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PERMIAN VOLCANISM AND ITS RELATION TO THE TECTONIC DEVELOPMENT OF SUMATRA

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ABSTRACT

The Permian volcanic deposits covering an extensive area southeast of Lake Singkarak, Central Sumatra, have been mapped in detail and studied in relation to the structural development of the pre-Tertiary Sumatra orogene. During the Permian time, Central Sumatra was occupied by an elongated sea basin in which thick sequences of bathyal and neritic sediments were deposited. Pelitic sediments dominated, but at the same time volcanic activity started in this area. The volcanic products comprise mainly flows of hornblende and augite andesites whit their tuffs. In some parts of southern Sumatra the volcanic activity lasted till Cretaceous time. The main phase of folding took place about 120 m.y. ago accompanied by an emplacement of granitic rocks. After an uplift in younger Cretaceous time, the area was strongly attacked by erosion. The regional geologic history of Sumatra revealed clearly a divergent behaviour from the classical concept of magmatic evolution in an orogenic belt as demonstrated by the dominantly andesitic character of the geosynlinal volcanism Other examples of volcanism associated with geosynclinal subsidence, possessing an andesitic rather than a basaltic character, could also be observed in the Tertiary Sunda mountain system of Sumatra. The Indonesian examples and similar occurrences of andesitic volcanism during a geo-sysnclinal subsidence in other parts of the world, show that much work still will have to be done in order to gain a better understanding regarding the relationship between volcanism and orogenesis.

CONTENTS

Introduction. 4
Occurrence and petrography of Permian volcanic rocks in Central Sumatra. 4
Occurrence of Permian and Cretaceous volcanic rocks in other parts of Sumatra. 8
Regional volcanic and structural history. 9
Relation of Permian volcanism to the structural development of Sumatra. 10
Acknowledgements 12
References. 12

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INTRODUCTION

Detailed fieldwork carried out by the author in the area SE of Lake Singkarak, Central Sumatra, revealed the occurrence of an important and extensive Permian volcanic-sedimentary sequence of strata known as the Silungkang formation. This formation is divided by the author into a calcareous member and a volcanic member.

The calcareous member which forms the upper part of the formation consists chiefly of limestones with Permian fossils while the underlying volcanic member comprises flows of hornblende and augite andesites, tuffs with thin intercalations of limestones and shales containing also Permian fossils.

It is the purpose of this paper to give a brief description regarding the mode of occurrence of the Permian volcanics in Central Sumatra, and to carry out a comparative study with deposits of similar age and character in other parts of the island. The occurrence in Central, South, and North Sumatra will be discussed briefly in order to come to a certain conclusion concerning the character of Permian volcanism, the history of volcanic activity during the Late Paleozoic time in this island and the relation of volcanism to the pre-Tertiary tectonic development of Sumatra.

OCCURRENCE AND PETROGRAPHY OF PERMIAN VOLCANIC ROCKS IN CENTRAL SUMATRA.

The Permian volcanic deposit SE of Lake Singkarak, Central Sumatra occupies the northern border of the Lassi granite mass (fig. 1). The Lassi mass is a complex rock assemblage of Permian volcanics and sediments and Triassic deposits intruded by plutons of Middle Cretsceous age (Katili 1960). These volcanic rocks which formerly have been referred to as diabase (Verbeek 1883) consist of flows of hornblende and augite andesites and their tuffs with thin intercalation of limestones and silicified shales, meta-andesites, metadacites, and basic hornfels.

Andesites and their tuffs were studied by the author in the vicinity of Silungkang, Padang Highlands. In general these rocks are hard, silicified and possess a green-grey and black colour. Sometimes they are strongly chloritized, brittle, and macroscopically show a distinct volcanic character. The hardened tuffs possess a porphyritic texture and are easily recognized. Higher in the profile this porphyritic character increases, the colour becomes more greyish and pale while the plagioclases are clearly recognizable.

In these volcanic tuffs alteration of thin-bedded limestone shales are present. Fusulines found in tuffs indicate – as will be discussed later – an Upper Permian age. Deeper into the profile the character of the volcanic rocks changes strongly and becomes more compact and also the colour becomes darker. These andesites are dark grey to black in colour with an aphanitic and sometimes phaneritic groundmass, containing phenocrysts of prismatic green hornblende which reach a length of about 0,4 cm.

Feldspar occurs as round spots in these rocks. In certain hand-specimens the hornblende phenocrysts are more rare, while laths of plagioclase reaching a length of 0,5 cm. occur more frequently. These plagioclase-bearing rocks are mostly yellow-green and greenish in colour. In several rocks, however, no phenocrysts of hornblende or plagioclase are visible.

Microscopically, the following minerals are recognized : amphiboles and plagioclases as the main components, also epidote, chlorite, biotite, quartz, apatite, sphene, calcite and oxidic ore. The texture is porphyric. The phenocrysts consist mostly of plagioclase and hornblende, while the groundmass is in general microcrystalline; in several cases, however, vitrophyric. Amphibole occurs in eu-and subhedral crystals. The slightly altered minerals display a pleochroism of dark-green (n γ), to green (n β) and yellow-green (n γ). The hornblende phenocrysts have been transformed into fibrous actinolitic hornblende which possesses sometimes a radial pattern. Hornblende crystals are also present in the groundmass, mostly in fibrolammelar aggregates.

Alteration of hornblende into fine fibrous chorite and granular epidote masses with a cloudy appearance, is a general phenomenon. Biotite can also be considered as the alteration product of hornblende, and occurs as irregular brownish flakes. The plagioclases occur in sub-and anhedral shapes. Twinning in the strongly altered rocks is no longer visible. In fresh rocks twinning occurs according to the Karlsbad, albite and pericline law, and a distinct zonal structure is also recognizable. The An-content varies between 30% and 48%. Alterations occur mostly in the form of sericitisation and sausuritisation and in several thin-slides in the form of calcificaton and enpidotization. In many cases epidote occurs pseudomorphous after plagioclase. Quartz occurs as inclusions and sometimes as a substituting mineral. Apatite occurs sporadically in granular and elongated shapes. Sphene is also present in small granular masses, sometimes together with hornblende. The above described rocks are hornblende-andesites.

Besides hornblende-andesites, augite-andesites are also present. Together with hornblende-andesites they occur in elongated small bodies and are sometimes very hard to distinguish from the andesites in the field, especially when they have been metamorphosed.

Microscopically the following features can be recognized :

The augites have been altered completely or partly into fibrous uralitic hornblende; however, most still retain their original shape.

Alterations into calcite and chlorite have also been observed. The augites are colourless, with little or no pleochroism. The $n\gamma/c$ varies between 36° and 44°. Sphene occurs as inclusions. Amphibole phenocrysts and smaller individuals which occur in the groundmass show alteration into epidote and chlorite. They are, however, smaller in number than the augite. Plagioclases which mostly occur as phenocrysts occupied the groundmass.

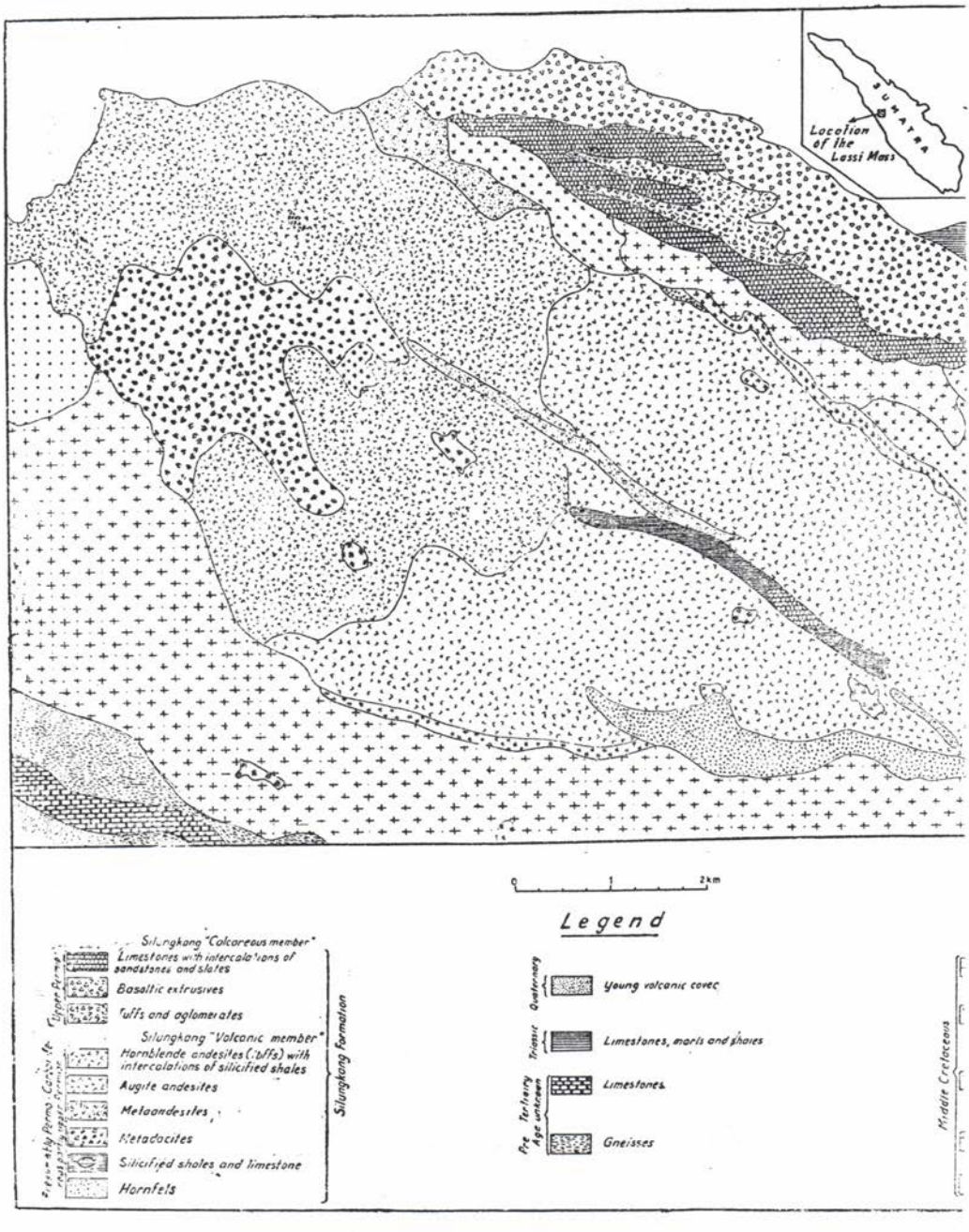
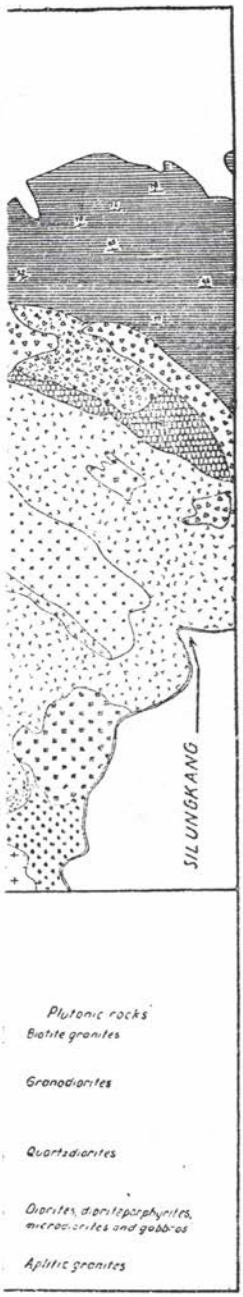


Fig. 1. Geological map of part of the Lassi mass.



The above described augite and hornblende-andesites show a begining propilitization process in general. With the augite andesites one can see that the original augite crystals have been completely or partly altered into fibrous pale-green hornblende. The plagioclase also shows alterations into sericite, epidote, and calcite, while albitization has also been observed. Veining by quartz and carbonate occurs in several cases. The original phenocrysts of hornblende are now represented by biotite together with chlorite and epidote.

Well-exposed areas of metaandesites, metadacites, basic hornfels can be found in the surounding of Panindjauan. In general the metaandesites are of a yellow-green and dark greenish colour with small spots of epidote. Pyrite is visible with the naked eye. The surface of the rock is irregular and bumpy due to silicification. Rocks with a distinct porphyritic texture are present with hornblende and plagioclase as phenocrysts.

Metadacites can also be found together with the metaandesites. The colour is also green. Numerous quartz phenocrysts are present and the average diameter of the crystals is approximately 0,5 cm. The andesites and dacites in the investigated area have endured a weak thermal metamorphism. The hydrothermal processes resulted in sericitisation, calcification and impregnation of pyrite.

The age of these metavolcanics can also be determined by the fossils found in the sedimentary intercalations. Silicified shales occur between the metavolcanics. Fusulines are present, so that it is quite certain that the metavolcanics in the investigated area is Permian in age.

Basic hornfels have also been found in these areas together with the andesites. Since these rocks are very hard, they are mostly resistant to erosion and are restricted to the highest peaks in the investigated area. They possess a dark colour with a conchoidal fracture, and in several rocks a weak orientation of the hornblende needles has been observed. Sometimes the rocks have a green-grey colour in which blasto-phenocrysts of hornblende can be observed.

Microscopic studies show that the rocks could be classified as biotite hornblende plagioclase hornfels and diopside hornblende plagioclase hornfels. Remnants of igneous texture indicate an igneous origin of the rock, which can also be seen in the blastoporphyritic texture of the augites. In many rocks the groundmass has been recrystallized completely leaving a mozaic of quartz, feldspar, and biotite. It can be observed in these rocks how the igneous texture disappear slowly; the blasto-phenocrysts have been completely altered into a fine-grained mass. Large aggregates of biotite, pseudomorphous after hornblende, represent the remnants of these ferro-magnesian minerals.

The meta-andesites, meta-decites, basic bornfels are the result of thermal metamorphism, caused by the intrusion of the granites into these Permian volcanic rocks. The granites known as the Lassi granites possess an age of 112 $\pm$ 24 million years, which places the formation of these granites in Middle Cretaceous (Katili 1962).

The volcanic rocks described above, which possess a thickness of about 1000 m, is called Silungkang volcanic member to distinguish of this formation. The Silungkang calcareous member consists chiefly of massive to thin-bedded fossiliferous limestones with interbedded shales, sandstones, basaltic flows and tuffs. The thickness of this member is estimated at 500 meters. Fossils determined in these rocks are *Doliolina lepida* **SCHWAGER,** *Pseudofusulina padangensis, Neoschwagerina multiseptata* **DEPRAT,** *Fusulinella lantenoisi* **DEPRAT.** According to Marks (personal communication) these fossils point to a Permian age of these rocks. Fossils found in the limestones and shales which occur in the already mentioned volcanic rocks are similar to the ones found in the calcareous member, so that it is with certainty that the age of volcanic rocks is Permian.

OCCURRENCE OF PERMIAN AND CRETACEOUS VOLCANIC ROCKS IN OTHER PARTS OF SUMATRA

Permian volcanic rocks in the Djambi area, Southern Sumatra, have been investigated by Tobler (1917) and Zwierzycki (1930). The main part of the Permian deposit consists mainly of volcanic products of dacitic, liparitic and andesitic composition which were deposited during periods of volcanic paroxysm or as denudation products along a descending coast. Lava flows are found in the upper part of the section. The volcanic layers are interbedded with limestones, shales and conglomerates and particularly the occurrence of foraminifera limestones in various places points to a marine environment of deposition. The fusulinides reach till the upper part of the section and are species characteristic for the Permian, so that the upper part of the series is certainly of Permian age.

Another important occurrence of pre-Tertiary volcanic rocks has been investigated by Musper (1937) in the Gumai mountains. The rocks occur in two different facies, the Saling series consisting of coarse volcanic breccias, lava flows and reef limestones and the Lingsing series comprising monotonous formation of thin-bedded silicious marly and clayey shales with radiolarian chert. Volcanic rocks also occur in the Lingsing series consisting of green andesitic and basaltic rocks. Musper (1937) could not determine whether the volcanic rocks occur as lava flows or as sills. Fauna found in these series point to a lower Cretaceous age. Van Bemmelen (1949) assumed that the Saling series represents a volcanic near-shore facies, while the Lingsing series are probably formed in a geosynclinal fore-deep. Whatever the condition of the deposition, we could conclude from the description given by the previous investigators that the volcanic rocks are predominantly andesitic in character.

A similar occurrence of volcanic-sedimentary deposit as described in the foregoing pages from Central Sumatra has also been observed in many parts of Northern Sumatra. The Permo-Carboniferous (?) deposit of Gk Gle Si Top is comparable to the Silungkang formation of the Padang Highlands. They comprise intermediate volcanic products intercalated with fusulines-bearing limestones. The occurrence of fusulina limestones intercalated with volcanic tuffs has been described by Zwierzycki (1919). Van Es (1917) correlated the so-called diabase formation of Northern Sumatra with the Permian volcanic deposit of the Padang Highland. Further detailed field and petrographic investigations in areas occupied by the so-called diabase and diabase tuffs in Sumatra will certainly reveal more clearly the distribution and character of the Permian volcanic deposit.

REGIONAL VOLCANIC AND STRUCTURAL HISTORY

Based on field observations in Central Sumatra and literature study concerning Permian volcanic deposits in other parts of Sumatra (Katili 1962, 1964) a synopsis concerning the volcanic and structural history of this island is as follows :

During the Permian time Central Sumatra was occupied by an elongated sea-basin in which a thick sequence of bathyal and neritic sediments was deposited. The longitudinal axis of the basin coincides more or less with the present Sumatra direction. Pelitic sediments dominated, but at the same time volcanic activity started in this area. At the beginning the volcanic activity produced mainly tuffs, but later on the intensity increased considerably, and lavas, mostly hornblende and augite andesites, were produced alternating with thin beds of limestones and shales. In some places these andesitic volcanoes formed protruding islands, while at other places they occur as submarine volcanoes or possibly as submarine volcanic ridges. The extrusion of andesitic lavas continued until the younger Permian. A greater depth in the basin, undisturbed sedimentation of pelitic material, continued.

With the beginning of the younger Permian the andesitic volcanic acitivity decreased considerably and the volcanoes produced only tuffs, while limestone reefs were formed around the volcanic islands and ridges. The deposition of the limestones was dominant but was occasionally interrupted by the deposition of volcanic products. The younger Permian closed in Central Sumatra with a period of renewed volcanic activity, though less intense, and producing material of a more basic composition. Again the volcanic activity started with the formation of tuffs followed by a production of basaltic lavas.

At the beginning of the Triassic time the volcanic activity became very weak; during the younger Triassic it came to a complete standstill. Sedimentation continued undisturbed into the Triassic, and sediments analogous to those of the younger Permian were deposited.

The volcanic activity in the Djambi area, South Sumatra, was similar to the development in Central and North Sumatra. In the Gumai mountains, however, the volcanic activity continued till lower Cretaceous time in which volcanic breccias, lava flows of andesitic composition were formed alternating with limestones.

It is quite probable that within the geosyncline in the Gumai area two major longitudinal divisions can be discerned: a eu-geosynclinal region characterized by the deposition of radiolarian chert and thinbedded siliceous marly and clayey shales with green andesitic and basaltic rocks (Lingsing series) and a miogeosyncline with coarse volcanic breccia, lava flows and reeflimestones (Saling series).

The main phase of folding in Sumatra took place about 120 m.y. ago when the complete sequence of pre-Tertiary pelitic rocks were thrown into isoclinal folds. The folding in Middle Cretaceous time was accompanied by an emplacement of granitic and granodioritic rocks now well exposed along the Barisan mountains of Sumatra. This emplacement has produced several contact phenomena. Close to the contact garnet-epidote-hornfels and marble were formed, while the volcanic rocks a little bit farther from the contact underwent only a weak thermal metamorphism, so that meta-andesites and meta-dacites were formed (Katili 1960). After an uplift in younger Cretaceous time the area was strongly attacked by erosion and a considerable thickness of sediments disappeared. Few Jurassic and Cretaceous deposits occur in Sumatra. It is quite probable that a part of the area has already risen above sea-level shortly after the deposition of Triassic rocks.

RELATION OF PERMIAN VOLCANISM TO THE STRUCTURAL DEVELOPMENT OF SUMATRA

It has already been pointed out by many authors that in orogenic regions three phases of magmatic evolutions could be distinguished, well known in the literature as Stille's "initiale vulkanismus", "synorogene plutonismus und subsequente vulkanismus,", and "finale vulkanismus".

The "initiale vulkanismus" is characterized by ophiolitic eruptions accompanied by mafic and ultra-mafic intrusions, the "synorogene plutonismus" and "subsequente vulkanismus" by the emplacement granitic rocks succeeded by a later stage of igneous injections accompanied by the eruptions of andesitic lavas and pyroclastic rocks and a "finale vulkanismus" or continental phase of basaltic eruptions.

Indonesia is the most suitable region for the study of mountain building processes with all the accompanying typical phenomena such as volcanism and plutonism. Stille's concept has been ably applied by Van Bemmelen (1949) in the Barisan range of Sumatra and in the Meratus range of SE Borneo.

Studying the history of volcanic activity during Permian time in Sumatra, however, we encounter some features which demonstrate a divergent behavior from the well-known classical magmatic evolution of an orogenic belt. The volcanic activity accompanying the geosynclinal subsidence in this area was not characterized by ophiolites, but by dominantly andesitic rocks. The Permian andesitic rocks could not be ascribed to the "subsequente vulkanismus" of the variscian cycle of orogeny, as traces of a variscian orogeny are completely missing in Sumatra (Klompé 1955, 1957). Neither could they belong to a postorogenic or continental phase of basaltic eruptions, as in this area no sediments older than Permo-Carboniferous have been encountered so far. Their occurrence with sedimentary deposits of Permian and Triassic age and their location within the folded mountain range, intruded by synorogenic granites (Katili 1962) makes it quite clear that the andesitic rocks belong to the geosynclinal volcanism. If this assumption is true then there must be other examples occurring somewhere else of similar features, from the same or different age.

A prodominance of intermediate and more acid rocks among the Cretaceous volcanic products in the southern part of the Cordillera Blanca, Peru, has also been reported by Egeler (1954). This author describes the interesting fact that the chemical composition of the pre-orogenic volcanics shows no conspicuous difference from that of the granodiorite and tonalite intrusions emplaced after the main phase of the Andean folding and consequently questions the validity of Stille's concept.

Extensive occurrence of andesitic geosynclinal volcanism has also been described by Dickenson (1962) from areas along the Pacific margin of North America. The andesitic rocks of Permian, Jurassic and Triassic age described here occur in a eu-geosyncline known as the Fraser belt. Dickenson (1962) is of the opinion that the geosynclinal andesitic magma from the Fraser belt were probably formed by contamination of primary basaltic magma with sialic crustal materials or by partial fusion of the lower part of the sialic crust.

Other examples of andesitic volcanism related to the formation of a geosyncline could also be studied in Sumatra in a younger mountain system, the so-called Sunda orogen. This belt developed into a longitudinal strip of zones of subsidence which were gradually filled up with a thick sequence of lavas, breccias, and agglomerates and by Miocene sediments. The volcanic rocks in this belt are known in the literature as "old andesites". The andesitic volcanoes formed a row of islands on the southwestern margin of the pre-Tertiary Sumatra orogene. In the middle of the Miocene time this mixed series was strongly folded and subsequently intruded by dikes and bosses if andesitic and dacitic rocks and by extensive dioritic and granitic plutons (Westerveld 1953).

It should be emphasized that the transgression of the Lower Miocene sea over the eroded structures of the pre-Tertiary Sumatra orogene of South Sumatra was preceded and accompanied by a period of volcanic activity comprising mainly andesitic rocks.

In conclusion we may say that the geosynclinal volcanism during the Permian and Oligo-Miocene time in Sumatra was dominantly andesitic rather than basaltic in character; hence, of a type expected in the classical Stille's concept, respectively only during or after the middle Cretaceous and intra-Miocene phase of diastrophism.

The features described above demonstrate clearly that a lot of field and petrographic work still will have to be carried out in order to get a better picture regarding the relationship that exists between volcanism and orogenesis.

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