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CIRCUM-PACIFIC PERIODICITY IN VOLCANIC ACTIVITY

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We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Geosciences--Geology.

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ABSTRACT

For volcanic areas of the circum-Pacific belt, graphs of the number of volcanoes in eruption each year against years, from 1900 onwards, indicate a periodicity in volcanic activity.

These areas may be grouped into three main regions: the Western Pacific, North America and South America, and in each of these, the central dates of the pulses representing the maximum or one less than the maximum number of volcanoes in eruption show a positive correlation with the approximate mean angular distances of the areas from the North Pole. Four of these pulses appear to be continuous from the Western Pacific into South America, but North America does not fit readily into the same pattern.

The volcanic periodicity of the New Guinea-Solomons region was investigated more fully. Here, there is a spectacular increase in volcanic activity since 1935, as well as short pulses in volcanic activity with intervening quiet periods. An interval with no volcanic activity occurs from 1925 to 1935 and, for smaller tectonic units within the area, the first volcanic pulse after this quiet period occurs progressively later with increasing latitude, showing a similarity to the larger circum-Pacific areas, though subsequent maxima do not convincingly follow this trend.

During the period 1935-1962, the large-magnitude tectonic earthquakes of the New Guinea-Solomons region display a periodicity similar to the overall volcanic periodicity, with a one- to two-year phase difference, the earthquake maxima occurring earlier than the volcanic pulses but, for the smaller tectonic units mentioned previously, comparison of graphs of five-year running means of numbers of earthquakes per annum with those for volcanic eruptions does not give such a good correlation. When $M \geq 6$ earthquakes, with epicentres within 25 km. of an active volcano, are considered for the period 1904-1962, all correlation in time between the earthquakes and volcanic eruptions vanishes.

Thus, it appears that in the New Guinea-Solomons region, large magnitude tectonic earthquakes are usually neither a direct cause nor a result of volcanic eruptions, but that both seismic and volcanic periodicity may be caused by the same process, possibly variations in the rate of movement in elements of the Melanesian Shear Zone.

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1. INTRODUCTION

The circum-Pacific volcanic belt, including the Indonesian arc, contains 88 per cent of the world's active volcanoes, situated along the Andesite Line.

The first aim of the present study is to investigate pulses of volcanic activity in the individual volcanic areas of the Pacific margin to determine whether or not there is an overall pattern in volcanic periodicity.

Indonesia is included because it also lies along the Andesite Line, but the Scotia Arc and Antarctica are excluded because of lack of continuous volcanic observations; New Zealand is excluded because complete data are not readily available (there being no Catalogue of Active Volcanoes). Two volcanoes, Vétéran and Ile des Cendres, off the south-east coast of Vietnam are also excluded because they do not form part of the regional trend of western Pacific arcs.

The study is limited to eruptions in this century because of lack of complete data for some regions before 1900. The Catalogue of Active Volcanoes of the World provided the chief source of data.

Very little work has been done on volcanic periodicity on a global scale. Eggers and Decker (1969) found that "the apparent frequency of eruptions increases with time to the present" probably due to "better observation and recording of more recent events." Machado (1967) noted that there has been "a remarkable sequence of volcanic eruptions...in the Atlantic during the last twenty years" and concluded that "the long period components of the earth tide seem to influence the eruptive epochs, acting as trigger-forces."

The second aim is to study one circum-Pacific area, the New Guinea-Solomons region, in more detail and to try to relate its volcanic periodicity to the local tectonics and seismic activity. This region is suitable for this kind of study because it contains five to ten per cent of the world's earthquakes, some of which have foci deeper than 500 km. (Brooks, 1965), as well as thirty-five active or solfataric volcanoes, fifteen of which have erupted during this century. Fairly reliable eruption data are available since 1900, and earthquake data since the 1930s.

No previous graphical treatment of periodicity has been attempted for the New Guinea-Solomons region, but G.A.M. Taylor is interested in the volcanic and seismic pulses of the area and has noted that "data on tectonic earthquakes...in the New Guinea region reveal a pattern with marked fluctuation in frequency, as if the region were subjected to a periodic crustal stress pulse which produced a 'seismic fever.' Reactivation of volcanic centres often followed such pulses" (Taylor, 1958).

2. C I R C U M - P A C I F I C   V O L C A N I C   P E R I O D I C I T Y

2.1 METHOD OF ANALYSIS OF DATA

Initially, for each volcanic area, the volcanoes and their eruption dates were noted in tabular form. Except for the Aleutians, for which data were extracted from Coats (1950), all data came from the Catalogue of Active Volcanoes of the World. The New Guinea-Solomons data were augmented by later information from the Rabaul observatory.

The number of volcanoes in eruption each year was then totalled and entered in a table. Reports of solfataric and fumarolic activity were not included. Data are very reliable for some areas, such as Japan, but rather vague for others, such as the Aleutians and Colombia-Ecuador. For the Aleutians, reports of smoke or unspecified activity were omitted because Coats states that there are numerous inaccuracies in the records and a common error is that cloud is often confused with smoke.

Lastly, the data were depicted graphically as a series of plots of the number of volcanoes in eruption each year against years, one graph for each area.

2.2 RESULTS

These graphs are shown in figures 1, 2 and 3 and, in each figure, are arranged in order of increasing distance from the North Pole.

Comparison of the small-amplitude, short-period fluctuations is both difficult and dubious because they are so numerous.

However, this is not so for the larger amplitude, longer period pulses. In the following discussion, the only pulses considered are those which include the maximum and/or one less than the maximum number of volcanoes in eruption per annum in a given area.

Tables I, II and III show the years in which the greatest and one less than the greatest number of volcanoes erupt for the areas arranged in order of increasing approximate mean angular distance, X, from the North Pole. Pulses believed to correlate from area to area are arranged vertically below one another and designated by the letters A, B, C, D, H, L, M, N, V and W (see also figures 1, 2 and 3). In general, pulses occur later in more southerly areas. If only one year of a series for one area falls below one less than the maximum number of volcanoes in eruption, the series is still considered to be part of a single pulse. If, however, two or more years fall below the required level, then the series of dates is interpreted as part of two separate pulses. The central date of the pulse is taken to be the average of the first and last of the series, even if one of the middle years of the series falls below the required level of activity.

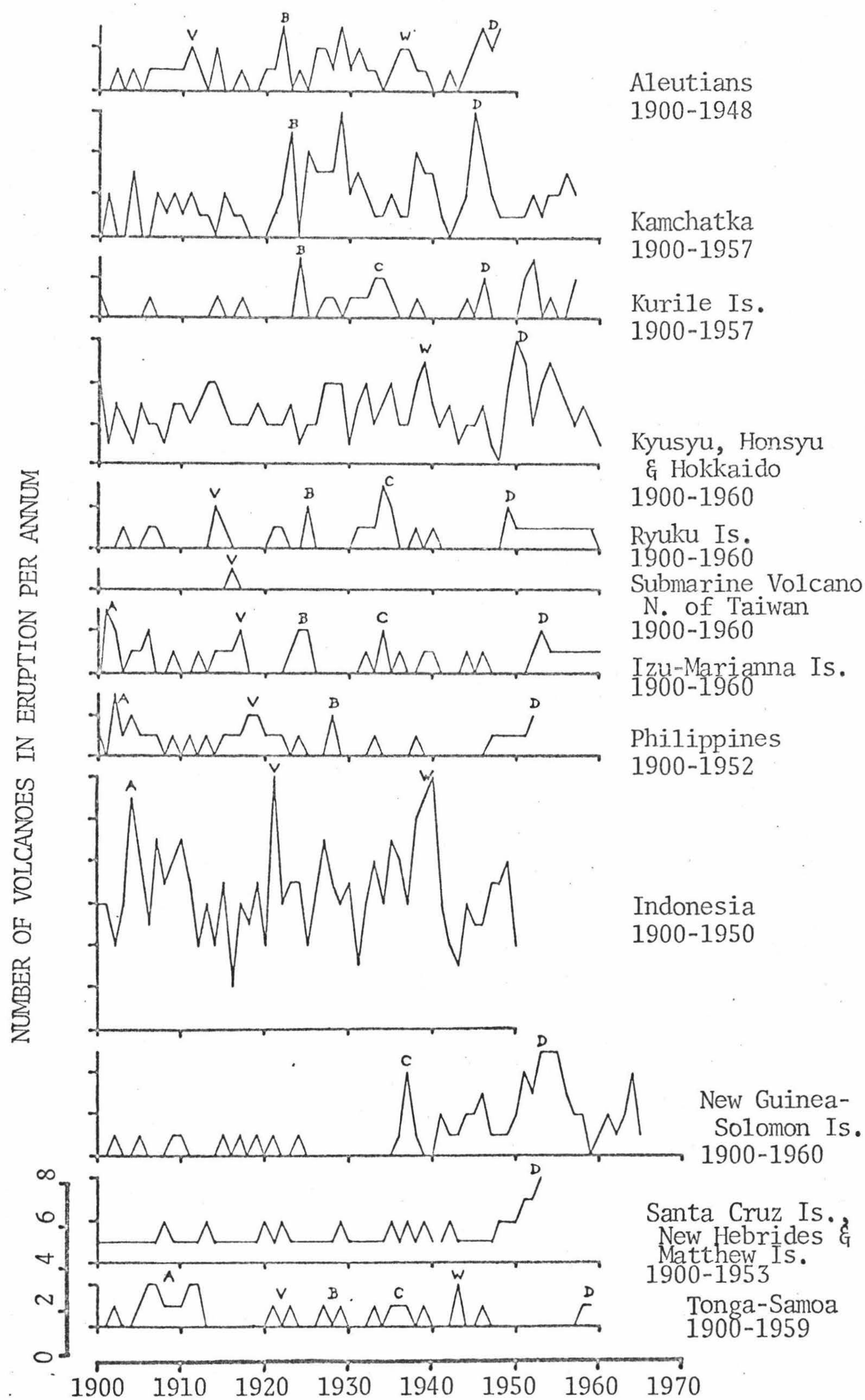


FIG. 1. NUMBER OF VOLCANOES IN ERUPTION EACH YEAR ON THE WESTERN PACIFIC MARGIN

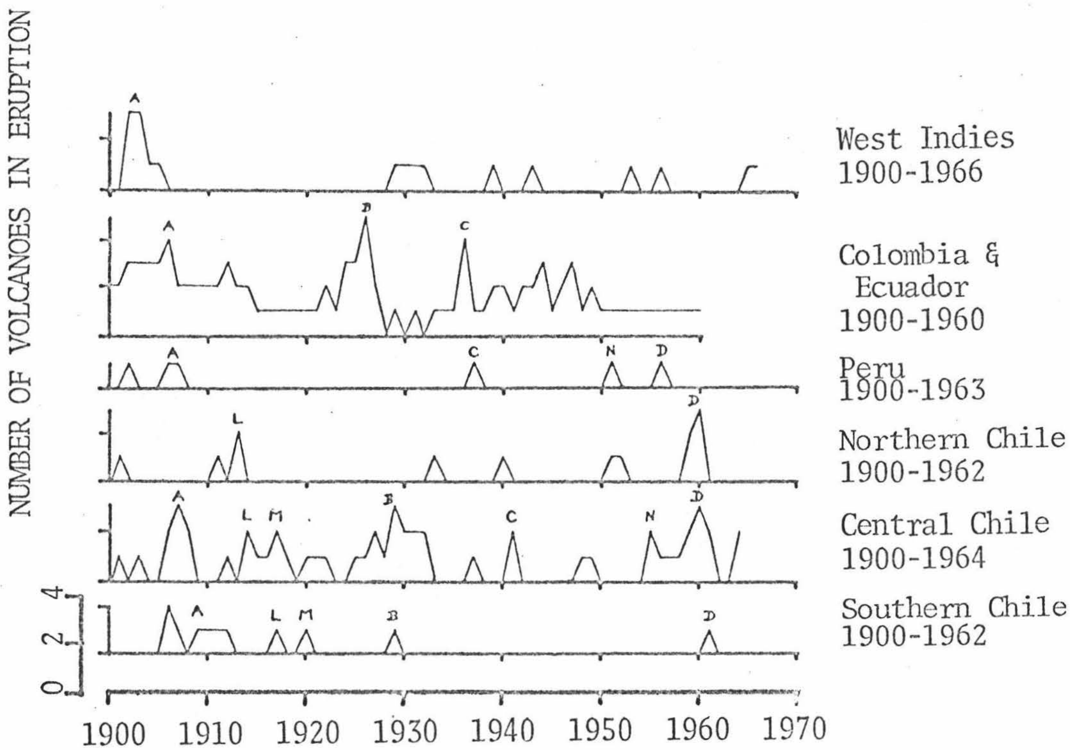


FIG. 2. NUMBER OF VOLCANOES IN ERUPTION EACH YEAR IN WEST INDIES AND SOUTH AMERICA

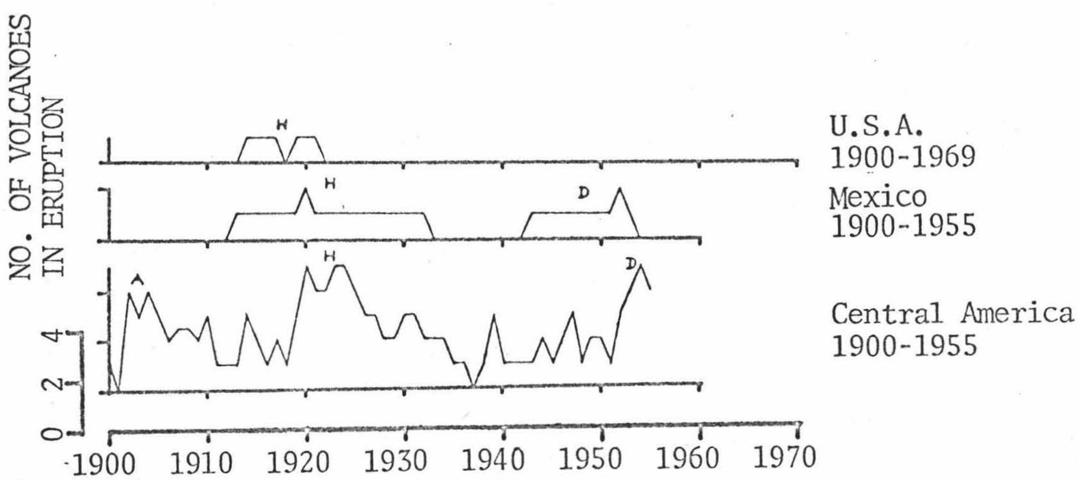


FIG. 3. NUMBER OF VOLCANOES IN ERUPTION IN NORTH AND CENTRAL AMERICA

TABLE I. VOLCANIC PERIODICITY IN THE WESTERN PACIFIC

	Approximate mean latitude	X	Dates of maximum and one less than maximum number of volcanoes in eruption											
				A		V		B		C	W		D	
Aleutians	55 1/2°N	34.5				1911	1914	1922	1926 1927 1929 1931		1936 1937		1945-1948	no data after 1948
Kamchatka	55°N	35						1923	1929				1945	
Kuriles	47°N	43						1924		1933 1934			1946	1951 1952 1957
Kyusyu, Honsyu, & Hokkaido	35°N	55									1939		1950 1951	1954
Ryuku Is.	27°N	63				1914		1925		1934 1935			1949	
Submarine volcano north of Taiwan	26°N	64				1916								
Izu-Marianna Is.	25°N	65		1901 1902	1906	1917		1924 1925		1934			1953	
Philippines	13°N	77		1902 1904		1918 1919		1928					1952	no data after 1952
Indonesia	5°S	95		1904		1921					1939 1940			
New Guinea-Solomons	5°S	95								1937			1951 1953-1955	1964
Santa Cruz Is., New Hebrides & Matthew Is.	17°S	107											1951-1953	no data after 1953
Tonga-Samoa	17 1/2°S	107.5	1902	1905-1912		1921 1923		1927 1929		1933 1935-1937 1939	1943	1946	1958 1959	no data after 1959

TABLE II. VOLCANIC PERIODICITY IN THE WEST INDIES AND SOUTH AMERICA

	Approximate mean latitude	X	Dates of maximum and one less than maximum number of volcanoes in eruption							
				A	L	M	B	C	N	D
West Indies	14°N	76		1902 1903						
Colombia & Ecuador	1 1/2°N	88.5		1906			1926	1936		
Peru	16 1/2°S	106.5	1902	1906 1907				1937	1951	1956
Northern Chile	22°S	112			1913					1959 1960
Central Chile	37°S	127		1906-1908	1914	1917	1927 1929-1932	1941	1955	1959-1961 1964
Southern Chile	47°S	137		1906 1907 1909-1912	1917	1920	1929			1961

TABLE III. VOLCANIC PERIODICITY IN NORTH AND CENTRAL AMERICA

	Approximate mean latitude	X	Dates of maximum and one less than maximum number of volcanoes in eruption		
			A	H	D
U.S.A.	40 1/2°N	49.5		1914-1917 1919-1921	
Mexico	19°N	71		1913-1932	1943-1953
Central America	13°N	77	1902 1904	1920-1925	1953-1955 (no data after 1955)

Using this interpretation, the circum-Pacific belt may be divided into three regions, each with its own pattern of pulses: the Western Pacific (including the Aleutians and Indonesia), North America (including Central America) and South America (including the West Indies). This has been done in constructing figures 1, 2 and 3, and tables I, II and III.

The central dates, Y, of these pulses are plotted against X in figure 4. Dates which represent a pulse present in one area only are omitted, as is one pulse which occurs only in the Aleutians and Kamchatka, because it consisted of two points so close together that a meaningful curve could not be fitted through them.

The points seem to fall approximately on to a series of straight lines with a positive slope. Pulses A, B, C and D contain points in both the Western Pacific and South America, and D may include North American points as well. North American pulse H may also include the Colombia- and Ecuador point of pulse B.

Unfortunately, none of the pulses contain enough points to do any meaningful statistical analysis, but a linear regression and correlation were performed on the values in pulses A, B, C and D, which had the most points. Note, though, that pulse D is not very well-defined, as some of the data do not extend far into the 1950s.

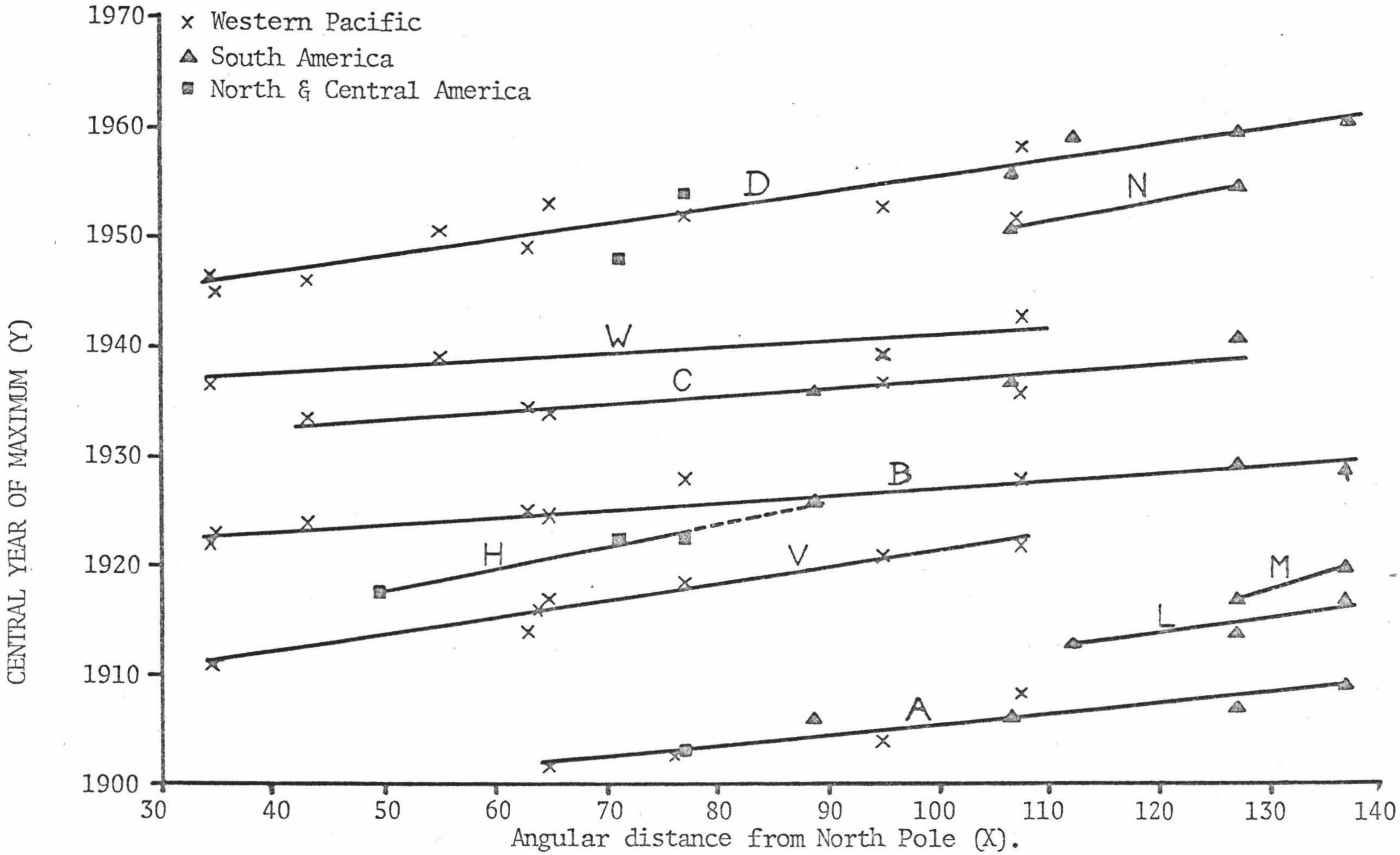


FIG. 4. RELATIONSHIP BETWEEN CENTRAL DATE OF THE LARGE VOLCANIC PULSES AND THE ANGULAR DISTANCES OF THE AREAS FROM THE NORTH POLE

The results are as follows:

for A, $Y = 1895.4 + 0.10\ X$, and $\gamma = 0.91$,

for B, $Y = 1920.8 + 0.07\ X$, and $\gamma = 0.94$,

for C, $Y = 1929.2 + 0.08\ X$, and $\gamma = 0.94$, and

for D, $Y = 1940.6 + 0.15\ X$, and $\gamma = 0.92$,

where γ is the correlation coefficient.

The correlation coefficients are all very high, indicating a strong degree of positive correlation between X and Y but, as mentioned above, the statistical population is really too small for this type of analysis. The slopes of the regression lines are all approximately 0.1, indicating approximately one year change in Y for a corresponding ten degree change in X.

2.3 CONCLUSIONS

On the basis of the pulses containing the maximum and/or one less than the maximum number of volcanoes in eruption in a given area, the circum-Pacific belt may be divided into the Western Pacific, North American, and South American regions, each with its own characteristic large pulses (V and W for the Western Pacific, H for North America, and L, M and N for South America). Central America and Colombia and Ecuador seem to be transitional between North and South America.

Pulses B and C occur in both the Western Pacific and South America, suggesting that they were initiated in the northern part of the Western Pacific, then continued into South America and the southern part of the Western Pacific. Pulses A and D contain points from all three regions and are thus the geographically most widespread.

All the pulse lines in figure 4 have a positive slope, generally of approximately 0.1. Linear regression and correlation strongly suggest a linear relationship between the central dates of the pulses and the mean angular distances of the areas from the North Pole, but the statistical population is too small for these results to be taken very seriously. However, it does appear that the pulses occur approximately one year later for every ten degrees southward shift in latitude, in both the northern and southern hemispheres and on both sides of the Pacific. This behavior, asymmetrical with respect to the Equator, may be, in some way, related to other hemihedral asymmetries of the earth discussed by Carey (1963), such as the northern hemisphere being smaller and having less continental dispersion and geomagnetic activity, but greater seismicity, than the southern hemisphere.

3. NEW GUINEA-SOLOMONS VOLCANIC AND SEISMIC PERIODICITY

3.1 VOLCANIC PERIODICITY FOR THE WHOLE REGION

Figure 5 shows more detail for the graph of the number (N) of volcanoes in eruption each year against year of eruption.

This graph has two salient features:

1. A spectacular increase in volcanic activity in the period after 1935 as compared with the preceding period.

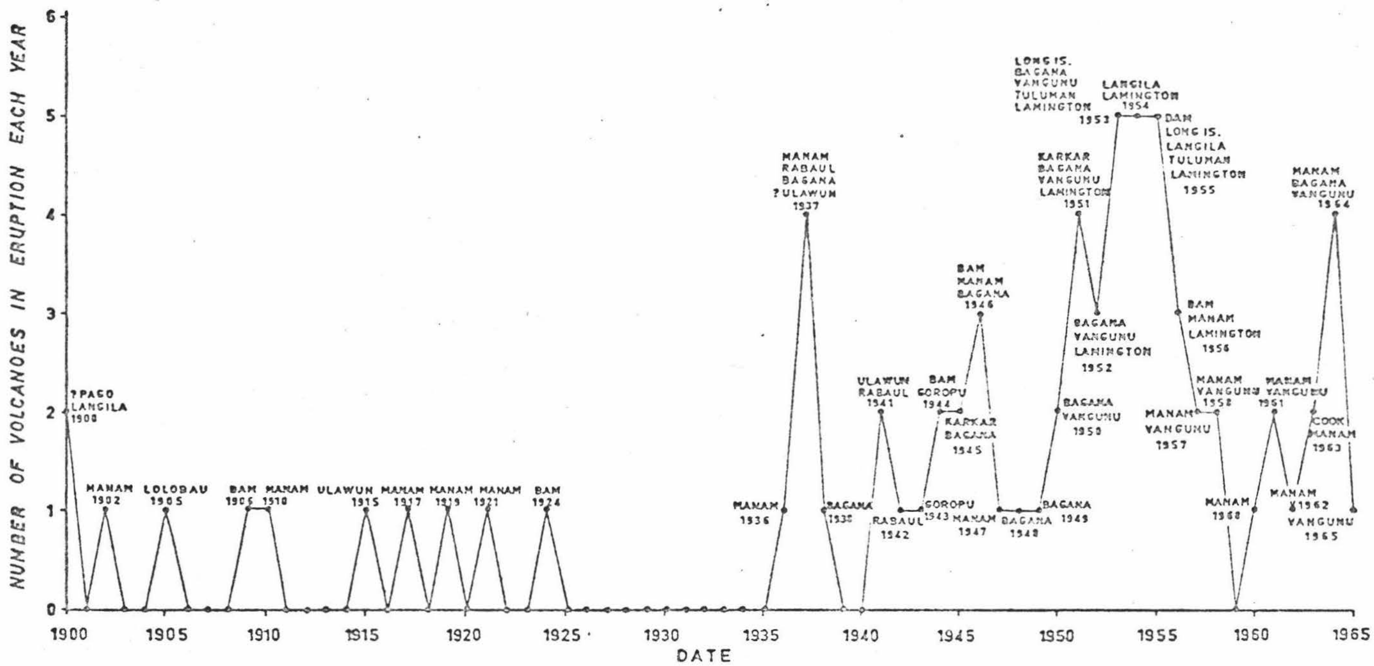
That this is the result of more consistent observation in later years, owing to the establishment of a permanent volcanological observatory at Rabaul after the 1937 eruption there, seems unlikely because, for most of this century, there have been reliable observers (such as patrol officers and mission stations) near most of the active volcanoes.

Thus this increase is probably real and may indicate a long-wavelength periodicity in volcanic activity.

2. A variable eruption frequency.

The question is whether these variations are significant or simply random fluctuations about a constant value, M, where M is the arithmetic mean of N.

To test this, a x^2 test was performed assuming an expected value $e = 1$ (because $M = 1.1$) for each of the years 1900-1965. Under this hypothesis, $x^2 = 126$ and hence it is 99.9% probable that, for this period, the graph does not represent random fluctuations about the line $N = 1$.



Abbreviations

Karkar: Submarine volcano N.N.E. of Karkar Is.

Vangunu: Submarine volcano S. of Vangunu Is.

Cook: Cook submarine volcano, New Georgia Group.

FIG. 5. VOLCANOES IN ERUPTION IN THE NEW GUINEA-SOLOMONS AREA DURING THE PERIOD 1900-1965

A x^2 test was performed also for the period 1935-1965 (because of the periodicity mentioned in 1) assuming that e = 1.7, the arithmetic mean of the number of volcanoes in eruption each year during the interval. The value $x^2 = 42.1$ was obtained, giving a 90% probability that the observed values of N are not random fluctuations about their mean.

Hence, these short pulses of volcanic activity, with quiet periods in between, may also have some tectonic significance.

3.2 RELATIONSHIP BETWEEN VOLCANIC PERIODICITY AND TECTONICS

The postulated long-wavelength periodicity in volcanic activity is a phenomenon affecting the whole of this active zone, and so is probably related to the condition of the upper mantle in the New Guinea-Solomons region. A local, fluctuating rate of extension in the mantle may provide an appropriate mechanism.

In order to interpret the short period fluctuations, the spatial relationship between volcanoes whose eruptions are closely related in time should be considered (see figures 5 and 6). The results are quite surprising.

For example, Long Island, Bagana, Tuluman, Langila and Bam erupted during the period 1953-1955, the dates being given in Table IV. The closeness of these dates is really striking, yet the volcanoes are all over 100 km. apart and cannot readily be fitted on to a single structural lineament.

However, Tuluman is situated at the northern edge, and Bam at the western end, of a belt of shallow seismic epicentres which tends east-west between latitudes 2°S and 4°S from New Ireland to the northeast coast of New Guinea. Langila and Long Island lie in a southeast-trending belt of epicentres between New Britain and New Guinea, and Bagana is situated in a parallel belt covering most of Bougainville and the trench to the southwest of it (Brooks, 1965).

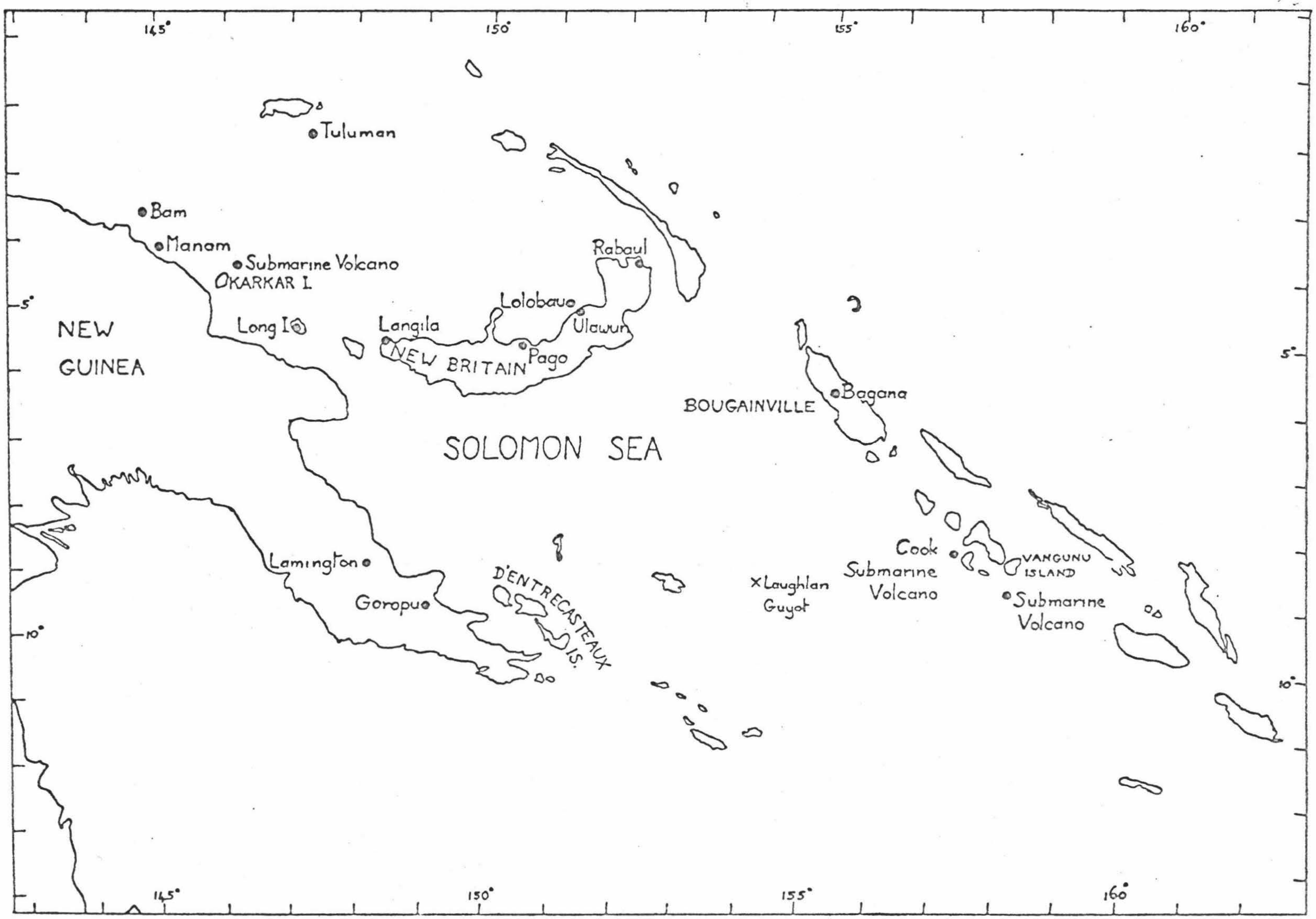


FIG. 6. VOLCANOES IN ERUPTION DURING THIS CENTURY IN THE NEW GUINEA-SOLOMONS REGION

TABLE IV. 1953-55 ERUPTIONS OF LONG ISLAND, BAGANA, TULUMAN, LANGILA AND BAM

Long Island	Bagana	Tuluman	Langila	Bam
8th May 1953				
	June 1953	27th June 1953		
		6th July 1953		
	10th July 1953 25th July 1953 August 1953			
		14th Nov. 1953		
7th Jan. 1954				
		18th Feb. 1954 9th April -- 13th April 1954		
			18th May -- 31st May 1954 4th June -- 5th June 1954 2nd July 1954 14th July 1954	
		10th July -- 27th July 1954		
				3rd Aug. 1954
			6th Aug. 1954 24th Aug. -- 12th Sept. 1954 1st Oct. 1954	
				6th Oct. 1954
		20th Oct. 1954		
			30th Oct. 1954	
		6th Nov. 1954		
			13th Nov. 1954	Nov. 1954
		10th Feb. 1955		
		15th Feb. 1955	15th Feb. 1955 17th Feb. 1955	
			1st June 1955	
				3rd June 1955
5th June 1955		5th June 1955		
			6th June 1955	
				7th June 1955
13th June 1955				
			16th June 1955	
		26th June 1955 21st July -- 2nd Aug. 1955 20th Sept. 1955 26th - 28th Sept. 1955 3rd - 7th Oct. 1955 15th Oct. 1955 16th Oct. 1955 23rd Oct. 1955 7th Nov. 1955		
				14th Nov. 1955
		25th Nov. 1955		26th Nov. 1955 2nd Dec. -- 8th Dec. 1955 31st Dec. 1955 1st Jan. 1956 2nd Jan. 1956

These belts are probably all tectonic lineaments which form part of the great, sinistral Melanesian Shear Zone of Carey (1958). In his figures he shows how this overall sinistral couple has produced these subsidiary structures. Hence, the 1953-1955 eruptions of Long Island, Bagana, Tulman, Langila and Bam were probably caused by increased movement in this shear zone.

The 1950-1951 eruptions of the submarine volcano south of Vanganu and Mt. Lamington provide a simpler illustration of this. The submarine volcano is reported to have erupted in late 1950. Lamington erupted on 15th January, 1951, then the submarine volcano erupted again on 22nd December, 1951. These volcanoes are approximately 1000 km. apart, and between them lies Laughlan Guyot, hundreds of kilometres from any other volcano.

Oceanographic work by Krause (1962) shows that the Guyot lies to the north of an eastsoutheast-trending sinistral fault, on the northern margin of the active Papua-Solomons Shear Zone which "occupies the whole zone of the D'Entrecasteau Islands and the Louisade Archipelago. The whole chain of the Solomon Islands is offset in that sense." Thus the Vanganu submarine volcano lies in this zone, and it seems possible that Lamington is at the western end. Taylor (1958) remarks that "1939 earthquakes seemed to indicate the beginning of protracted tectonic movement less than 80 miles southeast of Lamington and in a south-easterly-trending structure. The effects of this movement may well have had northwesterly extensions which distributed the Lamington system." Hence, the closeness in time of eruption of these two widely separated volcanoes may be due to movement along the Papua-Solomons Shear Zone, which is clearly part of Carey's Melanesian Shear Zone.

It is possible, therefore, that these short pulses of volcanic activity with intervening quiet periods are caused by variations in rate of movement in elements of the Melanesian Shear Zone.

3.3 LATITUDE VARIATION IN VOLCANIC PULSES FOR SMALLER TECTONIC UNITS WITHIN THE REGION

Figure 7 shows plots of the number of volcanoes in eruption each year against years for smaller tectonic units within the New Guinea-Solomons region.

The Bismarck Sea area includes the volcanoes Bam, Manam and Tuluman, East New Britain includes Ulawun and Rabaul, Bougainville includes Bagana, and the Papua-Solomons Shear Zone includes Goropu, Lamington and the submarine volcano south of Vangunu Island.

The post-1935 volcanic pulses have an overall tendency to occur later, the further south the mean latitude of the area, but this trend is most convincing for the first pulse after the 1925-1935 period of no volcanic activity (which can be seen on figure 5). However, the variation with latitude is much greater here than for the circum-Pacific belt as a whole, even if the 1943-44 pulse in the Papua-Solomons Shear Zone is omitted.

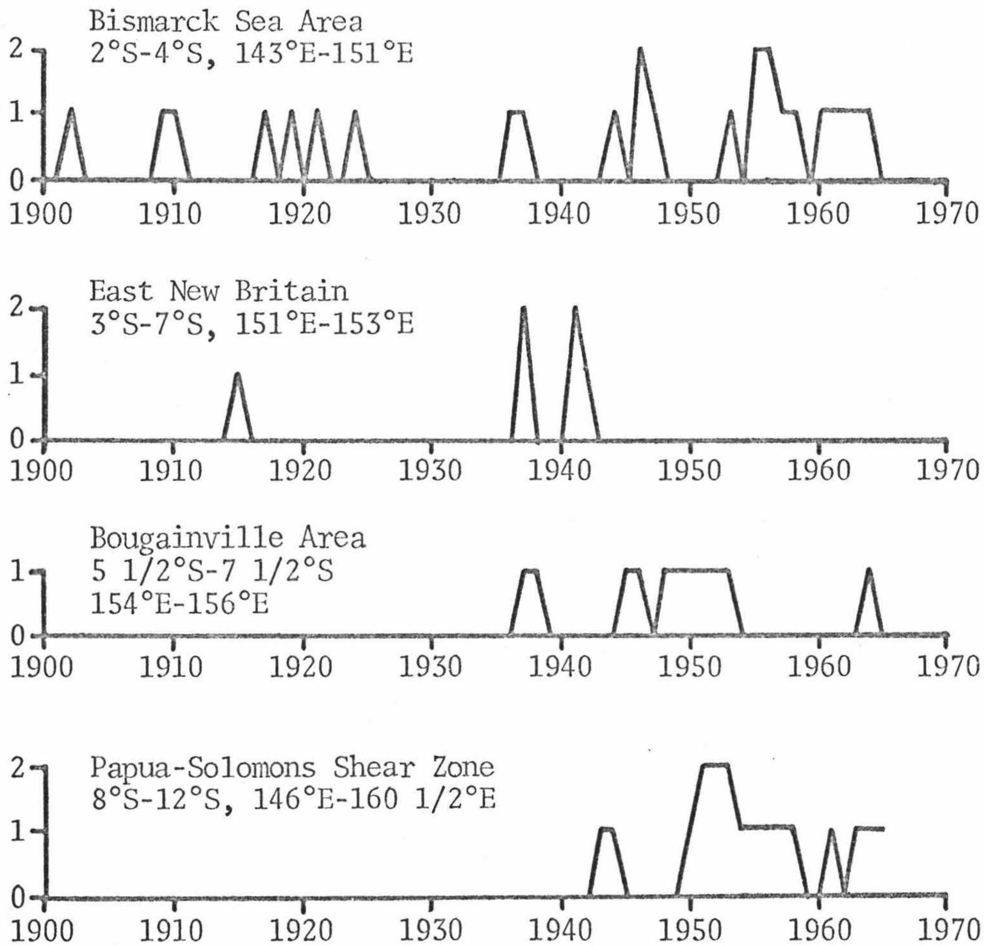


FIG. 7. VOLCANIC PULSES IN SMALLER TECTONIC UNITS OF THE NEW GUINEA-SOLOMONS AREA

3.4 RELATIONSHIP BETWEEN LARGE-MAGNITUDE TECTONIC EARTHQUAKES AND VOLCANIC ERUPTIONS, 1904-1962

Figure 8 compares the graph for the number of volcanoes in eruption each year against years with the corresponding graphs for $M \geq 6$ shallow, intermediate and deep tectonic earthquakes in East New Guinea and the Solomon Islands (rectangle 0°S - 12°S, 140°E - 160°E) for the period 1904-1962.

For the shallow earthquakes, there is a good correlation between post-1930 earthquake and volcanic pulses with a one- to two-year phase difference, the earthquake maxima occurring earlier. Pulses A, C and B on the earthquake graph appear to correspond to pulses α, γ and β in volcanic activity. Note that maximum earthquake activity takes place during 1931-1935, a period of minimum volcanic activity.

For the intermediate earthquakes, pulses A', C' and B' correlate almost exactly with pulses α, γ and β with no phase shift except that B' consists of two smaller pulses in contrast to B which is a single broad pulse.

With the deep earthquakes, no correlation is particularly convincing because the number of deep foci is very small. They may occur a year after volcanic pulses.

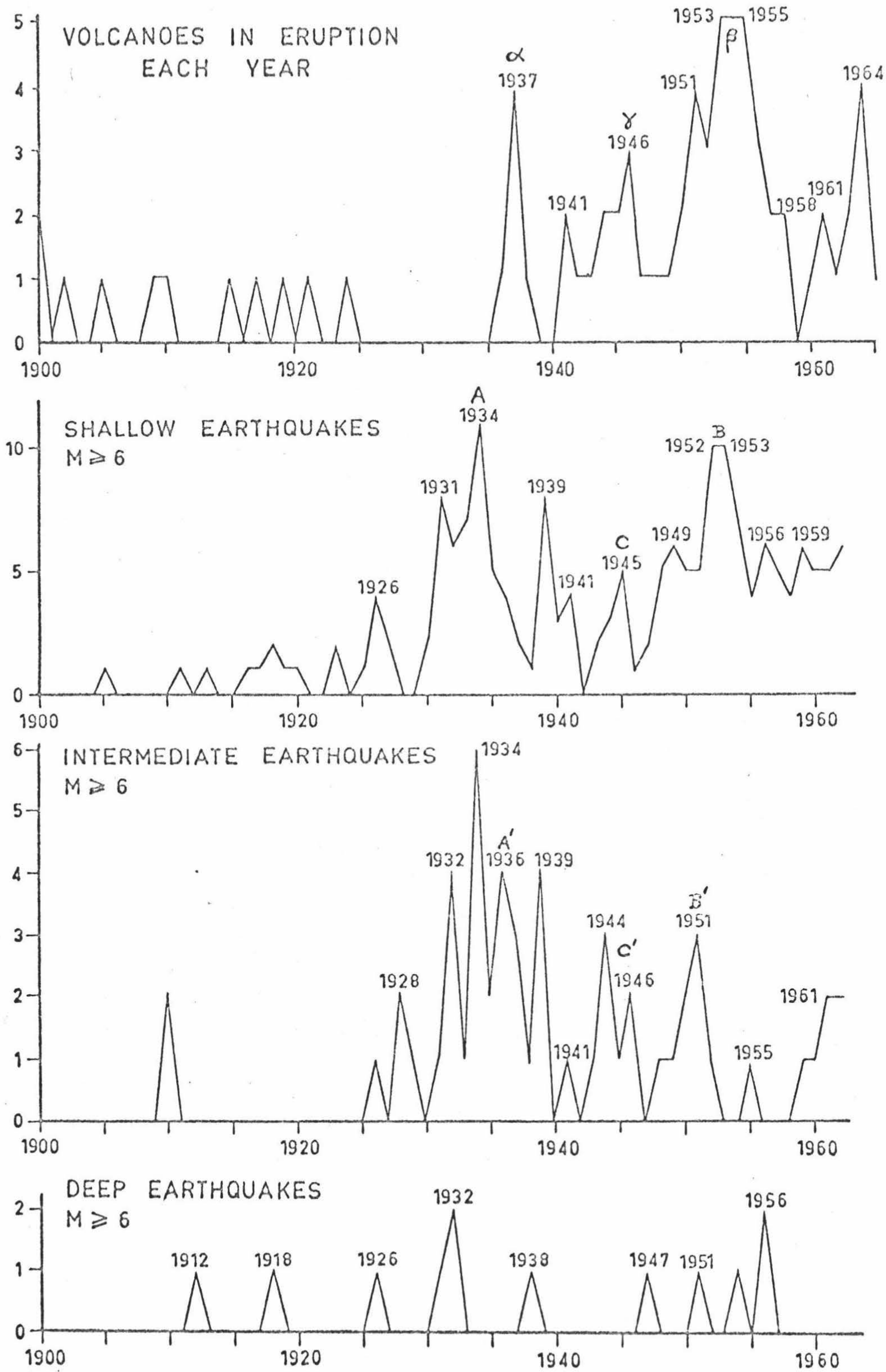


FIG. 8. VOLCANIC AND SHALLOW, INTERMEDIATE AND DEEP EARTHQUAKE PERIODICITY IN EAST NEW GUINEA AND SOLOMON ISLANDS (rectangle 0°S-12°S, 140°E-160 1/2°E)

These observations seem to contradict the findings of Grover (1967) in the Solomons area, and Blot and Priam (1963) in the New Hebrides, that deep and intermediate foci initiate subsequent shallow shocks or volcanic eruptions, the time interval between deep and shallow events depending on the depth of the initial earthquake and the distance of the epicentre from the volcano. However, my findings above are for the whole New Guinea-Solomons region, rather than for a specific small area near a volcano. Also, Grover's work is for the period 1963-1966, when epicentre determination had improved in accuracy because of the establishment of the U.S.C. & G.S. standard seismic net.

Figure 9 shows graphs of five-year running means of volcanic and seismic activity for the smaller tectonic units mentioned previously, in the New Guinea-Solomons area, their coordinates being marked on figure 7.

The Bismarck Sea area contains the east-west-trending earthquake belt between New Ireland and the northeast coast of New Guinea.

In region 1, pulses A, C and B correspond to pulses α, γ and β respectively, yet there is not a consistent phase relationship between the earthquake and volcano graphs.

In region 2, pulses α and γ have merged and correlate well with C, but $\alpha + \gamma$ starts ahead of C.

In region 3 also, the volcanic pulses start before the earthquake pulses, although α now seems to correlate with C rather than A.

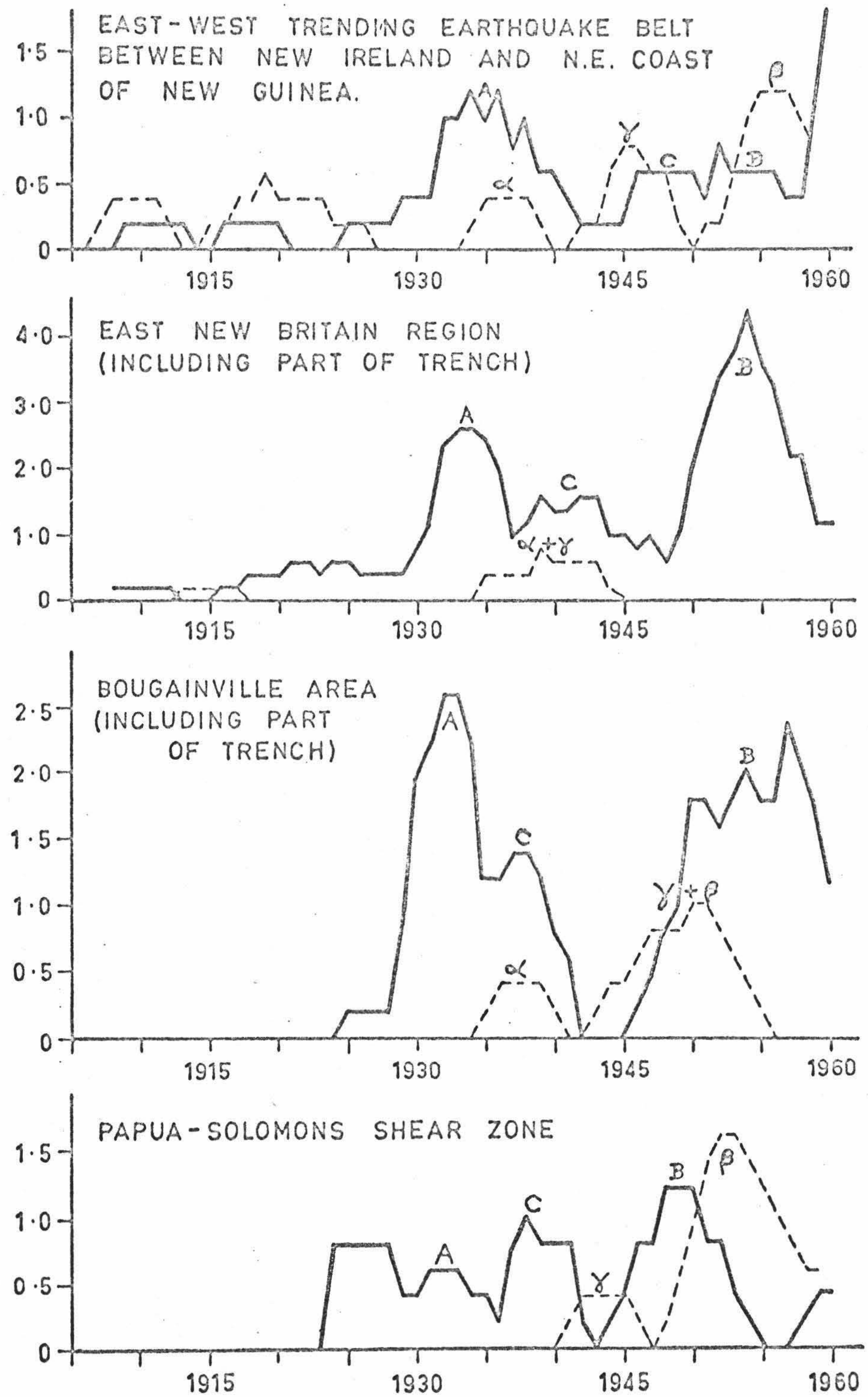


FIG. 9. FIVE-YEAR RUNNING MEAN OF NUMBER OF EARTHQUAKES PER ANNUM (SOLID LINES) AND OF VOLCANOES IN ERUPTION PER ANNUM (BROKEN LINES)

In region 4, there is a systematic relationship. C and B correspond to γ and β respectively, the earthquake pulses occurring ahead of volcanic pulses with a phase difference of about 4 years. However, note that all the foci except one are shallow (figure 5).

Thus it appears that, in these smaller tectonic units, there is no longer such a definite relationship between tectonic earthquakes and volcanic eruptions, although a general correlation is still observable.

However, these graphs do show an interesting phase shift in earthquake activity with latitude. The pulses occur first in region 4 and successively later in the more northerly regions. In contrast, as mentioned previously, the first pulse in volcanic activity after the 1925-1935 quiet period occurs earliest in region 1 and successively later in regions 2, 3 and 4.

When $M \geq 6$ epicentres occurring within 25 km. of an active volcano (I will call these "associated earthquakes") are considered for the period 1904-1962, all correlation in time between the earthquakes and volcanic eruptions vanishes. Bam, Manam, Goropu and Tuluman have no associated earthquakes. Of the other volcanoes which have erupted this century, only Bagana and Rabaul have associated earthquakes occurring within ten years of an eruption. Both had intermediate depth foci. The Bagana earthquake occurred 2 years after the 1953 eruption, and the Rabaul earthquake took place 3 years after the 1941-1942 eruption. Long Island is also associated with intermediate depth foci, but the other volcanoes have only shallow-focus associated earthquakes. No volcano, active this century, has more than two associated earthquakes. The rarity and shallowness of large-magnitude associated earthquakes under truly active volcanoes may be due to raised isotherms, necessitating a faster rate of strain for fracture to take place instead of flow (S. W. Carey, personal communication).

All the above observations suggest that $M \geq 6$ tectonic earthquakes are usually neither a direct cause nor a result of volcanic eruptions. However, the correlation between the two is sufficiently good, particularly when the whole New Guinea-Solomons area is considered, to suggest that the earthquake pulses may also be caused by variations in rate of movement in elements of the Melanesian Shear Zone.

4. CONCLUSIONS

For volcanic areas of the circum-Pacific belt, graphs of the number of volcanoes in eruption each year against years, from 1900 onwards, indicate a periodicity in volcanic activity. On the basis of the pulses containing the maximum and/or one less than the maximum number of volcanoes in eruption, the Pacific margin may be divided into the Western Pacific, North American and South American regions, each with its own characteristic pulses, but some pulses take place in more than one region.

The pulses tend to occur approximately one year later for every ten degrees southward shift in latitude, in both the northern and southern hemispheres and on both sides of the Pacific.

The graph for the New Guinea-Solomons region shows a spectacular increase in volcanic activity since 1935 (possibly a long-wavelength periodicity), as well as short pulses of volcanic activity with intervening quiet periods. The former may be caused by a local, fluctuating rate of extension in the mantle, whilst the latter may be due to variations in rate of movement in elements of the Melanesian Shear Zone. Smaller tectonic units within the region tend to show a latitude variation in volcanic activity somewhat similar to that of the circum-Pacific belt as a whole.

Tectonic earthquakes, with $M \geq 6$, in the New Guinea-Solomons region display a periodicity very similar to the volcanic periodicity, but earthquakes occurring in a given year tend not to be closely related geographically to erupting volcanoes. Thus, it appears that although $M \geq 6$ tectonic earthquakes are usually neither a direct cause nor a result of volcanic eruptions, the seismic periodicity may also be caused by variations in rate of movement in elements of the Melanesian Shear Zone.

5. REFERENCES

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