Source to sink siliciclastic delivery in the deepwater Gulf of Papua from SEM-MLA aided provenance of the turbidite sand

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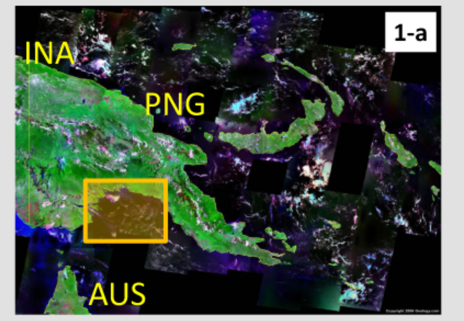
1. Abstract

An integrated provenance, textural and chronostratigraphic analysis of Pleistocene-Holocene turbidite sand in the Gulf of Papua (NSF Source to Sink Focus Area) has been undertaken to elucidate glacio-eustatic influences on sedimentary behavior in a modern deepwater depositional system. Sands were sampled in seven jumbo piston cores from the slope and basin floor, yielding 53 samples. A quantitative model mineralogy analysis was conducted using scanning electron microscopy (SEM) and mineral liberation analysis (MLA) of ~15,000 individual grains per sample. Tests using the Gazzi-Dickinson ternary diagram show a lack of differentiation among samples. Although free from grain-size effects, use of this diagram is strongly affected by the detailed mineralogical classification that results from automated MLA. MLA does allow sample differentiation using mafic/felsic ratio (m/f), light/heavy-heavy minerals ratio (l/h-hm), total heavy-minerals and pumice content. Furthermore our analysis of core thin sections and x-radiographs allows discrimination of two turbidite lithofacies with implications for separate routing: lithofacies A includes a unique succession of sand, woody debris and foraminifera, whereas lithofacies B is composed of thinly bedded very fine to medium sand turbidites, inter-layered with hemipelagic mud.

Time-sliced provenance based on our C-14 age model shows three major pathways: (1) long-distance NW-SE sediment transport of quartzo-feldspathic sand sourced from the Papuan Mainland, delivered from the Fly-Strickland fluvial system through Pandora shelf and slope (core MV-54), Pandora basin floor (cores MV-23, 33) and Moresby Channel (MV-25, 29), characterized by high m/f and low l/h-hm and unstable/tourmaline (uti) ratio basinward, recording turbidite lithofacies A and B; (2) short-distance NNE-SSW transport of felsic-mafic volcanic sand apparently from the collision margin of the Papuan Peninsula, delivered via small rivers narrow shelf, and deep-sea canyons (MV-22) characterized by high m/f ratio without distinct pattern of heavy minerals ratio, characterized by lithofacies B; and (3) intermediate-distance delivery from the Fly-Strickland and Papuan Peninsula along coastal pathways to the Moresby Trough (MV-22) characterized by high pumice contents, overall low in uti and l/h-hm, composed of lithofacies B turbidites. The vertical provenance pattern shows that the Pandora Trough samples (MV 23, 33, 54) were entirely pathway 1 during the time period 44-17 Ka, while Moresby Trough received sediment via pathway 1 (MV-25, 29) and pathway 2 (MV-22), gradually shifting to pathway 3 from late Pleistocene to the middle Holocene. We also suggest that the Gazzi Dickinson scheme be re-evaluated in light of powerful new automated MLA techniques, to allow better sample discrimination in fine-grained lithic and felsic sands typical of our study area, and many other deepwater basins.



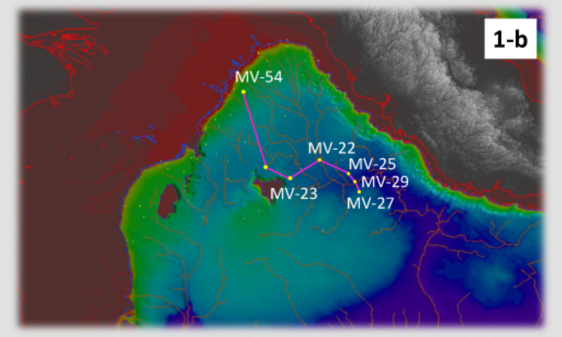
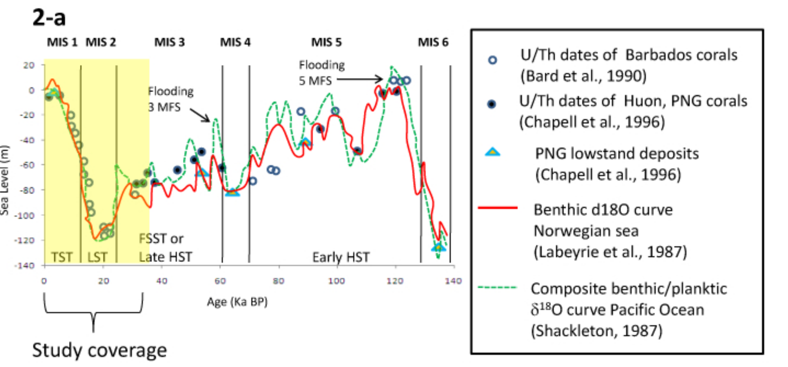
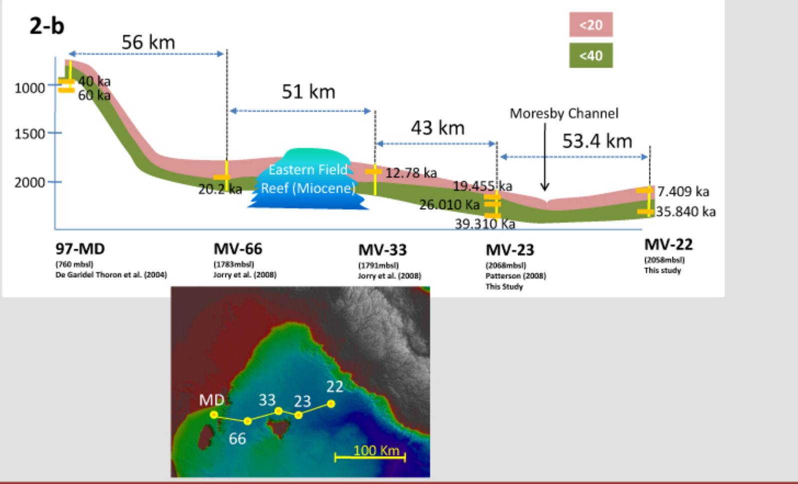


Figure-1a. Landsat thematic image of the Western Papuan mainland, the Gulf of Papua (cyan rectangle) shows the crescent shape embayment with 200-400 km width , figure 1.b. index map used for time-slice provenance in section 5 and 6.

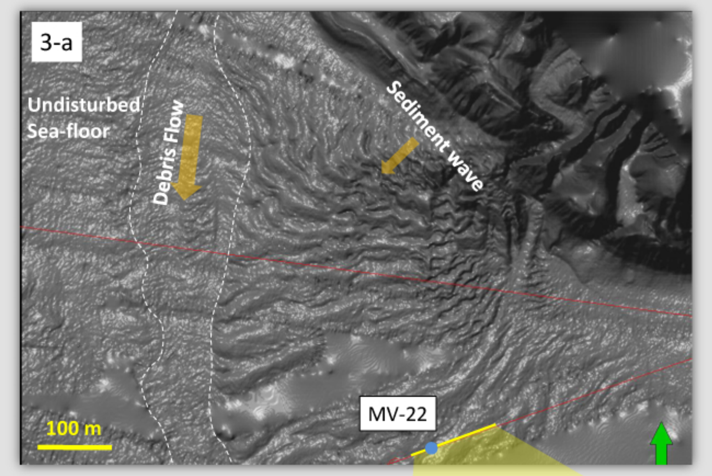
2. Chronostratigraphy Framework

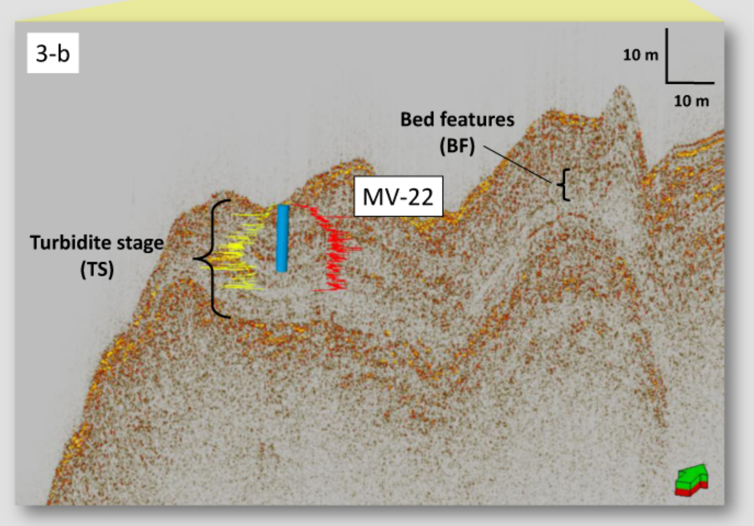


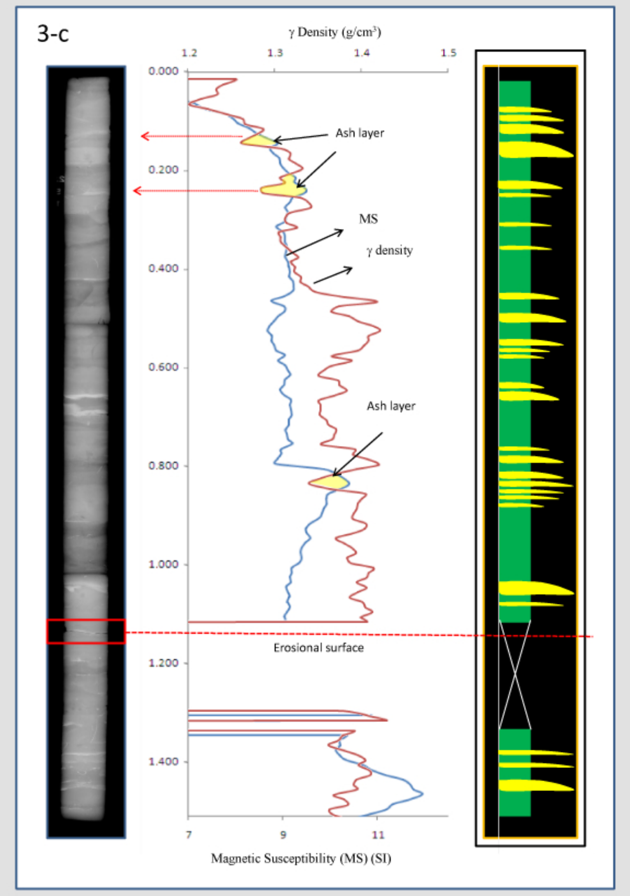


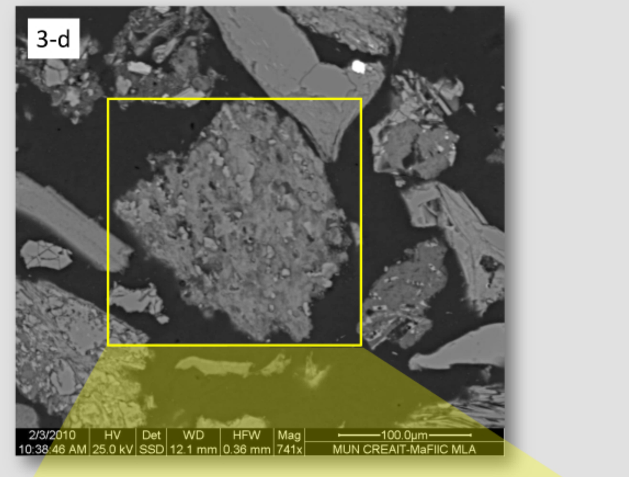
Previous work has shown that core-sediment ages in the study area range up to 30 ka (de Garidel-Thoron et al., 2004, Droxler et al., 2006, Febo et al., 2008, Jorry et al., 2008) which includes the time span from Late MIS 3 to MIS 1. Fig-2a shows the oxygen isotope excursion from various sources (Modified from Simms et al., 2007). This study will focus on the depositional system from late MIS-3 to MIS-2 (yellow fill). Fig-2b shows the chronostratigraphic frameworks from previous study and this study, East- West across study area (inset: location map)

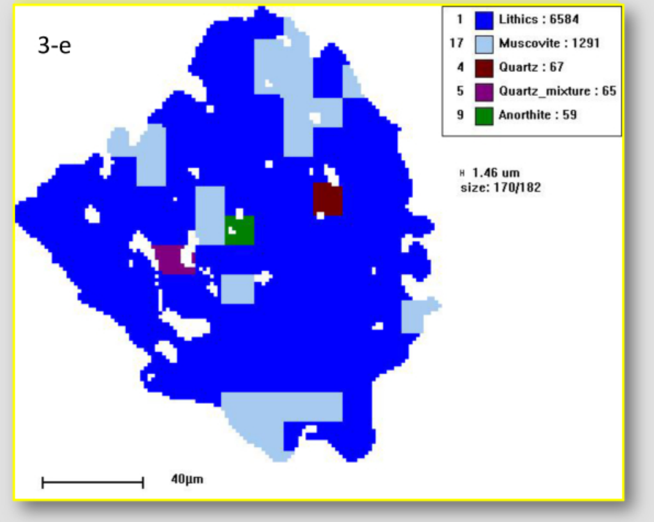
3. Methodology









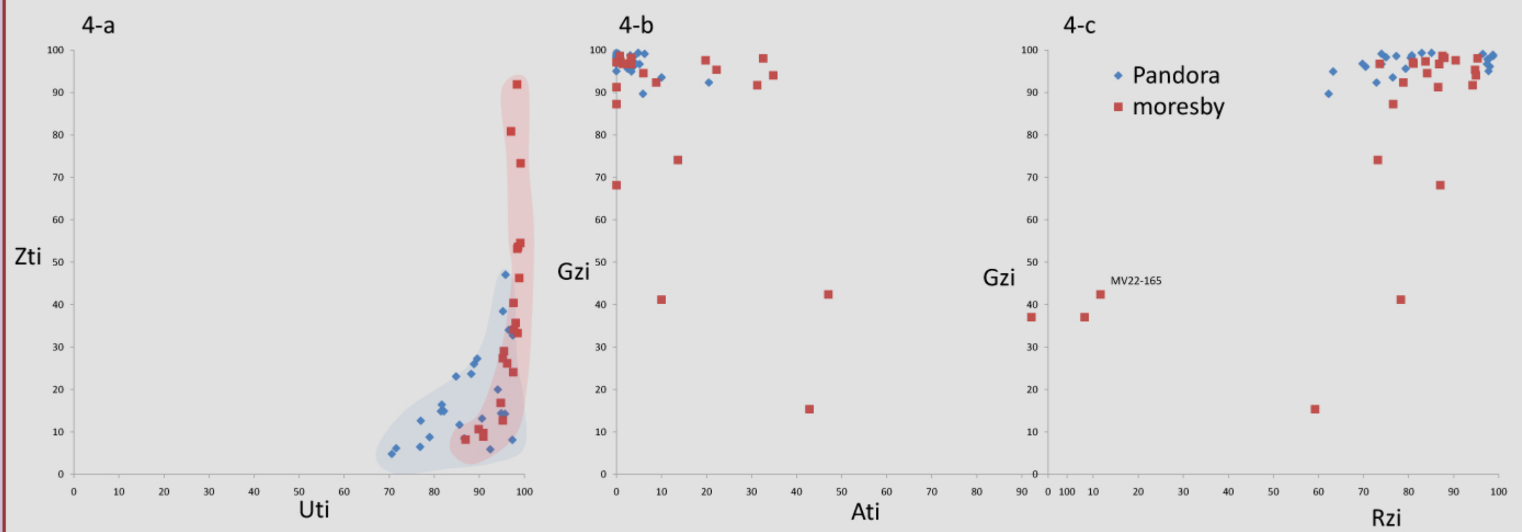


A total of 53 samples were collected from 7 jumbo piston cores (JPC), represent major physiographical elements Pandora slope and Trough (MV-54, 23 and 33), Moresby Channel (MV-25 and 29), Moresby Trough (MV-22), and Eastern Field Platform (MV-27) acquired during the M/V Melville cruise on 2004. The cores depth and position were also used to groundtruthed multibeam bathymetry digital elevation model (DEM) (Fig-3a). Furthermore, cores were tied with 3.5 KHz sub-bottom profile to define the depositional units and scale factor. This study mainly observe turbidite stage (TS) (3rd order) into sub-stages (TSS) (4th order) in the 3.5 KHz data (Fig-3b) and bed features (BF) (5th order) from the core data. The samples were selected and extracted from significant sandy layers guided by the core image and magnetic intensity and gamma-density curve from multicore logger (Fig-3c).

The samples were wet sieved to into sand size fraction (0.0625-2 mm), then undergone organic removal by using hydrochloric acid and hydrogen peroxide to remove the organic materials such as fossil, shell fragment, wooden fragment and vegetation remains. The air dried samples then grain mounted using epoxy resin under vacuum and gradually polished using diamond suspension under 30 – 15 – 5 – 1 - 0.1 µm. The prepared round samples then carbon sputtered to coat the surface with carbon to adding the conductivity and to carry away the charging electron. In order to review the petrographical properties and conduct manual point count, some samples (10 samples) were prepared as 70 µm thin sections, whereas the rest prepared as round samples.

Further analyses were performed on the turbidite sand samples with an FEI Quanta 400 scanning electron microscope (SEM). SEM is collecting backscatter electron thus enable to imaging the minerals by close to 50,000 times their original sizes (Fig-3d). The results then are quantified by mineral liberation analysis (MLA). The MLA technique first relies on *backscattered electron imaging* (BEI), as a measure of average atomic number, for discriminating grain boundaries, and then classify the grains as recognized minerals based on their density in the spectral library (Fig-3e).

4. Sensitive heavy minerals ratio

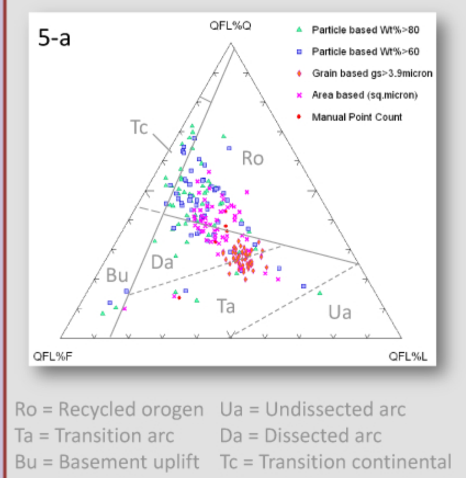


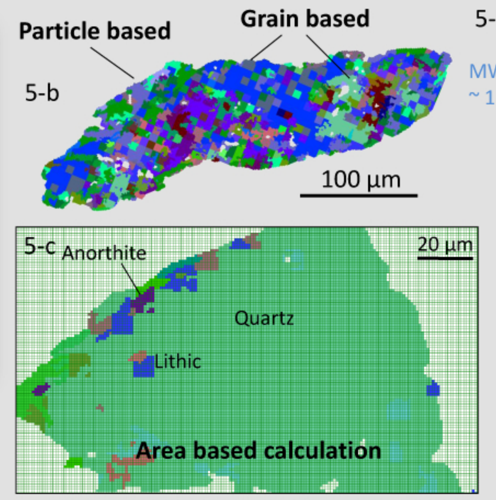
Zti = Zircon – Tourmaline index (total zircon in zircon + tourmaline);
Uti= unstable-tourmaline index (epidote+TiO_2 in epidote, TiO_2 and tourmaline)
Ati= apatite-tourmaline index (apatite in total apatite + tourmaline)
Gzi= garnet-ziiron indec (garnet in total garnet +zircon)

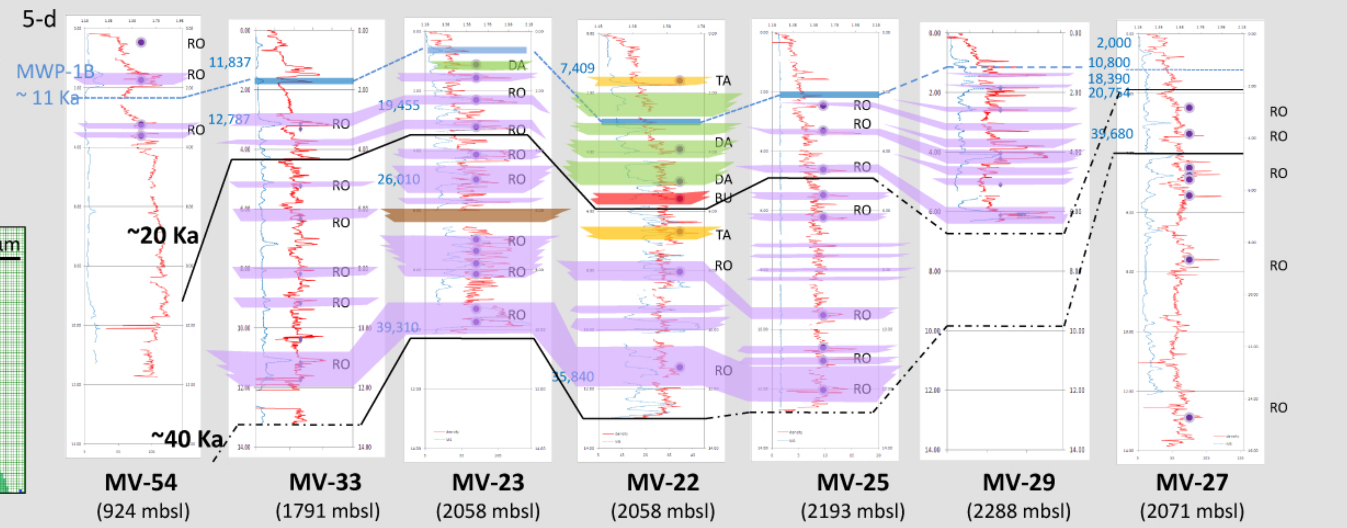
The sensitive heavy minerals ratio was used to detect the differentiation effect from minerals hydraulic behavior and diagenetic processes thus the discriminations if any, is expected to reflect solely heavy minerals (HM) inherited from the parental rocks (Morton et al., 2003). The binary plot between (Uti) and (Zti) shows that Moresby Trough (MT) samples were more constrained in high unstable HM (85-100 %) (Fig 4-a). Binary plot between (Ati) and (Gzi) shows that PT is tightly constrained in high Gzi (90-100 %) compared to the MT. The abundant of relatively stable HM possibly explained the prolonged transport (Fig 4-b). The Rzi and Gzi was plotted to show a similarity in the minerals hydraulic behavior, the plot shows both MT and PT samples is slightly overlap with more heterogeneity in MT. (Fig 4-c), thus do not show a distinct parental rock discrimination between Pandora and Moresby Troughs, but rather reflects a different hydrodynamic (transport pathway) and unstable minerals composition.

5. Gazzi-Dickinson Ternary diagram

(See fig 1-b. for index map)







This study is consider as the first study to perform the Gazzi-Dickinson provenance plot (e.g. Ingersoll et al. 1984) based on automated SEM-MLA. To test the consistency and to find the best result, the procedures were performed by several approaches, verified by the manual point counts from Moresby trough (Fig-5-a).

Grain based point counts: the grain based point counts were use by taking counting 30-50,000 grain with grain diameter larger than 3.9 µm. This method draw a results which is clustered closely in the transitional arc and dissected arc. This is possible because the method was unable to differentiate the lithic fragment from the matrix and individual grains in particles (Fig-5b)

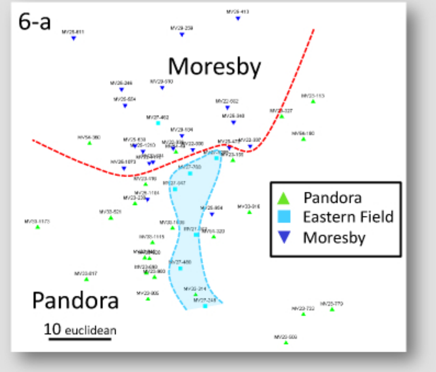
Particle based point counts: was performed by filter criterion of particle diameter larger than 62.5 µm and minimum area percentage of the designated minerals of 80 % and 60 %. Both of the results showing a good consistency. The results shows a significant negative lateral shift in Lithic fragment compared to the manual point counts because the use of this diagram is strongly affected by the detailed mineralogical classification that results from automated MLA (Fig-5b)

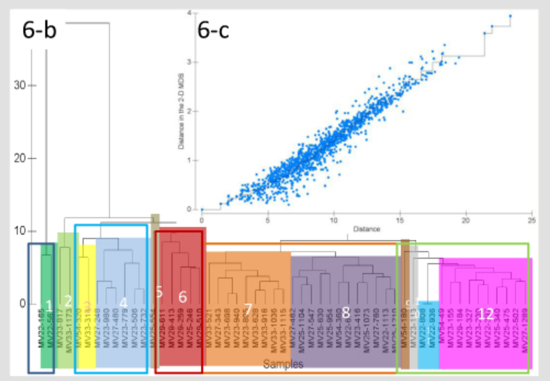
Area based counts: this method is used the minerals pixel map result from the MLA. This method showing a data spread mainly ranging from transitional arc, dissected arc and recycled orogen (Fig-5c)

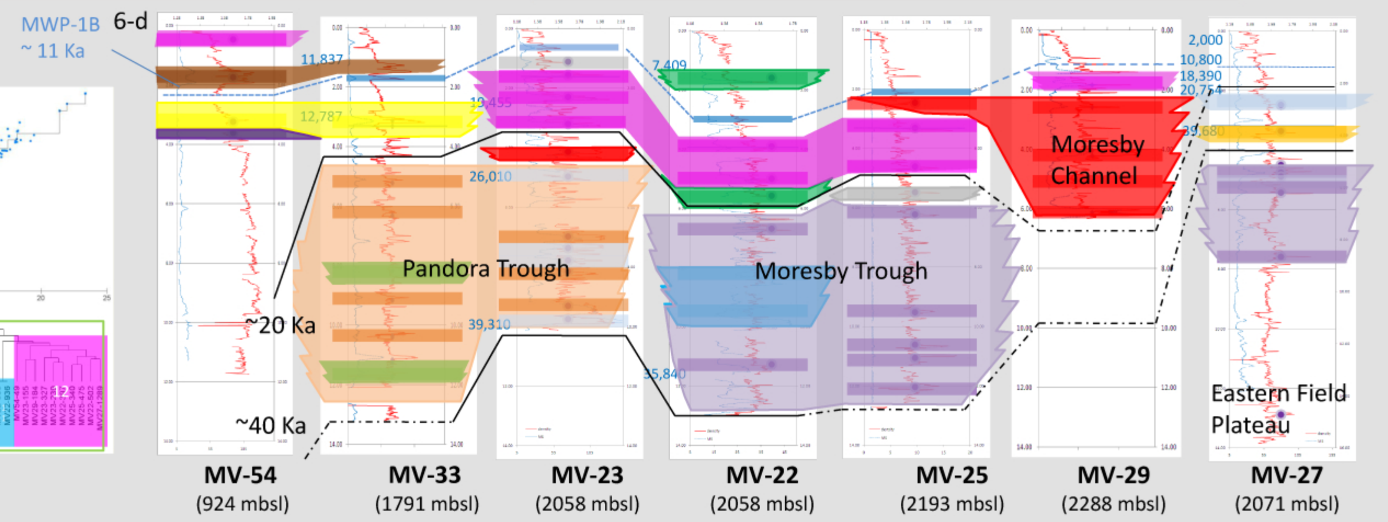
Plot of the provenance class in correlation is able to identify the volcaniclastic units in Moresby Trough in MV-22, However this methods could not characterized the routing/pathway (Fig-5d).

6. Non -metric multidimensional scaling (nMDS)

(See fig 1-b. for index map)







MDS visually represents the proximity between samples in the multi-dimensional domain. This study is using Euclidean distance to calculate the dissimilarity. Observation using SIMPER (similarity-percentage) shows there are 12 major minerals those gave the biggest contribution of dissimilarity which are: Quartz, Quartz Poly, Perthite, Chloritoid, Amphibole, Pumice, Lithic, Albite, Orthoclase, Muscovite, Anorthite and Epidote. The projection of the 12-D data into 2D shows distinct separation which could discriminate samples from Pandora Trough (MV23, 33 and 54), Moresby Trough (MV-22, 25 and 29) and Eastern Field Plateau (MV-27) (Fig 6-a). The dendrogram shows that samples could discriminate into 12 classes (Fig 6-b). The Kruskal fit scheme showing an acceptable stress value of 0.11 in 2D (< 0.15) (Fig 6-c). Time-slice provenance shows that before 20 Ka, Pandora (PT) and Moresby Troughs (MT) receiving separate sedimentary fill. PT was characterized by high Feldspar and Lithic whereas Moresby dominated by Mafic minerals. In period younger than 20 Ka, there is indication of the source mixing between both depocenters with increasing in volcanic contents. Sample from Moresby Channel shows a unique character which is high in Perthite, possibly derived from Pegmatitic along the river path in Papuan Mainland.

7. Principal component analysis (PCA)

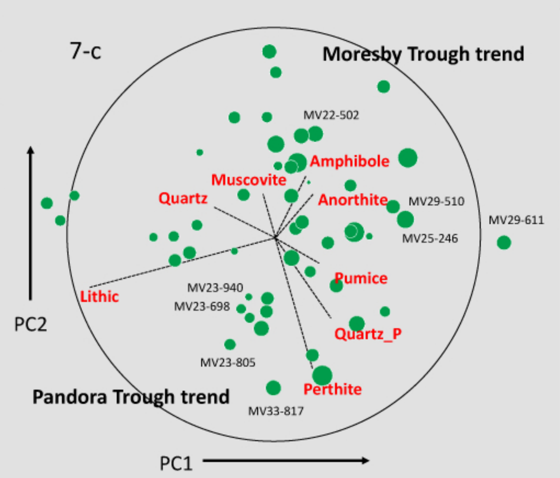
PCA is used to search a linear compound of correlated variable (Vezolli et all, 2010). The first two PC in this study dataset, PC1 and PC2 have explained more than 66% variability in the dataset thus selected as an axis (Fig-7-a). The eigenvectors shows that most of the major PC load factors were on PC1 or PC2 except in Pumice and Quartz (Fig 7-b). The ordinary plot between PC1 and PC2 shows that samples from Pandora Trough (PT) mostly characterized by lithic and perthite mineral assemblages and Moresby Trough (MT) samples were mostly characterized by abundance of amphibole and Anorthite. The apatite mean angularity trend shows that MT samples has more angular shape, is interpreted as reflect to the short distance transport system (Fig 7-c). PC loading plot overlayed with Al bubble map shows that the alteration is more intensive toward sample from PT. However, the ZTR index (ultra-stable HM) is also increasing suggest more mature sources or longer transport system from PT (Fig 7-d).

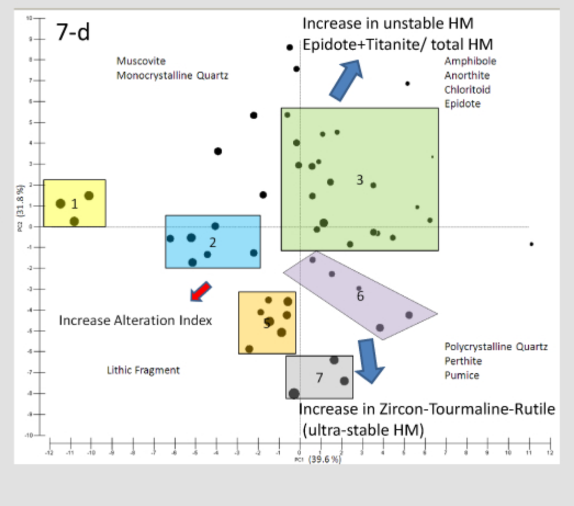
7-a

PC	Eigenvalues	%Variation	Cum.%Variation
1	0.631	43.9	43.9
2	0.323	22.5	66.4
3	0.211	14.7	81
4	7.34E-02	5.1	86.1
5	6.79E-02	4.7	90.9

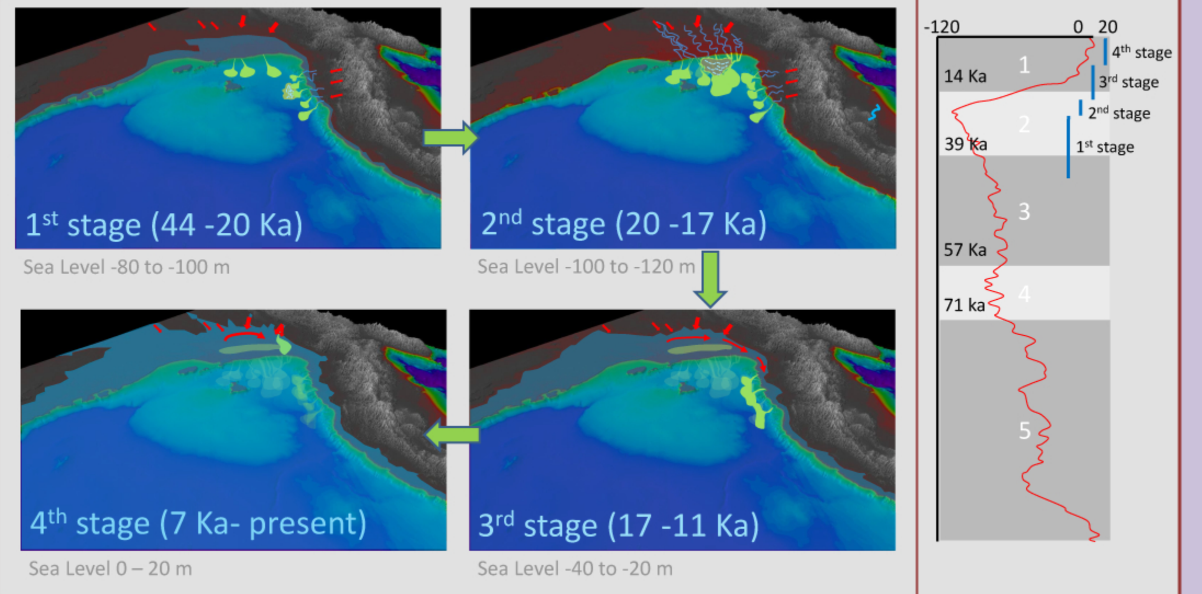
7-b Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5
Lithic fragment	-0.2	0.5	0.1	-0.1	-0.4
Amphibole	0.5	-0.2	-0.2	0.3	-0.1
Quartz	0	0.4	0.4	0.2	0.53
Quartz_poly	-0.2	-0.3	-0.3	0.4	0.5
Chloritoid	0.4	0.1	-0.2	0.2	-0.1
Epidote	0.4	-0.2	0.2	-0.3	0.19
Anorthite	0.2	-0.2	0.1	-0.5	0.03
Pumice	-0.1	-0.4	0.6	0.4	-0.5





8. Conclusion and Reconstruction



The provenance study aided by SEM-MLA provides various approaches with a powerful insight from data richness and detailed MLA. The sensitive heavy minerals (HM) ratio unable to discriminate the samples from both Pandora (PT) and Moresby Troughs (MT) based on their parental rocks but rather based on the texture maturity by compositional different in unstable heavy minerals and possibly hydraulic behavior of the grains during the transport. The particle based Gazzi-Dickinson ternary plots shows a good consistency with manual thin section point counts. However the plot shows a lack of differentiation among samples, despite apparent differences, suggests that the classical QFL approach is ill-suited to utilize the robust and detailed mineralogical identification of automated MLA.

The nMDS could detect the compositional affinity of the turbidite sands deposited in PT and MT. Time slice provenance shows that before 20 Ka, those two troughs are receiving detritus from different drainage systems. The PT sands shows abundant of feldspar, lithic and Perthite whereas MT sands dominated by mafic minerals. Above 20 Ka, there is an indication of the sources mixing between two troughs. The depositional is dominated by lithic fragment which suggests the intensive and rapid erosion during this period. The PCA could discriminate the samples into 7 groups based on their specific mineral assemblages. The overlay between compositional bi-plot with environmental factor such as mineral roundness, ZTR index, alteration index and unstable minerals ratio.

Based on the time-slice provenance we could reconstruct the turbidite sand depositional story into 4 stages (Fig 8-a) :

1st stage: both depocenter are totally isolated and received sediments from different sources.
2nd stage: peak of deepwater depositional, in latest stage, riverhead emerged basinward enables the mixing
3rd stage: the shelf edge drowned, turbidite sedimentation in PT is ceased, but continued in MT
4th stage: turbidite sedimentation decreased and ceased in MT

9. References

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