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EVIDENCE FOR RECENT PALAEOMAGNETIC SECULAR VARIATION IN LAKE SEDIMENTS FROM THE NEW GUINEA HIGHLANDS

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Palaeomagnetic declination and inclination data are reported from Mackereth mini cores taken from three lake sites in Papua New Guinea. ^{137}Cs, ^{210}Pb and ^{14}C dating provide a timescale for the palaeomagnetic oscillations. Tephrastratigraphy aids correlation between lakes. The palaeomagnetic data resemble the geomagnetic secular variation pattern deduced from historical observations. The new results greatly extend the latitudinal coverage of palaeomagnetic secular variation recorded in the last 10^4 yr. Their significance in assessing secular variation source models is discussed. The data suggest that the edge of the Pacific region of low non-dipole field activity has remained near New Guinea during the last 10^4 yr.

1. Introduction

Most of the evidence so far obtained from lake sediments for late Quaternary palaeomagnetic secular variation comes from sites in temperate latitudes, particularly Europe and North America. The present paper summarizes inclination and declination data obtained from 1-m Mackereth mini-cores (Mackereth, 1969) taken from three lakes in the Highlands of Papua New Guinea (Fig. 1). Two of the sites, Lakes Egari and Pipiak, lat. 6°12"S, long. 143°40"E, lie less than 2 km apart at ~1800 m above sea level in the Southern Highlands Province. The third site, Lake Ipea, lat. 5°25"S, long. 143°30"E, lies at ~2500 m above sea level in the Enga Province, about 80 km from the former sites. Egari and Pipiak are small crater lakes from which cores were obtained from central areas in water between 7.5 and 11 m deep. Lake Ipea is a larger shallow lake from which marginal cores were taken in 3–3.5 m of water.

The chronology of sedimentation of gyttja in each lake has been established by means of ten radiocarbon dates, seven ^{210}Pb profiles and one composite ^{137}Cs profile (Oldfield et al., in prep.). Within- and between-lake correlation has been facilitated by a sequence of five distinctive volcanic ash layers, three of which are common to all the lakes studied. These can be identified not only in extruded samples, but also in whole unextruded cores, by means of susceptibility measurements (Fig. 2) using the continuous core susceptibility bridge described by Molyneux and Thompson (1973). Fig. 3 summarises the correlations and chronological framework established for the cores taken from each lake.

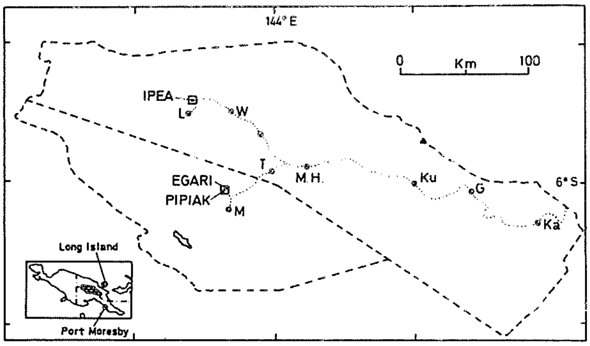

Fig. 1. Location map of Lakes Ipea, Egari and Pipiak, Papua New Guinea.

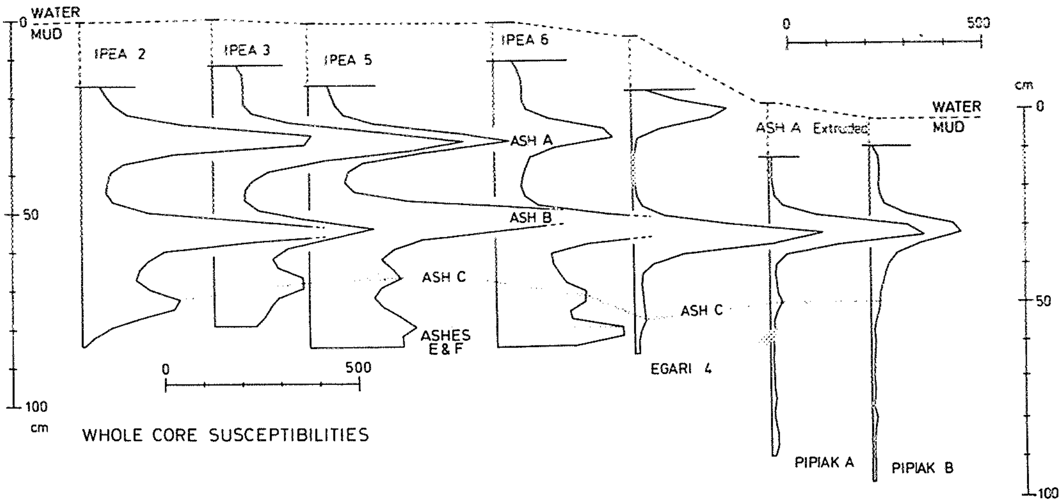

Fig. 2. Whole-core susceptibility logs for Lakes Ipea, Egari and Pipiak. Upper sediment (*dashed*) extruded prior to whole-core measurement. Susceptibility range in microgauss per oersted.

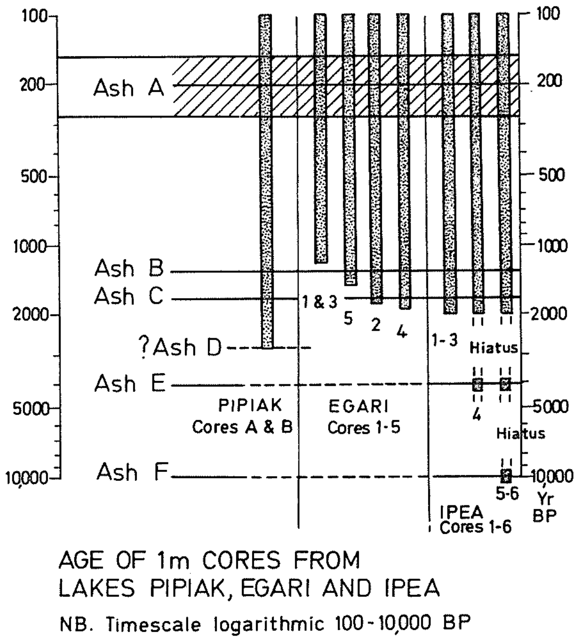

Fig. 3. The chronology of sedimentation in 1-m cores from Lakes Pipiak, Egari and Ipea, based on the correlated sequence of volcanic ashes and on ^{14}C and ^{210}Pb dates. Blong (in prep.) has shown that ash *A* corresponds with his Tibito tephra and ash *B* with his Olgaboli tephra at type sites close to the Kuk Tea Research Station in the upper Wahgi Valley near Mount Hagen.

2. Methods

The Mackereth 1-m minicorer operates pneumatically and no evidence has come to light for twisting of the core tube or distortion of the core during sampling. The cores obtained from Lakes Pipiak and Egari are thus regarded as undisturbed. Due to loss of equipment in the field, the Ipea cores were taken manually and some twisting of the core tube has occurred in some if not all of the cores.

In addition to whole-core susceptibility measurements, intensity of natural remanent magnetization (NRM) and declination were also determined on whole cores using a slow-speed fluxgate spinner magnetometer (Molyneux, 1971) modified to measure whole cores (Molyneux et al., 1972). 10 ml single samples in plastic boxes were taken for measurement of volume susceptibility and specific susceptibility and for intensity of NRM, declination and inclination.

Thirty pilot samples, which were chosen for demagnetization, demonstrated widely varying characteristics, the median destructive field ranging from 50 to over 400 Oe (Fig. 4). Several samples showed directional instability above 100 Oe but good clustering below 100 Oe (e.g. *S5 31*). Others lost a large proportion of their NRM in the low part of the coercivity spectrum (e.g. *S2 13*, Fig. 4). Thus a low field

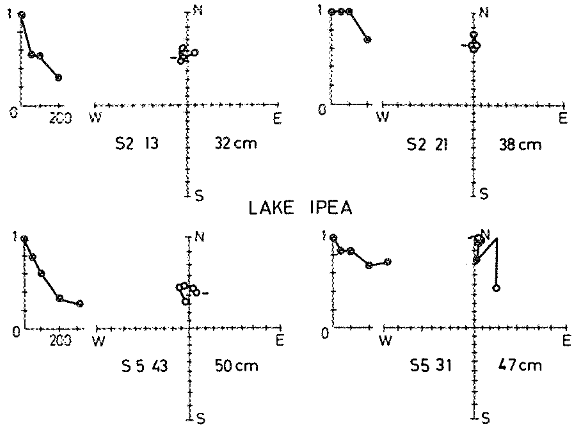

Fig. 4. Partial demagnetization curves. Normalized intensity versus peak (oersteds) and stereographic projection. *Open circles*, negative inclination; *closed circles*, positive inclination. NRM direction is indicated by *horizontal bar.*

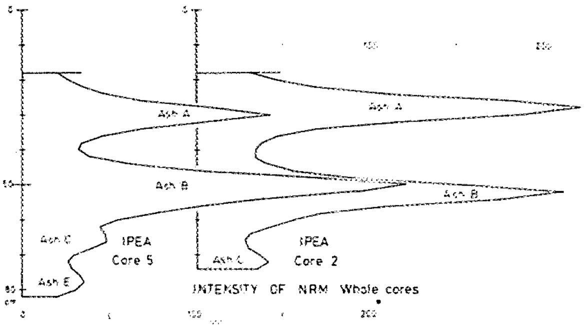

Fig. 5. Intensity of horizontal NRM from whole-core measurements of Ipea *2* and *5*. Intensity range in microgauss.

was selected simply to eliminate any viscous components, and the remaining paired suites of samples extruded from Ipea cores *2* and *5* were partially demagnetized in a peak field of 30 Oe.

Three problems have limited the amount of repeatable data obtained from the cores:

(1) Twisting of the core tubes at Ipea has made it impossible to use declination data from all but one Ipea core, despite the repeatability of the measurements.

(2) Although the intensity of NRM of the volcanic ash layers invariably reaches high values (Fig. 5) comparison of directional properties between paired samples, repeat measurements, and AF demagnetization experiments have shown that the remanence is highly unstable.

(3) Many levels in the Egari and Pipiak cores have very low intensities of NRM, close to or below the reliable measuring limits of the magnetometer used.

For these reasons, this article presents only that part of the data which has been confirmed from more than one core. Table I summarises the nature of the data presented in terms of site name, core number, the time interval spanned and the types of measurements made.

3. Palaeomagnetic records

3.1. Inclination

Fig. 6 shows the results of inclination measurements made after AF cleaning on paired sample suites

TABLE I

Summary of the palaeomagnetic data presented. All cores have been logged for magnetic susceptibility on whole cores before extrusion and subsequently as single samples

Lake	Core	Whole-core NRM (J and D)	AF-cleaned (30 Oe) single samples I and D	Approximate time interval covered by repeatable measurements
Egari	core *4*	D		1800–200 B.P.
Pipiak	core *A*	D		2000–1200 B.P.
	core *B*	D		2000–1200 B.P.
Ipea	core *2*	J and D	I and D	1000 B.P. to present (with gap)
	core *5*	J	I	10,000 B.P. to present (with gaps)

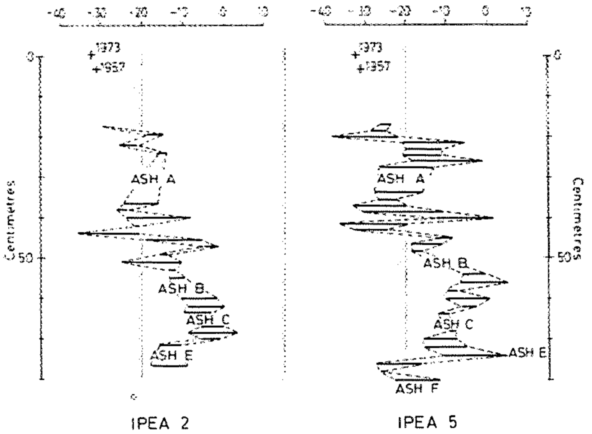

Fig. 6. Partially demagnetized (peak field 30 Oe) inclination logs for paired samples from cores *2* and *5*, Lake Ipea.

from each of Ipea cores *2* and *5*. With the exception of levels affected by the volcanic ash-falls, consistent results are obtained with good agreement within and between cores. The correlations below ash *B* are based on the lower ashes and a series of four radiocarbon dates associated with them. These dates coupled with detailed stratigraphic study (Oldfield et al., in prep.) have allowed the identification of the two long periods of interrupted sedimentation noted in Fig. 3. Between ashes *B* and *A* correlation is based on the inclination variations and on changes in magnetic susceptibility with depth in each core (cf. Thompson et al., 1975). The date of ash *A* has been determined by ^{14}C dating of wood peat associated with it elsewhere in the western Highlands (Blong, 1975 and in prep.) by ^{210}Pb (Oldfield et al., in prep.) and by documentary evidence (Ball and Johnson, 1976) to some period between the late 17th and early 19th century. The topmost points on the diagram are the 1957 and 1973 inclination measurements at Port Moresby Observatory some 550 km SE. The left-hand part of Fig. 9 shows an attempt to produce generalised curves of inclination variation derived subjectively from the data summarised. The dashed inclination curve for the last 350 years has been calculated by D. Barraclough (pers. commun., 1977) for the site of Lake Ipea from all available historic records, using both geomagnetic declination and inclination information. All the evidence presented suggests that inclination has varied by ~30°–35° over a timescale of 10^3 yr. and by ~15°–20° over a timescale of $2 \cdot 10^2$ yr. The recent values are compatible with nearby observatory records. However, the time interval covered by the uninterrupted part of the record is too short and the chronological control within it too coarse to permit any conclusions as to the periodicity or otherwise of the secular variations in inclination recorded.

3.2. Declination

For the time interval between ashes *C* and *B*, ca. 1600–1150 B.P., matching continuous core declination traces have been obtained from cores in all three lakes (Egari *4*, Pipiak *A* and *B*, and Ipea *2*). During this period declination varies by about 10° (Figs. 7 and 8). For the time interval between ashes *B* and *A*, 1150 B.P. to ca. 250 B.P., mutually consistent continuous core traces have been obtained from Egari *4* and Ipea *2*. The geomagnetic declination changes during this period were much lower than in the preceding 400 yr. In addition declination has been measured after AF cleaning at 30 Oe on the same suite of paired extruded single samples from Ipea core *2* as gave the inclination measurements (core *5* was badly twisted). Only very slight variations of less than 10°, which can be confirmed from more than one core, are recorded for the whole of this time interval (Fig. 8).

The trace for the last ca. 250 years is based solely on the paired extruded single samples from Ipea *2* and may have been subject to some distortion. However, if the trend of the topmost values is extrapo-

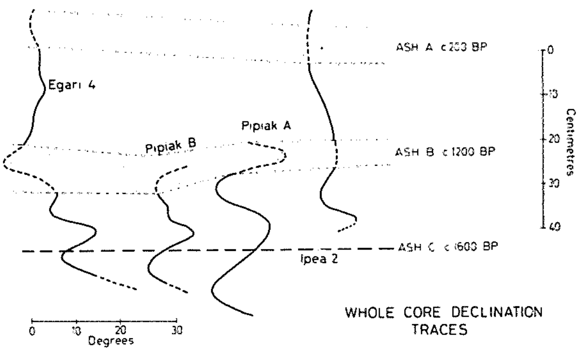

Fig. 7. Relative declination logs for parts of whole cores from Lakes Egari (core *4*), Pipiak (cores *A* and *B*) and Ipea (core *2*). Lower depth scale schematic to allow for variability of ash layers.

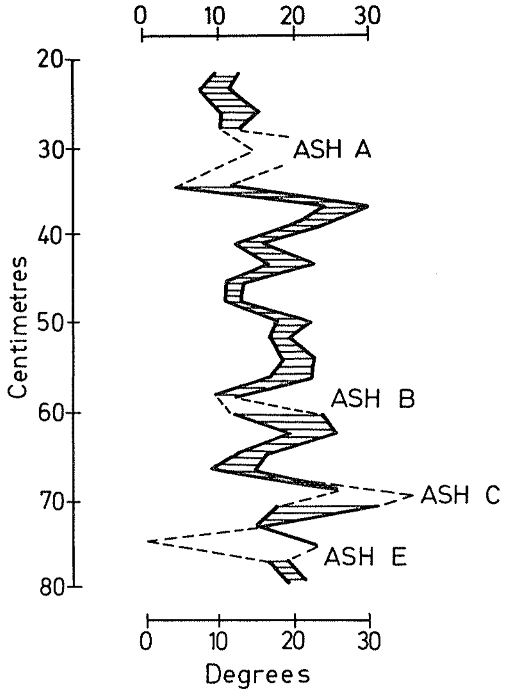

Fig. 8. Relative declination log for paired samples from Ipea core *2*. Aberrant directions from ash bands discarded.

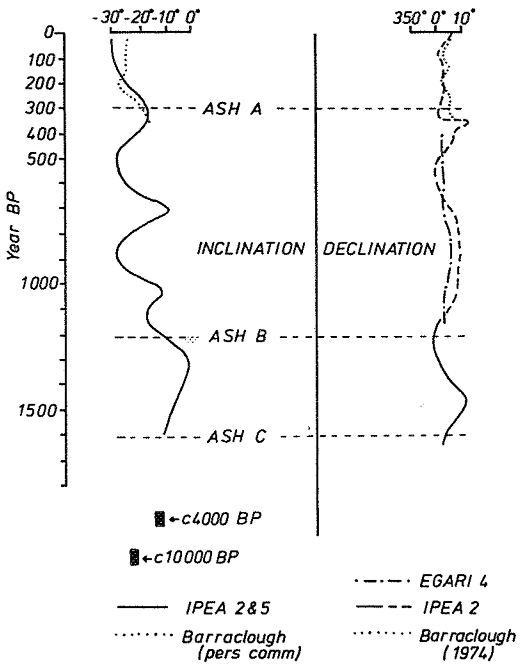

Fig. 9. Diagrammatic curves of geomagnetic field variation for the Highlands of Papua New Guinea, based on the data summarized in Figs. 5–7 and on Barraclough (1974 and pers. commun., 1977).

lated to the surface to give an approximate orientation to the trace, the variations in declination recorded are reasonably comparable to those calculated for the appropriate epochs by Barraclough (1974). The right-hand side of Fig. 9 plots inferred declination variations from all the available data and also includes a curve for the period since 1700 inferred from Barraclough's analysis and plotted against the ^{210}Pb timescale derived from the Ipea cores.

Over the whole period 1600 B.P. to the present, declination appears to have varied by less than 15°. This is much less than the variation indicated for that time interval in western Europe and also significantly less than the recorded variation in inclination in the same samples.

4. Geomagnetism

Geomagnetic secular variation models are based primarily on magnetic observations which have been made in increasing numbers over the last 350 yr. and now provide a very detailed picture of the geomagnetic field. Palaeomagnetic studies of igneous rocks have been used to study the angular dispersion of ancient field directions over timescales of the order of 10^6 yr. The present-day secular variation can be largely accounted for by a slow westward motion of the main magnetic field, although an improved approximation is found if some of the harmonic components drift westwards at a higher rate than the centred dipole (0.09° yr.^{-1}) while a few drift eastwards. The palaeomagnetic investigations have shown that, in general, the angular dispersion of the ancient virtual geomagnetic poles increases with increasing latitude, as would be expected from westward-drift source models, but that in the central Pacific region the average value of the non-dipole field has been unusually low, as it is at present (Doell and Cox, 1972).

Palaeomagnetic studies of limnic sediments can contribute to geomagnetic secular variation models by providing information covering intermediate periods between those of the investigations outlined above. The present investigation in New Guinea

(~5°S) and recent results from Finland (~65°N) (Stober and Thompson, 1977) provide a new opportunity for assessing the latitudinal variation of ancient field directions. Palaeomagnetic secular variation data from volcanic rocks are generally presented in terms of the angular dispersion of field direction or virtual geomagnetic pole positions. As palaeomagnetic results from limnic cores have to date not been orientated absolutely and contain a dispersion factor associated with sedimentological complexities such a rigorous approach is not attempted here. We have simply plotted the maximum range of inclination variation recorded in lake sediments and inland seas over approximately the last $5 \cdot 10^3$ yr. which (1) are repeatable in at least two cores; (2) are in sediment of mean grain size <62.5 μm; and (3) have been subjected to AF cleaning. These variations are compared with the total change in inclination of the present geomagnetic field found along lines of geographic latitude (Fig. 10). The variation of inclination, along lines of geographic latitude, for both the northern and southern hemisphere shows a very similar pattern to that of angular dispersion of field directions (cf. Fig. 5, Creer, 1962) and so appears a useful parameter for discussion of world-wide secular variation bearing in mind the restricted magnetic information available from lake sediments.

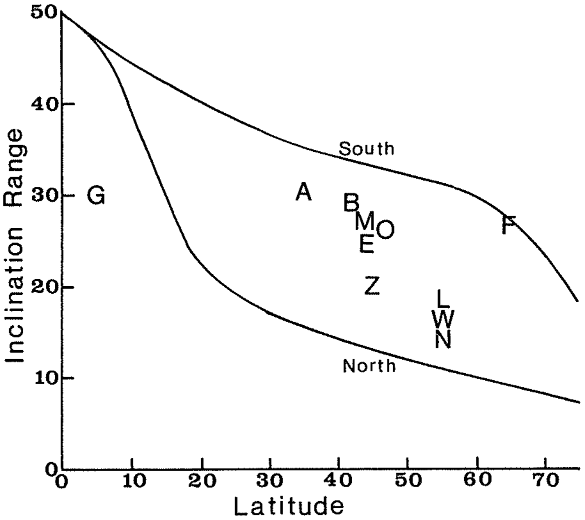

Fig. 10. Maximum inclination range versus latitude for present geomagnetic field and limnic palaeomagnetic records. G = Papua New Guinea; *A* = Aegean (Opdyke et al., 1972); *B* = Black Sea (Creer, 1974); *E* = Erie (Creer et al., 1976a); *M* = Michigan (Creer et al., 1976b); *Z* = Zug and Zürich (Thompson and Kelts, 1974); *O* = Ontario (Anderson et al., 1976); *L* = Lomond (author's data); *W* = Windermere (Thompson, 1973); *N* = Lough Neagh (Thompson, 1973); *F* = Finland (Stober and Thompson, 1977).

The North American and European mid-latitude palaeomagnetic secular variation data summarized in Fig. 10 appear compatible with those to be expected from a westward drift model of the main geomagnetic field. However, the New Guinea data have clearly too low a variation compared with the westward-drift model, and the Finnish data are rather high (particularly when compared to the well documented results from Great Britain). These differences could be explained by non-zonal or standing components in the long-period non-dipole geomagnetic field. A straightforward explanation of the New Guinea data would be that they fall on the edge of the central Pacific region of low non-dipole field activity established from volcanic rocks (Fig. 11). It is interesting to note that Finland lies near a high feature (the Siberian anomaly) in Fig. 11, although today these Siberian aberrant virtual geomagnetic poles result mainly from unusual declination and the present secular change in inclination in Finland is low.

Absolutely orientated cores are now being collected. These combined with statistical assessments of the angular scatter due to sedimentological noise (e.g., Clark and Thompson, 1978), should yield quantitative results on the angular dispersion of both field directions and virtual geomagnetic pole positions. Closer comparison with the secular variation recorded in igneous bodies and more definitive testing of geo-

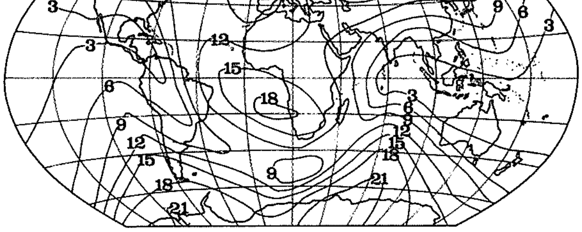

Fig. 11. The angular distance between the geomagnetic pole and virtual geomagnetic poles, calculated from 1945 geomagnetic field directions. (After Cox, 1962.)

magnetic source models based on observatory data will thus be possible. Even with present techniques the limnic results collected so far strongly suggest that both drifting and standing components of the non-dipole field have persisted over the last $5 \cdot 10^3$ yr.

H. Nevanlinna (pers. commun., 1977) has shown from magnetic observations since 1800 (Nevanlinna and Sucksdorff, 1976) that the secular variations in Finland can be explained by the Siberian anomaly remaining roughly stationary but changing rapidly in intensity, with other non-dipole anomalies, e.g. over Africa, having drifted westwards at 0.2° yr.^{-1}. The European palaeomagnetic data would similarly suggest a long history of geographically stationary, but hydrodynamically active core area beneath Siberia.

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