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ON BORON CONTENT IN PRODUCTS OF EXPLOSIVE VOLCANISM

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ABSTRACT. — Pumice from Vesuvius, Vulcano, Lipari and Santorini, as well as finer pyroclastic products and lavas from the same areas have been investigated with the aim of detecting any peculiarity of boron distribution which could be correlated with the stages of volcanic activity.

At Vesuvius, relatively high mean boron content of 20 ppm for pumices of « Pompei » eruption (79 A.D.) can be correlated with a long repose time after the « Avellino » event (3500 y. B.P.); for « Pollena » eruption (472 A.D.) the shorter interval can explain the lower value of 8 ppm as well.

While the low values observed at Vulcano (2.9 ppm) can be also in accordance with the ages of the recorded activities, for Lipari and Santorini, on the contrary, long activity gaps occurred, as witnessed by the development of soil horizons.

RIASSUNTO. — È stata studiata la distribuzione del boro in alcuni prodotti vulcanici — pomici, ceneri e lave — raccolti al Vesuvio, Vulcano, Lipari e Santorini. Tale distribuzione è stata correlata con i varî stadî di attività vulcanica.

Al Vesuvio, il contenuto medio relativamente alto (20 ppm B) trovato nelle pomici dell'eruzione di « Pompei » (79 d.C.) può essere attribuito al lungo periodo di riposo seguito all'eruzione di « Avellino » (3500 a.C.); per l'eruzione di « Pollena » (472 d.C.) il tenore più basso (8 ppm B) può essere spiegato con un intervallo di tempo minore.

Per i prodotti degli altri apparati eruttivi i bassi tenori trovati (inferiori alle 4 ppm B) sono stati messi in relazione a intervalli di riposo più brevi o ad un possibile allontanamento dal sistema sotto forma di composti gassosi.

Introduction

The behaviour of volatile species is of a great importance in studying explosive volcanism, but not many evidences are available because of the difficulty of obtaining direct information on abundances of volatiles in the melts before the eruptive events.

The distribution of fluorine and chlorine in lavas and pyroclastic products allowed to provide some hypotheses on the activity of volcanic systems (CORADOSSI and MARTINI, 1981, 1982 a). Due to its crystal-chemical properties, during magmatic differentiation boron is enriched in residual melts and is expected to concentrate in the upper portions of magma chambers; its distribution in products of explosive processes could thus provide additional information when investigating explosive volcanism.

According to recent studies (PICHAVANT, 1981, 1983) the partition coefficient of boron in magmatic conditions shows that this element is preferentially partitioned in the vapour phase, but a significant fraction can dissolve into the melt. Because of this, in spite of a major release to the atmosphere during eruptive phenomena, it is possible that the boron content of quenched glassy phase pertaining to the same processes represent a sufficient indication of the order of magnitude of the concentration of this element in magma chamber prior to the explosive event.

Samples of pumices, as well as finer pyroclastic products and lavas, from Vesuvius, Vulcano, Lipari, and Santorini have been investigated in order to verify to what extent the present distribution of boron can contribute to the knowledge of the activity of volcanic systems.

Analytical procedure and results

The analyses have been carried out by extraction of boron from crushed samples (size less than 100 mesh) by means of a sulphuric acid solution and subsequent colorimetric determination using 1-1′ dianthrimide (ELLIS et al., 1949). The blue colour of the solution obtained has been estimated visually against a series of standards of known concentration; intervals of 0.1 μg/ml *B* were used for concentrations up to 1 μg/ml *B*, and steps of 0.25 μg/ml *B* were preferred in the range 1-2 μg/ml *B*.

This procedure is preferred to a normal spectrophotometric measure because of the possible presence of suspended particles. The precision, however, appared sufficient for the need of the investigation.

According to the experiments carried out on standards rocks G-1 and W-1 (QUIJANO-RICO, 1968), about 90 % of total boron can be determined by this method.

All samples have been analyzed in duplicate, with a resulting variation coefficient of about 20 %.

The analytical data for the investigated areas are given in tables 1-4. The following points, concerning the different volcanic systems, can be noted:

1) The samples from Vesuvius (fig. 1) are mainly represented by pumices belonging to the events « Avellino » (about 3500 y. B.P.), « Pompei » (79 A.D.) and « Pollena » (472 A.D.) (LIRER et al., 1973; DELIBRIAS et al., 1979; SHERIDAN et al., 1981; ROSI et al., 1981; ROSI and SANTACROCE, 1983).

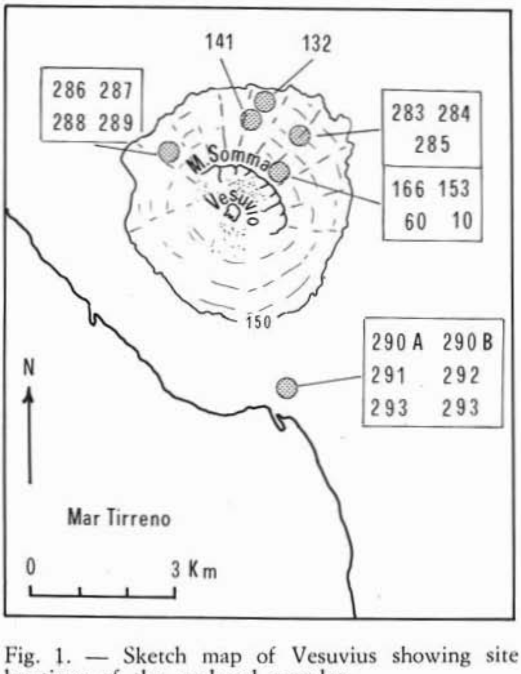

Fig. 1. — Sketch map of Vesuvius showing site locations of the analyzed samples.

TABLE 1

Boron content in samples from Vesuvius

SAMPLES	LOCALITY		DESCRIPTION	PPM B
PFSV 285	OTTAVIANO	472 A.D.	PUMICE FALL	2.6
PFSV 284	OTTAVIANO		PUMICE FALL	3.8
PFSV 283	OTTAVIANO		PUMICE FALL	10.5
PFSV 289	POLLENA	79 A.D.	PUMICE, PYROCL. FLOW	4.3
PFSV 288	POLLENA		PUMICE, PYROCL. FLOW	37.0
PFSV 287	POLLENA		PUMICE, PYROCL. FLOW	18.0
PFSV 286	POLLENA		PUMICE, PYROCL. FLOW	30.0
Φ_4 0.063	POLLENA		PYROCLASTIC FLOW	3.0
Φ_3 0.063	POLLENA		SAME LEVEL AS PFSV 289	10.0
Φ_2 0.063	POLLENA		SAME LEVEL AS PFSV 288	7.5
Φ_1 0.063	POLLENA		SAME LEVEL AS PFSV 287	15.0
Φ_0 0.063	POLLENA		SAME LEVEL AS PFSV 286	6.5
Φ_4 0.50-0.71	POLLENA		PYROCLASTIC FLOW	4.5
Φ_3 0.50-0.71	POLLENA		SAME LEVEL AS PFSV 289	6.5
Φ_2 0.50-0.71	POLLENA		SAME LEVEL AS PFSV 288	6.5
Φ_1 0.50-0.71	POLLENA		SAME LEVEL AS PFSV 287	9.8
Φ_0 0.50-0.71	POLLENA		SAME LEVEL AS PFSV 286	10.0
PFSV 294	OPLONTI		PUMICE FALL	20.0
PFSV 293	OPLONTI		PUMICE FALL	24.0
PFSV 292	OPLONTI		PUMICE FALL	12.5
PFSV 291	OPLONTI		PUMICE FALL	17.5
PFSV 290 B	OPLONTI		PUMICE FALL	10.0
PFSV 290 A	OPLONTI		PUMICE FALL	27.0
PFSV 141	AMENDOLARE	~3500 B.P.	PUMICE FALL	13.0
PFSV 132	PALMENTELLO		PUMICE FALL	10.0
PFSV 166	MT. SOMMA	PRE-CALDERA	LAVA FLOW	6.0
PFSV 153	MT. SOMMA		LAVA FLOW	10.0
PFSV 60	MT. SOMMA		LAVA FLOW	5.0
PFSV 10	MT. SOMMA		LAVA FLOW	9.0

Finer components of pyroclastic flow of the « Pompei » eruption, as well as samples of the underlying lavas of Mt. Somma, have been also investigated. No distinct differences are apparent between the boron concentrations for the «Avellino» and «Pollena» pumice samples, with average values of 11 and 5.6 ppm respectively; «Pompei» pumices are characterized by higher boron contents, with the mean of 20 ppm. The finer samples from the pyroclastic flow have a lower content than the corresponding «Pompei» pumices, namely 8 ppm (in table 1). The mean content in lavas is 7.5 ppm.

2) The samples from Vulcano (fig. 2) are lavas of different eruptive cycles of the Fossa, as well as pumices produced by recent explosive activities. The observed boron contents are very similar, 2.6 and 2.8 ppm for lavas and pumices respectively. Sample IV 21, however, displays a very high content (24 ppm *B*) for which a satisfying explanation is not available (table 2).

3) Lavas and pumices pertaining to the recognized four periods of activity at Lipari

have been considered (fig. 3). The mean content of boron in lava samples (2.2 ppm) does not differ substantially from that of pumices (3.6 ppm) (table 3).

4) For Santorini, the pyroclastic deposits of the Minoan eruption (1470 B.C.) have been studied (fig. 4), taking into account threee different sections at Oia, Phira and Athinios.

Boron mean content of pumices and of finer pyroclastic deposits is very low and in the most of them the analytical measures are below the detection limit of the method here used (table 4).

Discussion

In considering the distribution of boron in different products of volcanic activity, we have to take into account the volatilities of its compounds in comparison with other volatile species which are present in magma chambers prior to the explosive processes. Most of these volatiles are released to the atmosphere at the moment of the outburst, while the chemical characters of some species allow their persistence in quenched glassy products of the same eruptions.

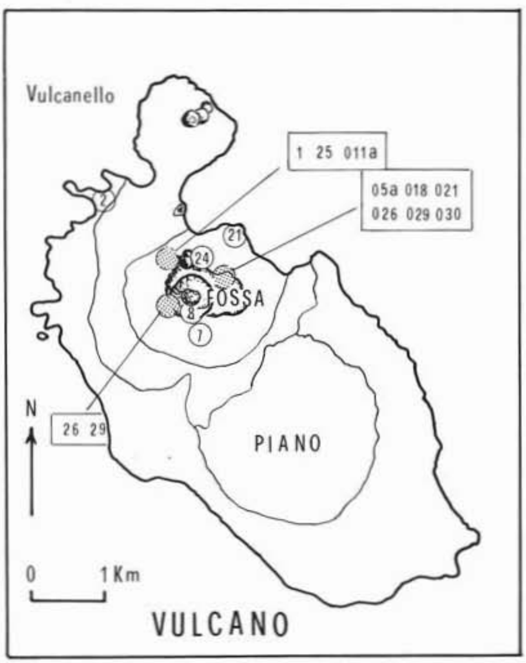

Fig. 2. — Sketch map of Vulcano showing site locations of the analyzed samples.

TABLE 2

Boron content in samples from Vulcano

SAMPLES	LOCALITY	DESCRIPTION	PPM B
VULC 05 A	FOSSA CRATER	BOMB 1888-90 ERUPTION	1.3
VULC 018	FOSSA CRATER	BOMB 1888-90 ERUPTION	0.5
VULC 021	FOSSA CRATER	BOMB 1888-90 ERUPTION	1.3
VULC 026	FOSSA CRATER	BOMB 1888-90 ERUPTION	1.3
VULC 029	FOSSA CRATER	BOMB 1888-90 ERUPTION	1.0
VULC 030	FOSSA CRATER	BOMB 1888-90 ERUPTION	1.0
IV 29	FOSSA CRATER	PUMICE	1.3
IV 26	FOSSA CRATER	PUMICE	1.3
IV 24	FORGIA VECCHIA CRATER	OBSIDIAN FLOW	0.5
IV 25	PIETRE COTTE	OBSIDIAN FLOW	1.0
VULC 011 A	PIETRE COTTE	OBSIDIAN FLOW	1.3
IV 1	PIETRE COTTE	PUMICE	4.5
VULC 022	COMMENDA	OBSIDIAN	1.3
IV 8	FOSSA CRATER	PUMICE	3.8
IV 7	GROTTA PALIZZI	PUMICE	3.5
IV 2	LENTIA SURROUNDINGS	LAVA FLOW	0.5
IV 21	PUNTE NERE	LAVA FLOW	24.0

Water, carbon dioxide, hydrogen, sulphur species, are mainly represented in the volcanic clouds, while partially chlorine and to a greater extent, fluorine, can be trapped in the solid phases.

The experimental ratio Cl vapour/Cl melt at 750° C and 2 Kbar resulted of 43.2 (KILINC and BURNHAM, 1972) while the same ratio for F is 0.18 at 850° C, 0.12 at 680° C, at 1 Kbar (HARDS, 1976); these figures, even if pertaining to restrict physical-chemical conditions, appear rater consistent with the observed distribution. For boron, a partition coefficient vapour/melt of 3.0 has been obtained at 750° C and 1 Kbar (PICHAVANT, 1981) pointing out an intermediate behaviour in volcanic processes between chlorine and fluorine.

This character can be probably extended to the low temperature phenomena, mainly represented by weathering processes, which could have modified the original distribution of boron in the studied samples.

For fresh glass phases, a substantial persistence of fluorine has been verified while chlorine is sometimes partially leached away (CORADOSSI and MARTINI, 1982 b); it appears thus reasonable, given the intermediate behaviour of boron, to infer a sufficient persistence for this element as well (fig. 5).

If the determined concentrations of boron can be considered representative of the original ones, it is rather easy to verify systematic higher concentrations in pyroclastic products from Vesuvius. In considering pumice samples only, which can better represent the melt phase before the eruptive phenomenon, mean values of 20 ppm are obtained for the « Pompei » event, 11 ppm for « Avellino » and 5.6 ppm for « Pollena »; 2.9 ppm result for Vulcano, 3.6 ppm for Lipari, less than 0.5 ppm for Santorini.

The concentrations of fluorine and chlorine in the same areas follow a similar trend, with the highest mean values observed in pumices from Vesuvius (CORADOSSI and MARTINI, 1982 a).

The increase of volatile species content in magma chambers as a consequence of magmatic differentiation is the natural process which can account for the observed situation; higher boron contents should have been produced by longer intervals between eruptive phenomena. In accordance with this, different repose times appear to explain the higher values obtained for «Pompei» products in comparison with the «Pollena» ones, but similar inter-eruptive times are recorded also for Lipari (PICHLER, 1980) and Santorini (VITALIANO et al., 1978; PICHLER and KUSSMAUL, 1972), without any similar relative enrichment in boron content; any evidence of this kind is lacking for Vulcano (KELLER, 1980). An increase of volatile species in the upper portion of magma chambers due magmatic differentiation can result for closed systems only; if on the contrary a certain degree of permeability for gaseous species occurs, no excess in volatiles can be obtained. Open system situations have been already hypothesized on the basis of chemical composition of volcanic products for Lipari and Vulcano (CORADOSSI and MARTINI, 1981) and it is possible that something similar occurred at Santorini as well. Besides this, we have to consider that boron compounds can persist in gaseous phase even at low temperature, when the volatilities of chlorine and fluorine species are insufficient to allow their presence in fumarolic exalations; a volcanic system can be thus open for boron, while being closed for chlorine and fluorine.

A tight comparison of the distribution of these three elements is not possible because of some differences in their responses to the changing environmental conditions, but the general picture arising from the data here presented for boron allows similar conclusions as those obtained on the basis of fluorine and chlorine distribution; moreover, since boron is more sensitive to even a slight permeability, the increase of boron observed for the evolutive history of a volcano can

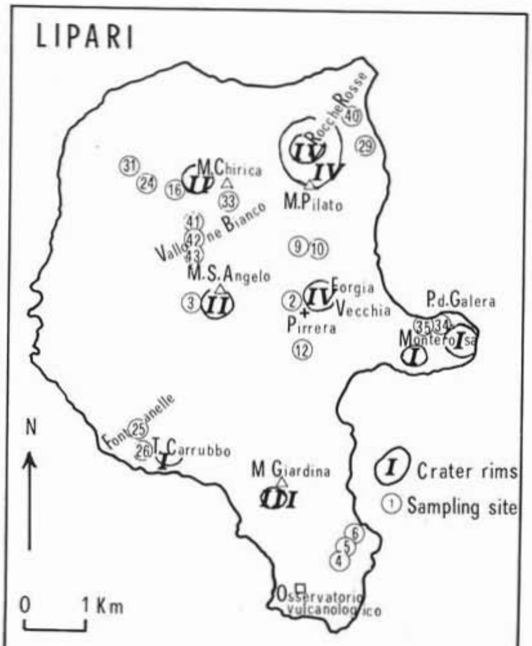

Fig. 3. — Sketch map of Lipari showing site locations of the analyzed samples.

TABLE 3

Boron content in samples from Lipari

SAMPLES	LOCALITY	PERIOD	DESCRIPTION	PPM B
IL 2	NEAR PIRRERA CEMETERY	IV	OBSIDIAN FLOW	1.5
IL 41	VALLONE BIANCO QUARRY		PUMICE	10.0
IL 42	VALLONE BIANCO QUARRY		OBSIDIAN BLOCK IN IL 41	1.5
IL 43	VALLONE BIANCO QUARRY		PUMICE	0.5
IL 33	MT. CHIRICA SUMMIT		PUMICE	3.5
IL 29	PORTICELLO QUARRY		PUMICE	6.0
IL 16	ROAD TOWARDS MT. CHIRICA		PUMICE	2.5
IL 40	ROCCHE ROSSE		OBSIDIAN FLOW	10.0
IL 10	VALLONE GABELLOTTO		PUMICE	1.0
IL 9	VALLONE GABELLOTTO		PUMICE	2.5
IL 4	ROAD TOWARDS OBSERVATORY	III	LAVA FLOW	0.5
IL 6	ROAD TOWARDS OBSERVATORY		LAVA BLOCK IN IL 4	0.5
IL 5	CAPISTELLO		LAVA FLOW	0.5
IL 12	NEAR PIRRERA CEMETERY	II	LAVA FLOW	1.0
IL 3	MT. S.ANGELO		LAVA FLOW	1.0
IL 31	COSTA D'AGOSTO		LAVA FLOW	1.0
IL 24	COSTA D'AGOSTO		LAVA FLOW	1.0
IL 25	FONTANELLE		LAVA FLOW	7.0
IL 35	MONTEROSA	I	LAVA FLOW	1.0
IL 34	PUNTA DELLA GALERA		LAVA FLOW	0.5
IL 26	TIMPONE CARRUBBO		LAVA FLOW	4.5

represent a further chemical witness of a close system.

Different initial concentrations of any element will produce different final contents as a result of magmatic evolution, but for a given system longer times of differentiation will correspond to higher values of elements enriched during processes of this kind.

The similarity of boron contents in lavas and pumices from Lipari, Vulcano and Santorini indicates short differentiation times or the opening of the systems with respect to boron compounds, if any evidence is there of long repose times before the studied explosive event.

Prolonged differentiation in closed magma chamber can be derived on the same basis for Vesuvius prior to « Pompei » eruption, while shorter time should result for « Avellino » and « Pollena » events; in this latter case the evidence fits the hypothesis.

Conclusion

During magmatic differentiation boron does not enter early separating minerals and is enriched in the residual melts. Because of this, boron is concentrated in the upper portions of magma chamber where it preferentially partitions into the vapour phase with respect to the melt.

A large quantity of boron is thus released to the atmosphere during volcanic activity,

TABLE 4

Boron content in samples from Santorini

SAMPLES	LOCALITY	DESCRIPTION	PPM B
TH 60	PHIRA	PUMICE FALL	- -
TH 61	PHIRA	PUMICE FALL	- -
TH 62	PHIRA	PUMICE FALL	- -
TH 63	PHIRA	MATRIX OF BASE SURGE	0.5
TH 64	PHIRA	PUMICE FALL	- -
TH 65	PHIRA	MATRIX OF BASE SURGE	- -
TH 66	PHIRA	MATRIX + PUMICE,PYR.FLOW	0.5
TH 67	PHIRA	PUMICE, PYROCLASTIC FLOW	- -
TH 68	PHIRA	PUMICE, PYROCLASTIC FLOW	- -
TH 69	OIA	PUMICE FALL	- -
TH 70	OIA	MATRIX OF BASE SURGE	- -
TH 71	OIA	MATRIX OF BASE SURGE	0.5
TH 72	OIA	PUMICE, PYROCLASTICFLOW	- -
TH 73	OIA	LAVA BLOCK, PYROCL.FLOW	- -
TH 74	OIA	PUMICE, PYROCLASTIC FLOW	0.5
TH 75	OIA	PUMICE, PYROCLASTIC FLOW	- -
TH 76	ATHINIOS	PUMICE FALL	- -
TH 77	ATHINIOS	PUMICE FALL	- -
TH 78	ATHINIOS	PUMICE, BASE SURGE	- -
TH 79	ATHINIOS	MATRIX OF BASE SURGE	0.5
TH 80	ATHINIOS	PUMICE, BASE SURGE	- -
TH 81	ATHINIOS	PUMICE, PYROCLASTIC FLOW	- -
TH 82	ATHINIOS	PUMICE, BASE SURGE	- -
TH 83	ATHINIOS	LAVA BLOCK, PYROCL. FLOW	- -

- - : BELOW THE DETECTION LIMIT

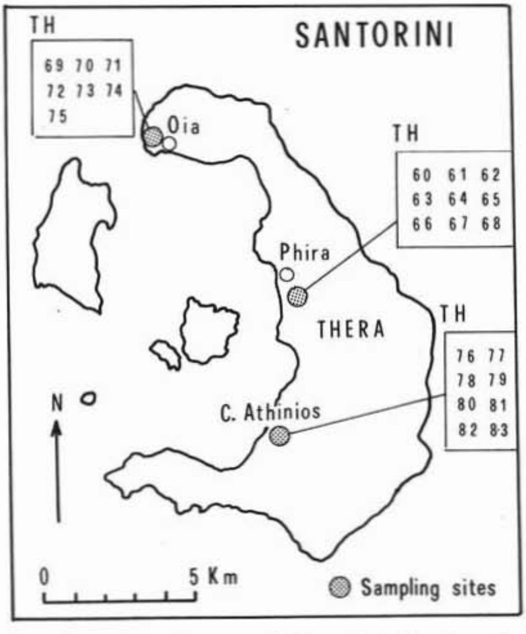

Fig. 4. — Sketch map of Santorini showing site locations of the analyzed samples.

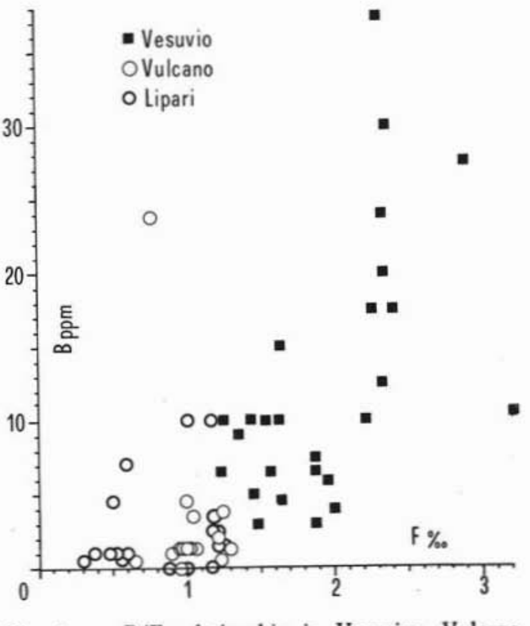

Fig. 5. — B/F relationship in Vesuvius, Vulcano and Lipari studied samples.

but it appears reasonable that quenched glass phases produced by the explosive processes can provide information about the original boron content in the melt prior to the eruptions.

Higher volatile concentrations are expected as a result of differentiation for longer repose times between the volcanic events, and it is possible that differences in the present contents of boron can be correlated to different characters in the activity of volcanic systems. The boron concentrations in pumices from « Pompei » eruption of Vesuvius, comparatively higher than similar samples pertaining to « Avellino » and « Pollena » events, can be explained by the repose time of about 1500 years, much longer than that preceded « Pollena » eruption. Besides this, by the enrichment in boron contents a situation of closed system can also be derived.

Values observed at Vulcano, Lipari and Santorini are much lower; for Vulcano no evidence of long time intervals is available, for Lipari and Santorini the development of soil horizons points out sufficient conditions for lasting differentiation processes. On the basis also of fluorine and chlorine distribution, the low values for boron are interpreted as produced by the escape from the system of gaseous compounds in form of fumarolic manifestations.

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