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MODAL ANALYSIS OF SANDSTONE AND SILTSTONE LITHOFACIES FROM NORTHLAND ALLOCHTHON ROCKS, NEW ZEALAND

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ABSTRACT: The Northland Allochthon is a structurally displaced rock unit located between Three Kings Island and Mt. Camel in northern North Island, New Zealand. Lithologically, the allochthonous unit is composed of different lithofacies comprising sandstone, siltstone, greensand, siliceous mudstone, argillaceous micritic limestone and rare coal measures along with dispersed organic matter. The objective of this paper is to study modal analysis of different lithofacies of Northland Allochthon to infer relationship between sandstone composition and tectonic setting of displaced allochthonous unit. For this purpose, petrographic technique is used following Point Counting method for classification of grains. Results indicate that facies of Tokerau Clastics and Mangakahia complex of the Northland Allocution rocks plot within the recycled orogenic fields while samples from Omahutta facies of the Motatau Complex fall in the transitional and Craton interior zones. QmPK plot reflects increasing maturing of the detritus with time. The relative concentration of quartz over feldspar indicates that feldspar has either been destroyed by abrasion/chemical weathering or has been diluted by cycle quartz.

Keywords: Northland Allochthon, Modal Analysis, Provenance, Tectonic Setting, Petrography, Ternary & discrimination diagrams.

INTRODUCTION

The Northland Allochthon is present both NE and SW of a structural high located between the Three Kings Island and Mt. Camel (Figure 1) in northern North Island of New Zealand. This is a thick widespread displaced allochthon rock unit contains rocks of Late Cretaceous to Early Miocene age (Kear and Waterhouse, 1977; Balance and Sporli, 1979). The Northland Allochthon is estimated to have a present day volume of 32000km3 in an area of 26000 km3. The volume of allochthon eroded from onshore Northland can only be guessed and the volume from the Three Kings Island-Mt. Camel Terrance is not yet known. Lithologically the allochthonous rocks are mostly composed of sandstone, siltstone, greensand, siliceous mudstone, argillaceous micritic limestone and rare coal measures along with dispersed organic matter. It overlies the autochthonous, paleogene non-marine to marine transgressive sediments (Hayward *et al*. 1989). It is unconformably overlain by the Waitemata and correlative groups of Upper Oligocene-Lower Miocene age.

Tectonism is the fundamental factor that affects sedimentation and bulk characteristics of sedimentary rocks (Pettijohn, 1957 and Krumbion and Sloss, 1963). It controls the source area, uplift and erosion, transport conditions to the depositional sites, degree of subsidence and diagenetic effects produced by the burial, folding and faulting (Blatt *et al*., 1980). Many workers have used

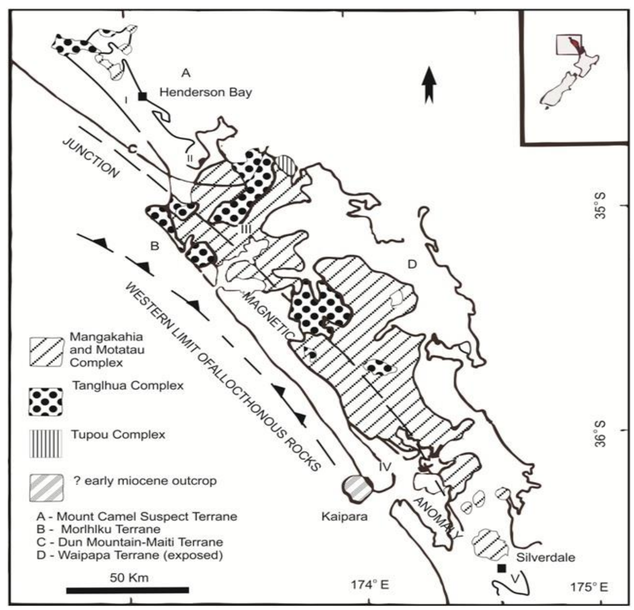


Figure 1: Outcrop distribution of the Northland Allochthon rocks and inferred basement terrane in Northland, New Zealand (after Isaac *et al*. 1974)

petrography of modern sediments from known tectonic sources (Ingersoll and Suczek, 1979; Dickinson and Valloni, 1980 and Potter, 1984) or ancient sandstone suites with well defined depositional histories (Graham *et al*., 1976 and Dickinson *et al*., 1983) to infer relationship between sandstone composition and tectonic setting of the source area. These relationships have been used to derive a range of provenance discrimination diagrams which are based on the assumption of a direct relationship between detrital mode and tectonic setting. The objective of this paper is to study modal analysis of different lithofacies of Northland Allochthon to infer relationship between sandstone composition and tectonic setting of displaced allochthonous unit.

MATERIALS AND METHODS

Point counting of 13 selected thin sections was carried out to determine the volume percentage of framework minerals and lithic clasts in the sandstone and siltstone (Table-I). More than 500 counts were made for each section, on a grid spacing that resulted in maximum coverage of the slide using the Swift mechanical stage and electric counter connected to a Leitz optical microscope. The point counting procedure followed is that developed by Gazzi and Dickinson (1983). This method relates modal variations in framework grains to probable source terrains. The grain parameters counted are described in Table-II following the identification criteria by Dickinson (1970) and Ingersoll and Suczek (1979) for the modal composition of sandstone and siltstone for Northland Allochthon rocks, New Zealand.

Table-1: Modal composition of different lithofacies of the Northland Allochthon rocks, Northland, New Zealand.

Lithofacies	Sample	Q	Qm	Qp	F	PF	KF	GL	MC	LI	CH	MAT	OP
Tokerau Clastics	AU46205	21.0	19.5	1.6	15.9	12.6	3.4	1.2	2.5	15.8	2.6	39.5	1.5
	AU46209	32.6	27.2	5.4	16.6	12.3	4.3	2.3	3.3	8.2	3.7	37.0	2.8
	AU46210	34.1	26.5	7.7	12.5	10.8	1.8	<1	1.4	7.2	2.0	40.5	2.2
Motukaraka	AU46188	29.1	25.8	3.3	17.7	15.6	2.1	<1	1.2	20.2	2.2	28.3	2.1
	AU46198	36.2	33.2	3.0	14.7	12.2	2.5	<1	2.6	10.1	4.4	29.0	2.3
	AU46200	35.3	29.2	4.1	13.6	10.5	3.1	<1	2.2	10.2	0.8	35.4	3.3
Punakitere	AU46185	41.5	36.2	4.3	15.4	10.3	5.1	_	1.2	12.0	3.1	23.2	3.5
	AU46173	22.3	19.4	3.0	5.5	5.5	_	_	2.5	4.1	24.3	31.2	6.3
Awapoko	AU46176	25.2	22.6	2.6	6.5	6.5	_	2.5	1.6	2.3	25.3	27.1	9.6
	AU46178	32.6	29.1	3.5	4.6	4.6	_	2.6	1.6	3.2	24.9	20.2	10.6
Whangai Formation	AU46171	23.4	17.5	5.9	15.2	15.2	_	45.3	1.0	10.5	_	20.1	_
Omahuta	AU46162	22.6	18.5	6.0	13.2	13.2	_	35.7	<1		_	27.8	<1
Sandstone	AU46163	26.1	24.4	1.7	14.2	14.2	1.2	32.3	1.2	1.4	_	25.2	1.0

Table 2: Grain parameters estimated for the modal composition of sandstone and siltstone for Northland Allochthon rocks, New Zealand (From Folk *et al*., 1070; Ingersoll and Suczek, 1979; and Ingersoll *et al*., 1979.

Q = Qm + Qp
F = P + K
L = Lm + Lv + Ls = R
Lt = L + Qp

RESULTS

Ternary compositional diagrams show the distribution of framework grain abundance for 13 samples point counter from Table-I (Figure 2; Dickinson and Suczek, 1979; Dickinson *et al*., 1983 and Ingersoll and Suczek, 1979). The sandstone of Tokerau Clastics and Mangakahia complex of the Northland Allocution rocks plot within the recycled orogenic fields whiles sandstones from samples from Omahutta facies of the Motatau Complex fall in to transitional and Craton interior zones (Figure 3). This is consistent with petrographic features. Sediments from the Tokerau clastics of Mount Camel Suspect Terrane and Whangai Formation fall under dissected arc region (Figure 3). Motukaraka lithofacies and Punakitere facies are mostly of mixed recycled nature. The Awapoko facies and Omahutta Sandstone indicate a transitional recycled and quartz recycled pattern respectively. Only one sample from Omahutta sandstone of Motatau Copmplex indicate transitional continental margin. On the QmPK plot, all samples from Northland Allochthon rocks plot between Pm-P areas (Figure 4).

The trend towards a dominance of quartz over feldspar within mono-crystalline component on QmPK plot reflects increasing maturing of the detritus with time. This is possibly a result of progressive peneplanation of the New Zealand land mass through the Paleogene (Balance, 1993) and seemed to be derived from the Continental blocks or recycled. Figure 4 shows the time-trend relationship of different lithofacies of the Northland

Allochthon rocks of Middle Cretacepus to Eocene/ Oligicene age. Only one sample of Whangai Formation does not plot within the trend line. This might be because of scarcity of samples of particular lithofacies. The dominance of sedimentary lithic grains in thin sections indicates that the provenance contain only a minor proportion of volcanic and metamorphic rocks.

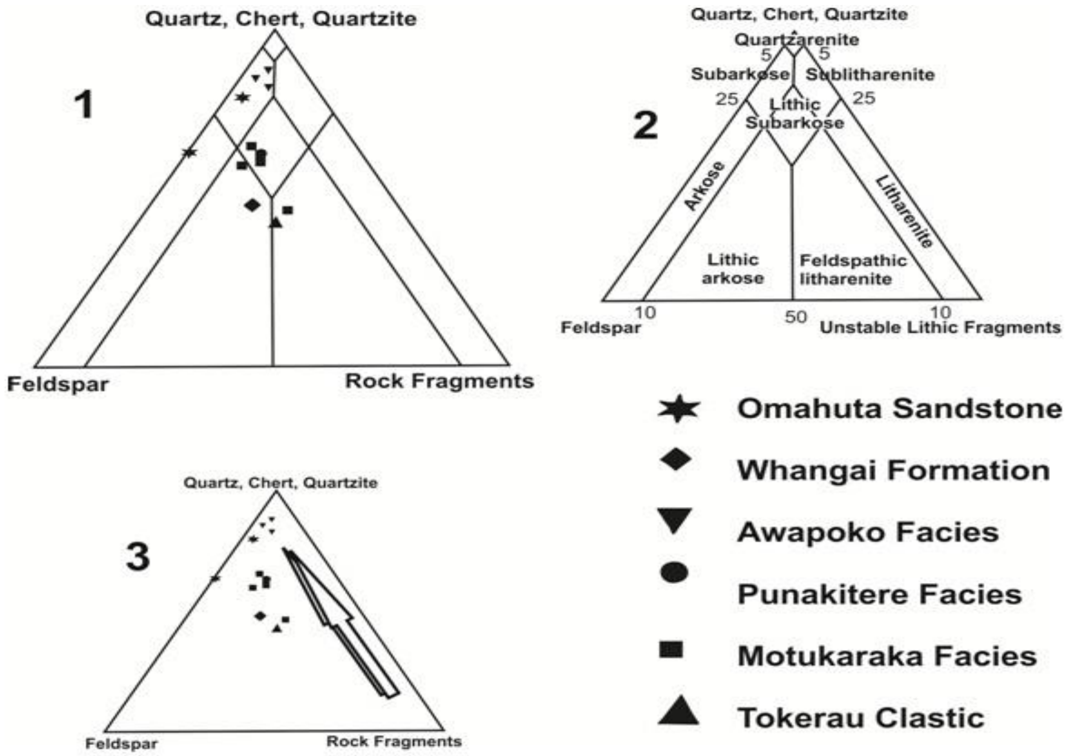


Figure 2: Ternary composition plot showing framework modes of different lithofacies of the Northland Allochthon rocks, Northland, New Zealand. Selected samples are plotted on the provenance fields of Dickenson *et al*., 1983.

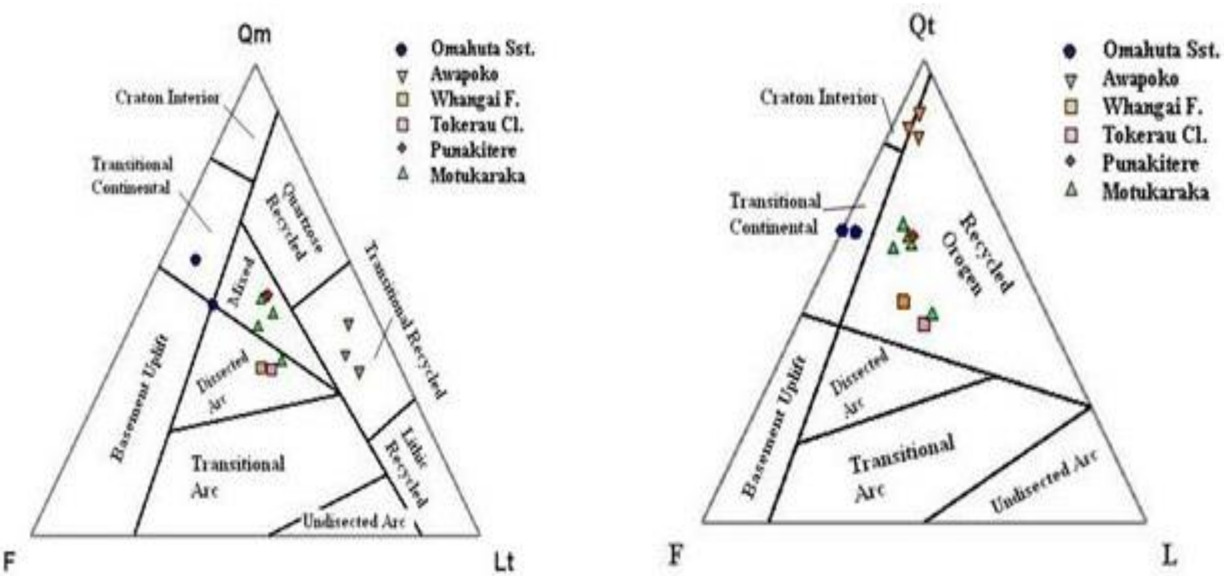


Figure 3: Ternary composition plot showing framework modes of different lithofacies of the Northland Allochthon rocks, Northland, New Zealand.

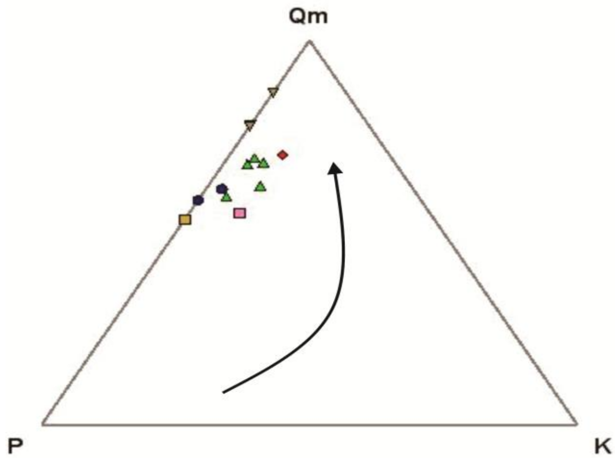


Figure 4: QmPK plot indicates that all samples from Northland Allochthon rocks plot between Pm-P areas

DISCUSSION

Mt. Camel Suspect Terrane

***Provenance*:** The angularity of silisiclastic grains of Tokerau clastic indicates a relative low amount of sediment transport from its source (Plate 1). As a result, low corrosion of the grains has allowed a small size difference between quarts and feldspar because with more transportation and abrasions, feldspar grains would be smaller than quarts owing to lower durability of feldspar. Plutonic monocrystalline quartz is present in the samples. Less amount of feldspar in the Tokerau clastics could be because of weathering and abrasion which removed excess feldspar before its deposition into the sedimentary basin. But then abrasion of the sediment may produce less angular quartz than is seen here. To account for this angularity, it may be concluded that extra feldspar may have been weathered out during temporary storage on low lying flood plain (Balance, 1983). Zircon, muscovite, hornblende and tourmaline support an acidic igneous source. This is also supported by the presence of albite and oligoclase, oligoclase also indicating an intermediate volcanic source. The presence of crenulated polycrystalline quartz supports a metamorphic source.

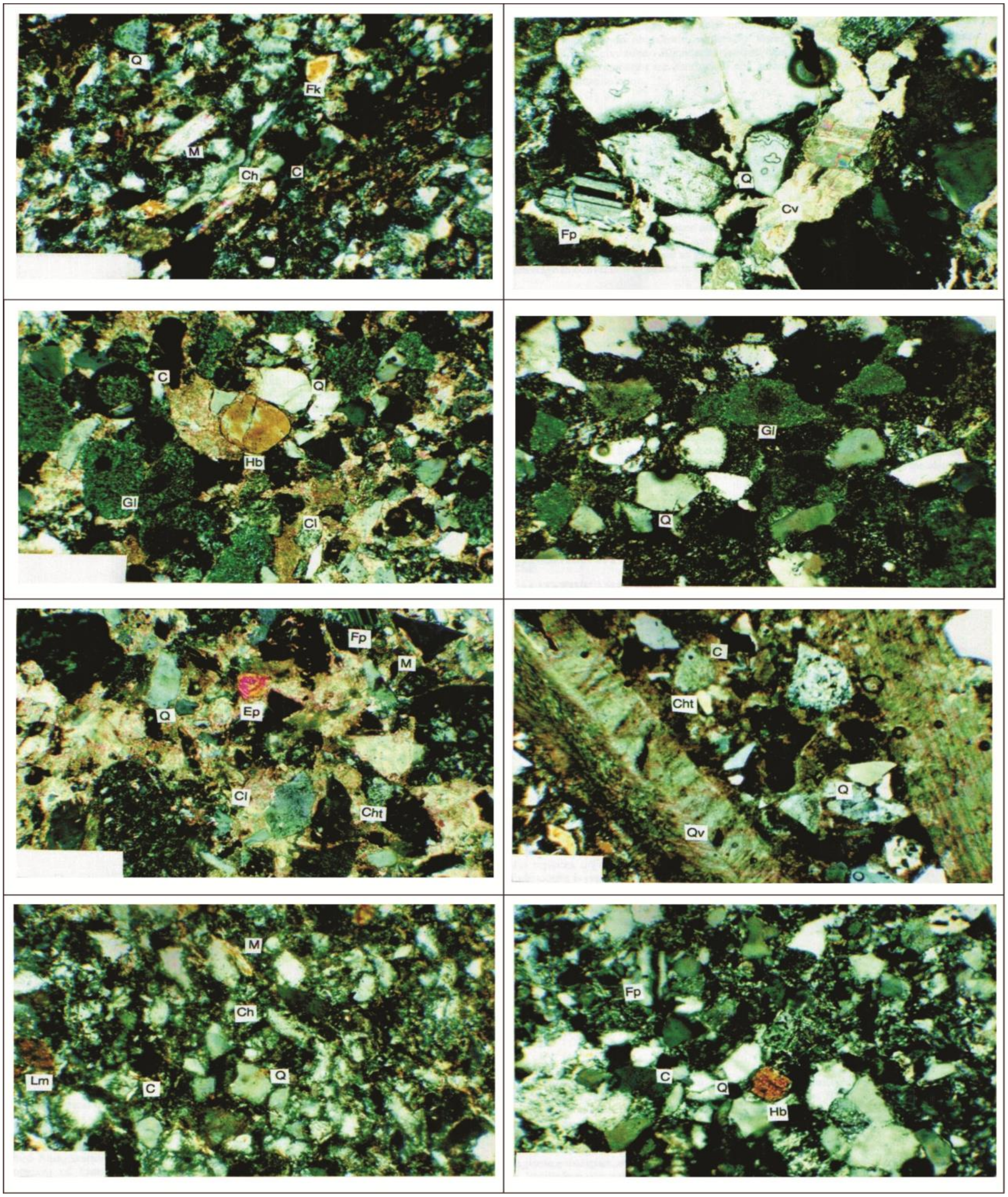
Tectonic Setting: Tokerau clastic plot into the dissected magmatic arc provenance area on the QmFLt diagram (Figure 3). Such a source land would have to be deeply eroded to allow the slow rate of sedimentation evident of this sandstone. Alternately, the source land could be more upstanding and some distance from the sedimentary basin, result in lowering the terrigenous detrital input.

Mangakahia Complex

Provenance: The angularity of silisiclastic grains within Mutukaraka, Punakitere and Awapoko sandstone indicate a relative close source land from where the sediments underwent little transport to their site of deposition (Plates 2 to 6). As a result, low corrosion of the grains has allowed a small size difference between quartz and feldspar because with more transportation and abrasions, feldspar grains would be smaller than quartz owing to lower durability of feldspar. Low silisiclastic contents in Ngataturi claystone (Whangai Formation facies) indicate a distant or low relief source but the presence of glauconitic suggests intermittent influxes of coarser silisiclastic material, possibly by turbidity current. The mode of deposition of Cretaceous lithofacies indicate the source land to be high relief, supplying large amount of detritus to the shelf which is then passed intermittently from the shelf as turbidity current while glauconitic pellets could have been transported from shallower shelf environment, with the surrounding lighter colored glauconitic forming in situ. A variety of source rocks can be inferred for this Complex sandstone.

Microcline and monocrystalline quartz with straight to slightly undulose extinction, indicate a granitic source. A hydrothermal vein source can also be interpreted from the minor quartz components with abundant vacuoles. Crenulate polycrystalline is formed from intense deformation without recrystallisation, probably a metamorphic source. Other sources could be gneiss, meta-quartzite, shear zones in granites, crushed veins or sheared sandstone (Folk, 1980). Dominance of plagioclase feldspar over alkali feldspar is interpreted as being the result of high volcanic input. This is supported by the presence of mainly felsic volcanic rock fragments and absence of plutonic/metamorphic rock fragments in these sediments. Other evidence is the dominance of biotite over muscovite. Folk (1980) mention possible reasons for dominance of biotite over muscovite. Firstly the erosional rate might have overbalanced the weathering rate in the source area or secondly, the sediment received contributions from volcanic rocks or ash. The second reason is probably more likely in this instance because of the volcanic rock fragment input. The presence of euhedral zircon and hornblende (Plates 2 to 6) indicate that ash falls have contributed to this sandstone. The angularity of these minerals and the instability of hornblende indicate that the volcanism was occurring close to the depositional basin. The presence of tourmaline with above minerals indicates an acidic plutonic source. Biotite, muscovite, zircon and hornblende also probably have igneous origin. Epidote is an indication of mafic igneous protolith, along with augite and hornblende.

Tectonic Setting: The quartz-feldspar-lithic fragments of the Mutukaraka, Punakitere and Whangai Formation facies plot in the mixed recycled provenance region of the QmFLt diagram of Dickinson (1982) (Figure 3). Mixed provenance includes input from continental block, magmatic arc and recycled orogen environment. Sediments characterizing mixed recycled provenance plot near the middle of QFL diagram, in the lithic feldspathic zone (Figure 2). Quartz is low to moderate in abundance and feldspar is in significant proportion with plagioclase: alkali feldspar ratio high. The proportion of volcanic lithic fragments is also high (Dickinson, 1980).



Plates 1-8: Photomicrographs indicate petrographic features of Tokerau Clastics (7-Mt. Camel Suspect Terrane), 2, 5 & 6-Motukaraka, 1 & 8-Awapoko (Mangakahia Complex), 4-Taipa Mudstone, 3-Omahuta (Motatau Complex) lithofacies of Northland Allochthon, New Zealand.

Motatau Complex

***Provenance*:** Low silisiclastic contents in the green sandstone indicate a distant or low relief source, but the presence of the glauconitic sandstone suggests intermittent influxes of coarse silisiclastic material, possibly by turbidity current (Plates 7 & 8). The smaller, rounded, darker pellets of composite glauconite within these sandstone beds could have been transported from shallower shelf environment, with the surrounding lighter colored authigenic glauconite forming in-situ. The presence of felsic volcanic lithic fragments, muscovite and biotite suggests an acidic igneous input. This is supported by the presence of mono-crystalline quartz with slightly undulose to no extinction, which is indicative of plutonic, probably granitic source. Sutured polycrystalline quartz could be indicative of a metamorphic source but other evidences are limited. Chert fragments and sandstone indicate some sedimentary source.

Tectonic Setting: The quartz-feldspar-lithic fragment proportions of sandstone plot onto the transition continental and quartzose recycled orogen provenance area and transition continental zones of the QmFLt diagram of Dickinson *et al*., 1983 (Figure 3). Such orogenic recycling occurs in various tectonic settings where the sediment sources include sedimentary strata and subordinate volcanic rocks which are exposed to erosion by orogenic or unroofing uplift of fold beds and thrust sheets. These setting include subduction complexes of arc orogens, foreland fore-thrust belts along the flanks of the arc or collision orogens, and highlands along the suture belts of the collision orogens (Dickinson and Suczek, 1979; Dickinson, 1980). The presence of lithic fragments, particularly chert, supports such a provenance according to Dickinson and Suczek (1979). The source of most of the Motatau detritus plutonic quartz within this sandstone could be the plutonic protolith associated with this setting. The relative concentration of quartz over feldspar indicates that feldspar has either been destroyed by abrasion/chemical weathering or has been diluted by cycle quartz.

Conclusion: *Based on above results and discussion, it is concluded that*

1. The provenance of Tokerau clastic is close to the source. Such a source land would have to be deeply eroded to allow the slow rate of sedimentation evident of this sandstone. Alternately, the source land could be more upstanding and some distance from the sedimentary basin, result in lowering the terrigenous detrital input
2. Mutukaraka, Punakitere and Awapoko sandstone indicate a relative close source land from where the sediments underwent little transport to their site of deposition with mixed provenance. This includes input from continental block, magmatic arc and recycled orogen environment.
3. Provenance of Motatau Complex indicates a distant or low relief source, but the presence of the glauconitic sandstone suggests intermittent influxes of coarse silisiclastic material, possibly by turbidity current. The source of most of the Motatau detritus plutonic quartz within this sandstone is considered as plutonic protolith.
4. The relative more concentration of quartz over feldspar indicates that feldspar has either been destroyed by abrasion/chemical weathering or has been diluted by cycle quartz.

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