30	40	Marine
297	37	36	27	Intertidal
300	36	37	27	Supratidal
303	36	30	34	Mangrove
307	24	33	43	Intertidal
309	38	26	36	Marine
312	29	37	34	Marine
315	28	24	49	Marine
316	27	37	36	Intertidal
317	36	31	33	Marine
319	41	29	30	Marine
322	32	33	35	Mangrove
323	32	29	38	Mangrove Inlet
324	35	32	34	Mangrove Inlet
325	33	35	32	Mangrove Inlet
329	37	26	38	Mangrove Inlet

APPENDIX 1: Continued

Sample No.	Kaolinite %	Illite %	Montmorillonite plus Mixed-layer %	Depositional Environment
70636-330	35	26	39	Mangrove Inlet
331	37	34	29	Mangrove Inlet
333	30	30	40	Mangrove Inlet
336	37	33	29	Mangrove Inlet
337	42	34	24	Mangrove Inlet
338	41	34	25	Mangrove Inlet
339	35	32	33	Mangrove Inlet
340	40	28	32	Mangrove Inlet
341	36	27	38	Mangrove Inlet
342	34	31	36	Mangrove Inlet
343	37	26	36	Mangrove Inlet
344	35	30	35	Mangrove Inlet
345	36	33	31	Mangrove Inlet
351	38	30	33	Mangrove Inlet
352	37	28	35	Mangrove Inlet
353	37	33	30	Mangrove Inlet
827	27	35	38	Intertidal
832	31	26	43	Intertidal
837	35	29	37	Intertidal
840	38	32	30	Intertidal
842	31	34	35	Intertidal

Clay Mineralogy of Creek-bank Samples from the Styx River Catchment

Sample No.	Kaolonite %	Illite %	Montmorillonite %
70639-308	84	16	
335	69	31	0
341	33	29	38
349	33	27	40
350	29	25	47
360	32	26	41
367	28	28	45
376	21	44	35
474	22	24	53

Qualitative Clay Mineralogy of Soil Samples from the Styx River Catchment

Sample No.	Mineraology in order of decreasing amount in sample
70639-299	Kaolinite
310	Illite, Kaolinite
409	Chlorite, Kaolinite, Montmorillonite
410	Chlorite, Kaolinite
516	Kaolinite, Illite
614	Kaolinite

APPENDIX 2: ERRORS IN MEASURING MINERALOGY

There are several possible sources of error in the measurement of percentage mineralogy of the clay samples. Errors occur in measuring the diffractometer peak areas, as the background level must be estimated, and some of the peaks (such as the illite 10A peak) must be extrapolated to the background where they overlap with other peaks before the areas are measured. The author tried to be as consistent as possible in the drawing in of background and extrapolating peaks. The actual measurement of area with a planimeter is in itself a source of error.

Errors due to poor alignment of the tiles in the x-ray beam of the diffractometer and the random nature of the production of x-rays may also occur.

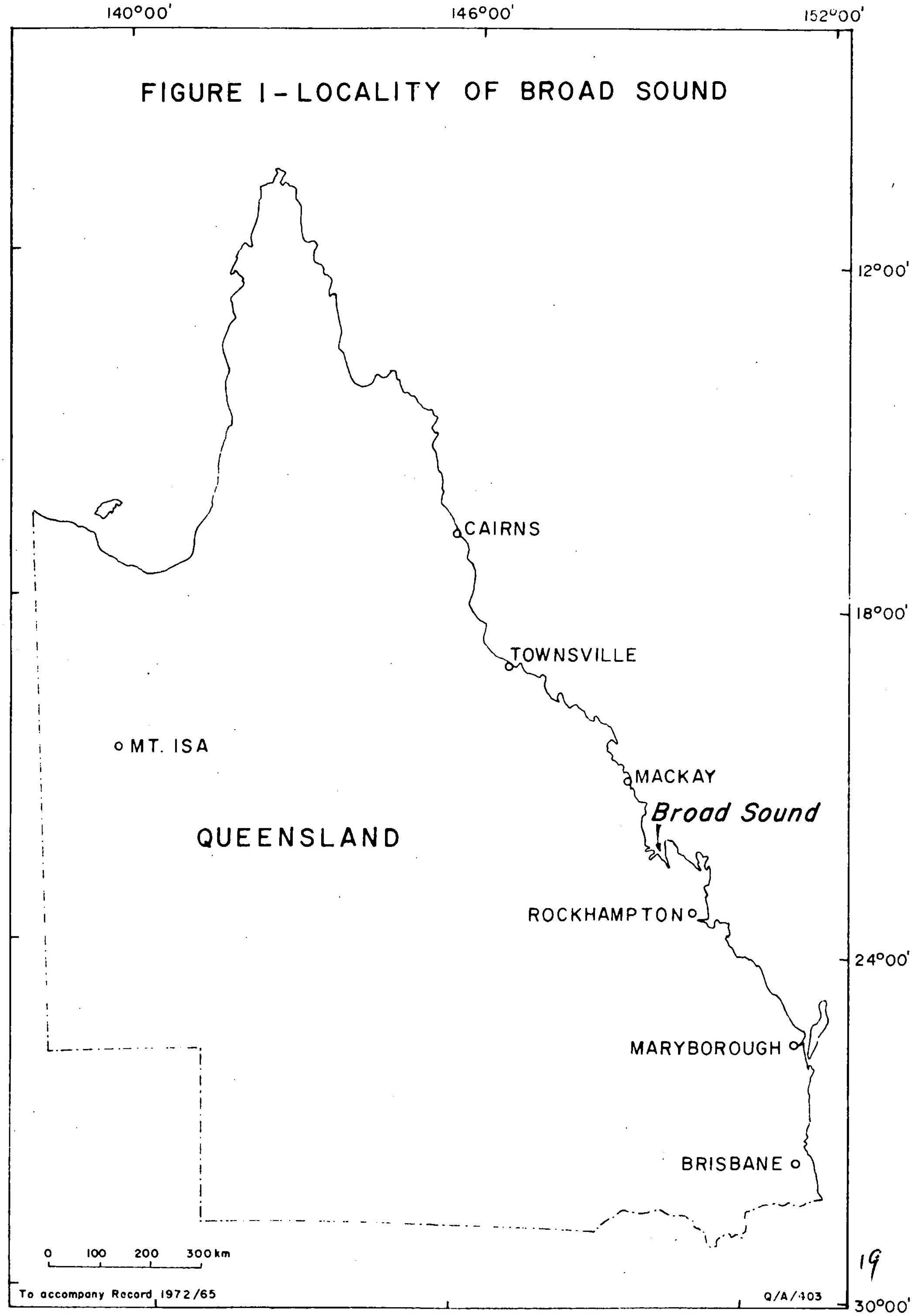
A more fundamental source of error is that the sample drawn onto the ceramic tiles may not be representative of the sample of clay being mounted.

Although the combination of these sources of error might be expected to give poor reproducability of results, the table below shows that five repeats of sample 262 gave reasonably consistent results.

Measured Mineralogy of Five Repeats of Sample 262

	Kaolinite %	Illite %	Montmorillonite (plus m.l.) %
	27	28	45
	32	28	40
	31	29	40
	33	31	36
	29	25	46
Mean	30.40	29.20	41.40
Unbiased S.D.	2.41	2.17	4.10

The higher standard deviation of the amount of montmorillonite (plus m.l.) is to be expected as this is measured by the difference between two different peaks, and errors in the measurement of both peaks are incorporated.



140°00'
146°00'
152°00'
FIGURE I - LOCALITY OF BROAD SOUND
12°00'
18°00'
24°00'
30°00'
CAIRNS
TOWNSVILLE
MT. ISA
MACKAY
Broad Sound
QUEENSLAND
ROCKHAMPTON
MARYBOROUGH
BRISBANE
0 100 200 300 km
To accompany Record 1972/65
Q/A/403

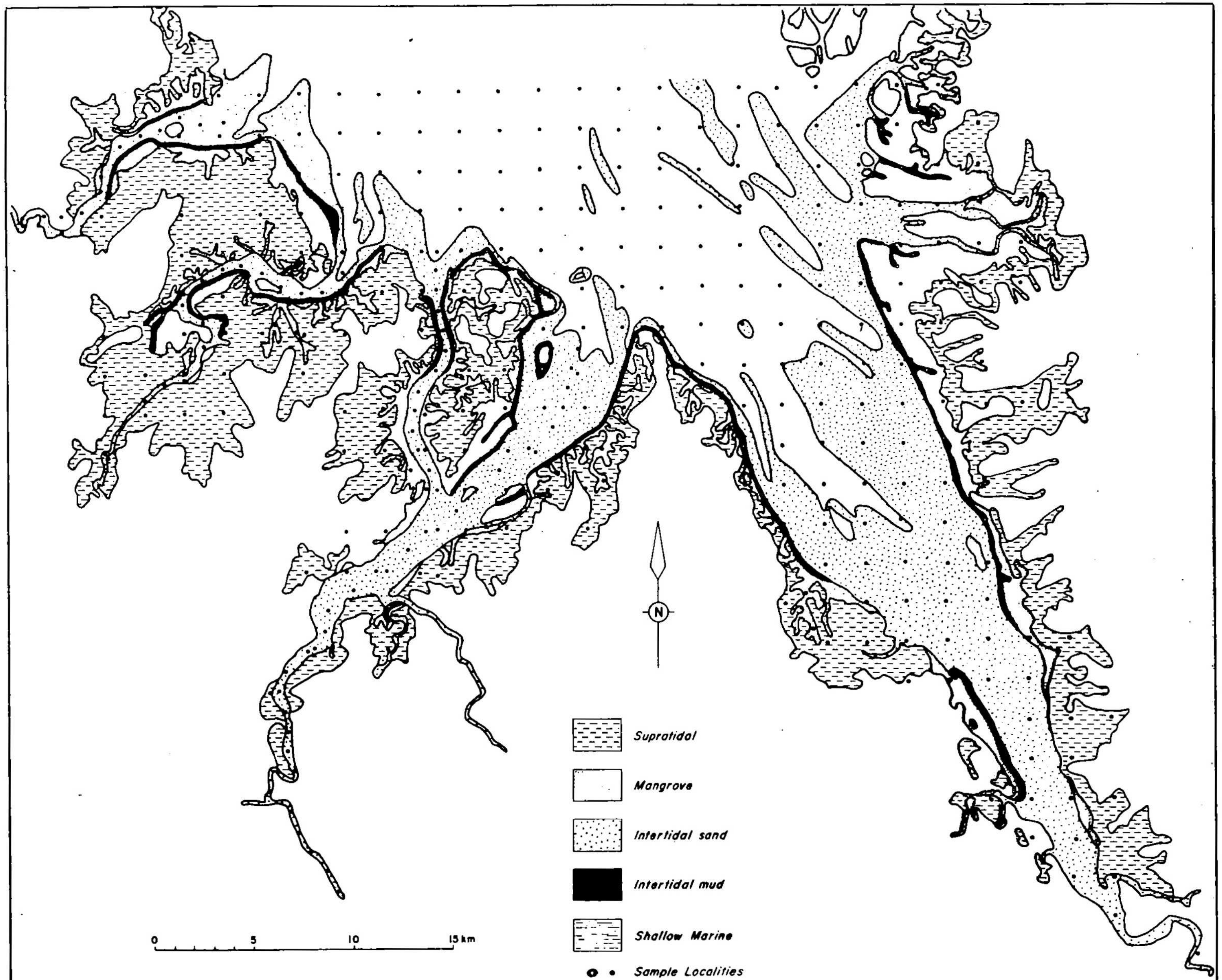


FIG 2-SEDIMENTARY ENVIRONMENTS-BROAD SOUND

To accompany Record 1972/65

F55/A12/9

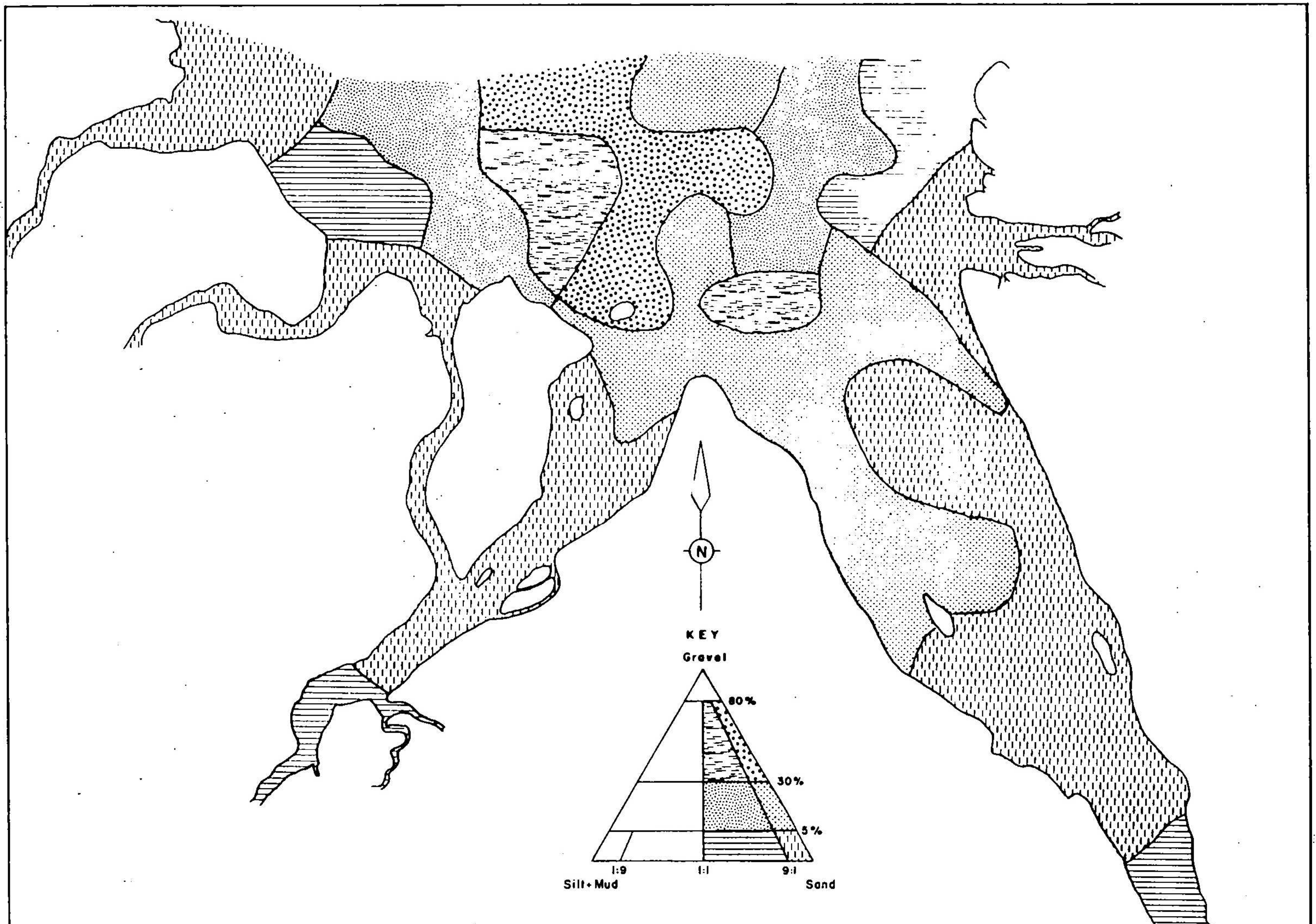
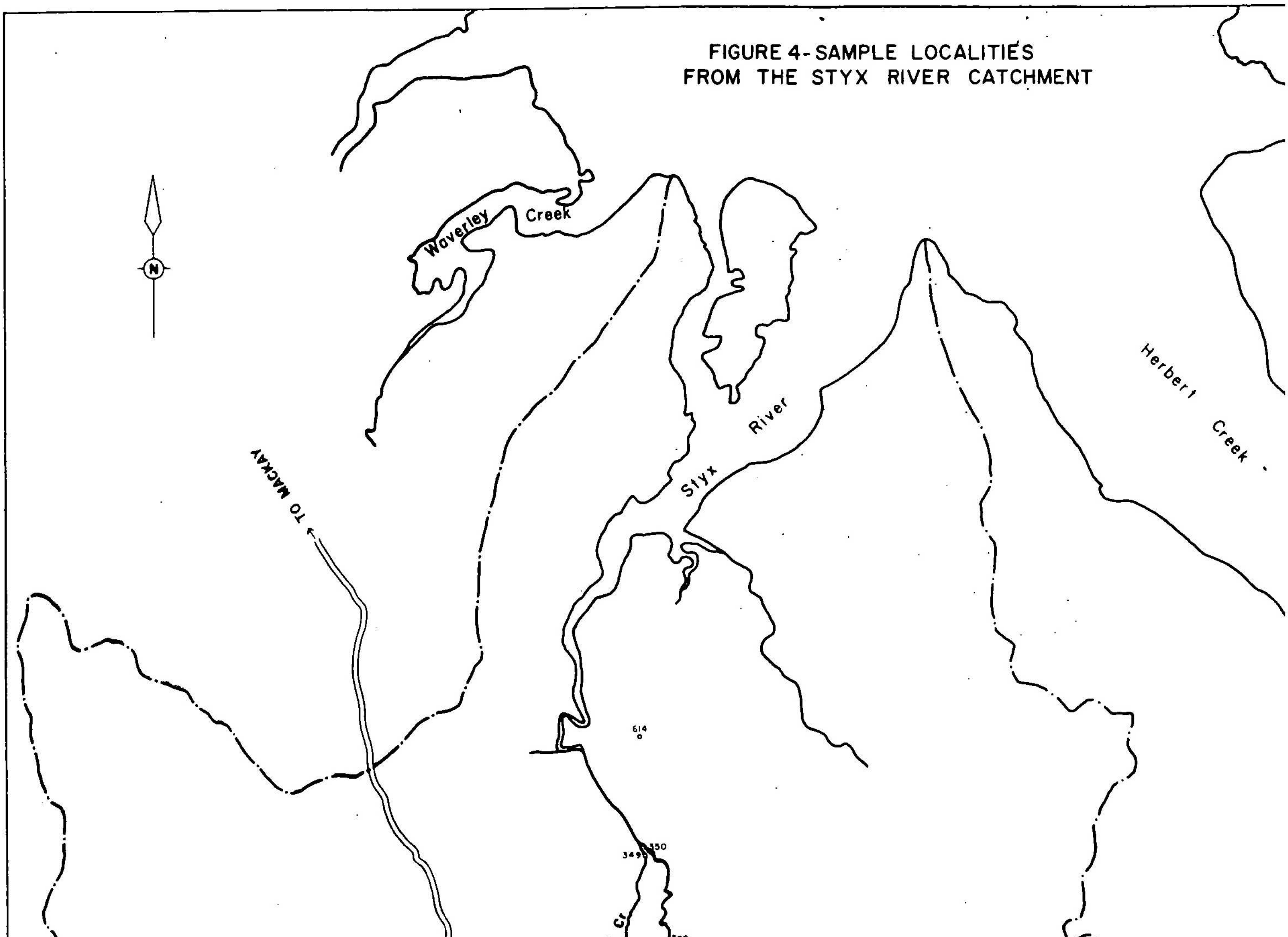


FIG 3-SEDIMENTARY FACIES MAP OF THE SHALLOW MARINE AND INTERTIDAL SAND ENVIRONMENTS - BROAD SOUND

To accompany Record 1972/65

F55/A12/10



To accompany Record 1972/65

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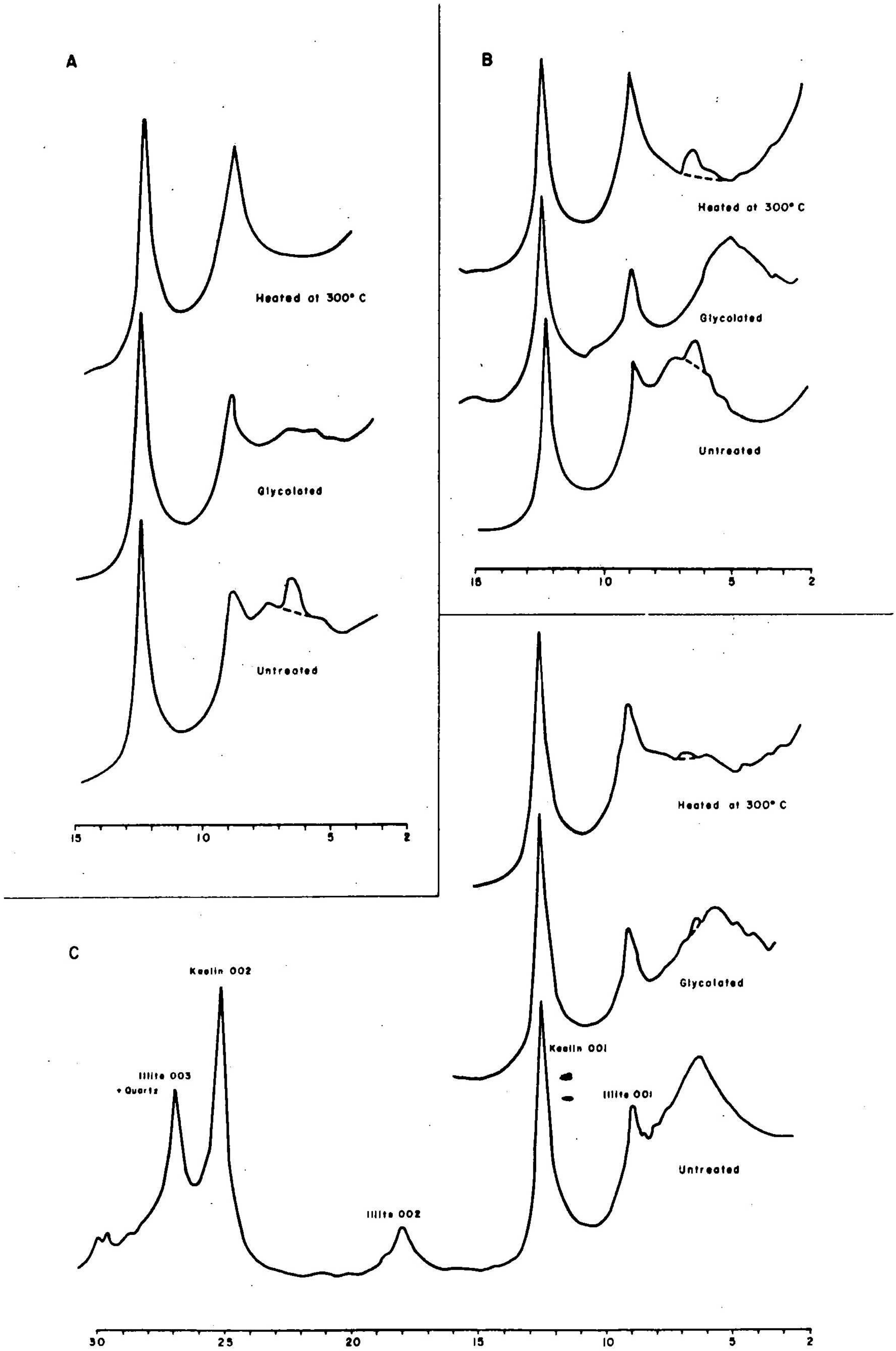

FIGURE 5 - TYPICAL DIFFRACTION CHARTS OF BROAD SOUND CLAYS
A-SAMPLE N.033 B-SAMPLE N. 141 C-SAMPLE N. 309

To accompany Record 1972/65

F55/A12/12

23

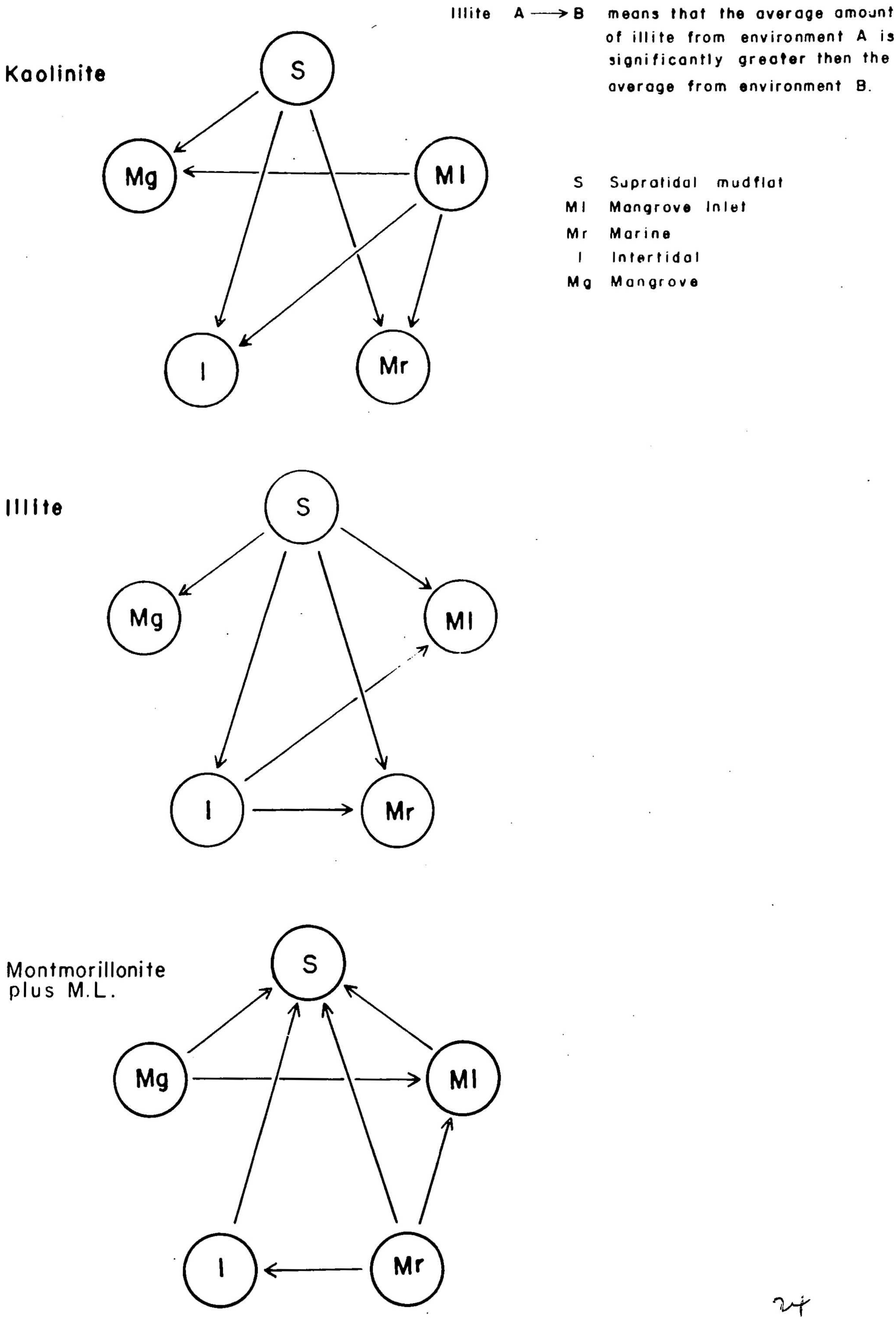

FIGURE 6-DIAGRAMMATIC REPRESENTATION OF THE SIGNIFICANT DIFFERENCES IN CLAY MINERALOGY BETWEEN THE FIVE DEPOSITIONAL ENVIRONMENTS OF BROAD SOUND

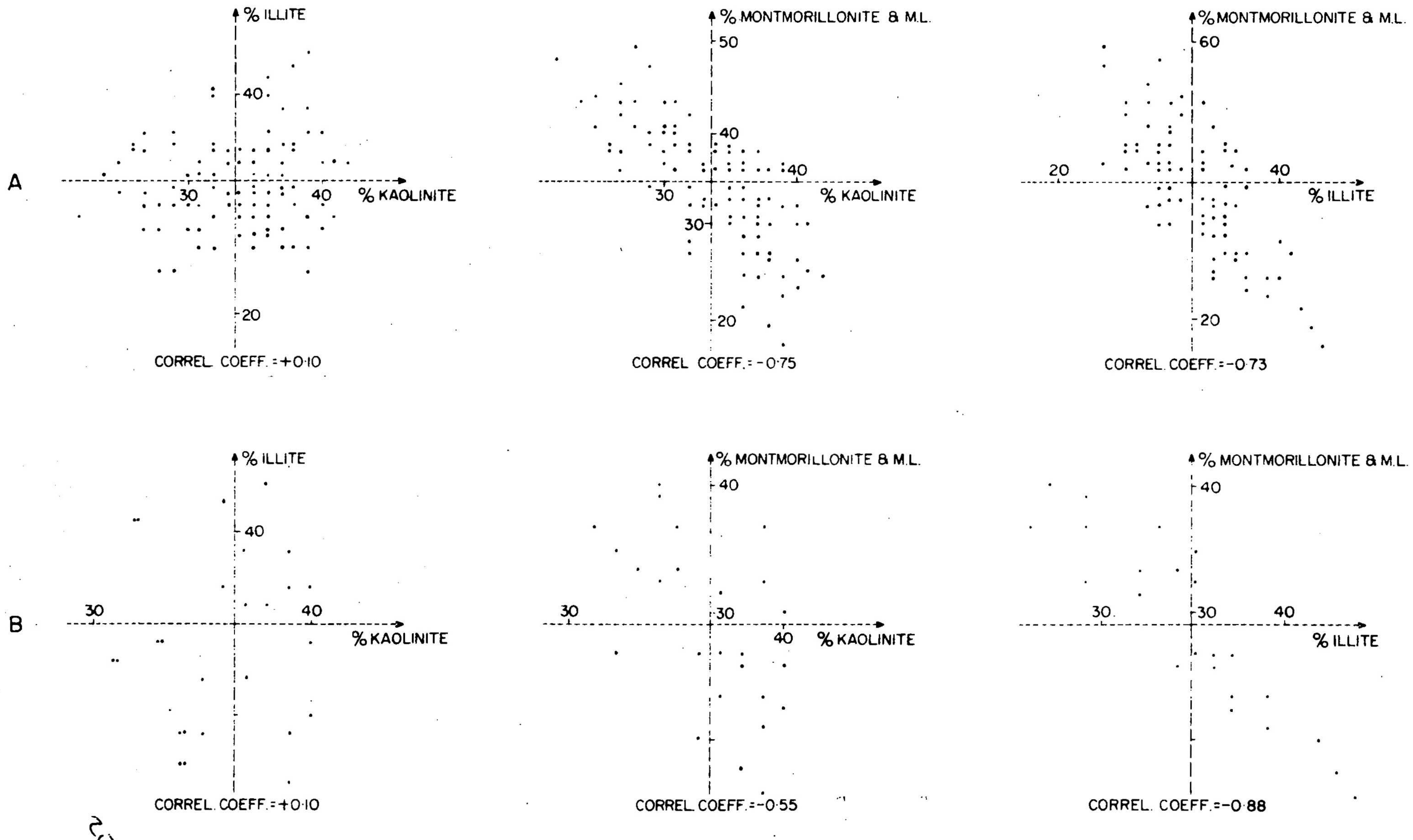

Figure 7: Scattergrams of % mineralogy with axes through sample means. A: all estuary samples, B: supratidal samples.

FIG 8- BROAD SOUND SAMPLING LOCALITIES