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THE TECHNIQUE OF DOLMEN CONSTRUCTION IN THE DETERMINATION OF A SEISM AROUND THE YEAR 2,700 B.C.

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Resumen

MARTINEZ-TORRES, L. M. (1997). La técnica de construcción de dolmenes en la determinación de un sismo hacia el año 2.700 a.d.C.. *Est. Mus. Cienc. Nat. de Alava* **12**: 25-31.

El análisis de las técnicas empleadas en la construcción de los dólmenes catalogados en la Rioja Alavesa, para determinar las causas del colapso de algunos de sus elementos constructivos, permite considerar a estos monumentos neolíticos como excelentes sismógrafos históricos. Como resultado del estudio se ha determinado un seismo hacia el año 2.700 antes de Cristo, posiblemente asociado a la actividad sísmica de la vecina Falla de Pamplona.

Palabras clave: arquitectura, dolmen, Neolítico, sismo, Falla Pamplona, Norte de España.

Abstract

MARTINEZ-TORRES, L. M. (1997). The technique of dolmen construction in the determination of a seism around the year 2,700 B.C. *Est. Mus. Cienc. Nat. de Alava* **12**: 25-31.

The analysis of the techniques employed in the construction of a number of dolmens in the North of Spain, in order to discover the collapse of some of their constructive elements, gives us good reason to consider each of these neolithic monuments as an excellent historical recording seismograph. As a result of the studies carried out, a seism of towards the year 2,700 B.C., associable with the Pamplona Fault, has been determined.

Key words: architecture, dolmen, Neolithic, seism, Pamplona Fault, North Spain.

Laburpena

MARTINEZ-TORRES, L. M. (1997). Trikuharriak eraikitzeko teknika K.a. 2700 inguruko lurrikara baten zehaztapenean. *Est. Mus. Cienc. Nat. de Alava* **12**: 25.31.

Arabar Errioxan katalogatutako trikuharriak eraikitzeko erabiltzen ziren tekniken azterketa egiten da, trikuharri hauen eraikuntza-osagai batzuk galtzearen zergatiak zehazteko. Azterketa honek erakutsi du Neolito aroko monumentu hauek sismografo historiko bikainak direla. Azterketaren ondorioz, K.a. 2700. urte inguruan lurrikara bat izan zela esan dezakegu, batez ere Iruñako Failaren iharduera sismikoaren eraginez.

Hitz gakoak: Arkitektura, trikuharriak, Neolitikoa, sismoa, Iruñako Faila, Espainiako Iparraldea.

INTRODUCTION

Dolmens are neolithic structures from around 7,000 to 2,000 B.C. which were used as pantheons. They usually consist of a circular floor chamber, which can be reached through a corredor or longitudinal passageway. The chamber is constructed of vertical stone slabs which normally support a single roofing slab. The corredor or passageway, less high than the chamber, is also constructed of vertical and horizontal slabs.

Dolmens are known in Europe, the North of Africa, the near East, Asia and even Japan, with their maximum concentration in Western Europe. Their construction is neolithic; for example dolmens in the near East have been dated at 7,000 years B.C.. In the North of Spain dolmens date from 3,500 B.C..

Dolmens can be considered as structures which encompass the oldest arquitectonic volumes in the South-Western Europe. Coevil or posterior megalithic forms, which do not encompass volumes, such as menhires and cromlechs should also be men-

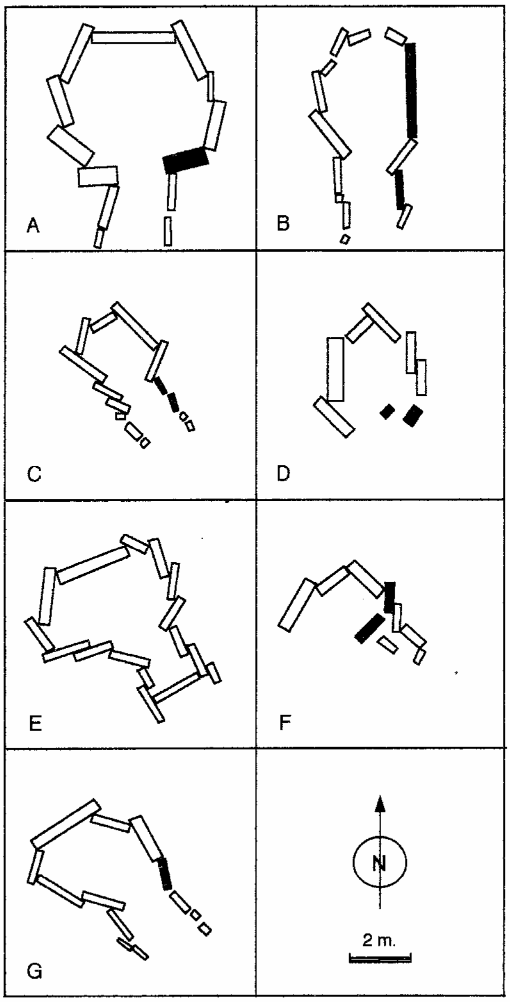

Fig. 1. Schematic representations of the El Sotillo(A), San Martín (B), Los Llanos (C), La Huesera (D), La Hechizera (E), El Encinal (F) and Layaza (G) dolmens. These show the imbrication of the stones and how the only one found perpendicular to the corredor (the generating stone) is not supported by any other stone, except in the case of Layaza. The stones in black were found fallen.

tioned. In all these constructions, the materials used were of regional stone, which may have been transported several kilometers.

The dolmens studied (Barandiarán et al., 1958; Vegas-Aramburu, 1986) are: El Sotillo, San Martín, Los Llanos, La Huesera, La Hechicera, El Encinal and Layaza. All are situated in La Rioja Alavesa, in the North of Spain, at the intersection of the Western Pyrenees with the Ebro Valley. In the case of each dolmen a schematic plan has been made and the lateral fallen slabs (at the time of the discovery of the monument) has been shown (Fig. 1). In order to understand the causes underlying the collapse of these slabs, the procedure of construction of the whole structure has been carefully examined; the system of forces which kept the monument stable has been analysed, and finally, some explanations of the cause of their collapse are given.

THE PROCESS OF THE CONSTRUCTION OF DOLMENS

The positioning of the stone slabs of the dolmens which have been studied suggests that only one has been dug into the ground to give it support while the rest learn against each other around it. This base supporting stone we have called the "generating stone".

The only exception to this principle of construction among the dolmens studied is that of Layaza (Fig. 1g), but we believe that this is due to its recent reconstruction as a local monument.

Once we accept that the generating stone is the first part of the monument, it is easy to deduce the placing of the other stones that go to make up a dolmen. The constructive process has been shown in Figure 2. The order of the placing of the stones supposes a certain symetry of the monument with regard to the generating stone and the field of forces which it must support, which is the progressive communication of one weight to another. In our opinion, when begining the construction of a dolmen, and in order to keep the generating stone upright, secondary materials such as wood, earth mounds, or stones were needed at least until it was well dug into the earth. Nevertheless, for the completion of the dolmen no secondary material was neccesary, as the other stone slabs rest against each other.

So it can be seen, that once the generating stone was vertically in place, the others had to lean towards the inside of the chamber to keep their balance. In this way, a stable, erect structure could be produced without external support. Later to be covered by a mound.

THE SYSTEM OF FORCES BETWEEN THE STONES

In order to define the system of forces which determines the stability of dolmens, and understand the possible causes of the collapse of some of their

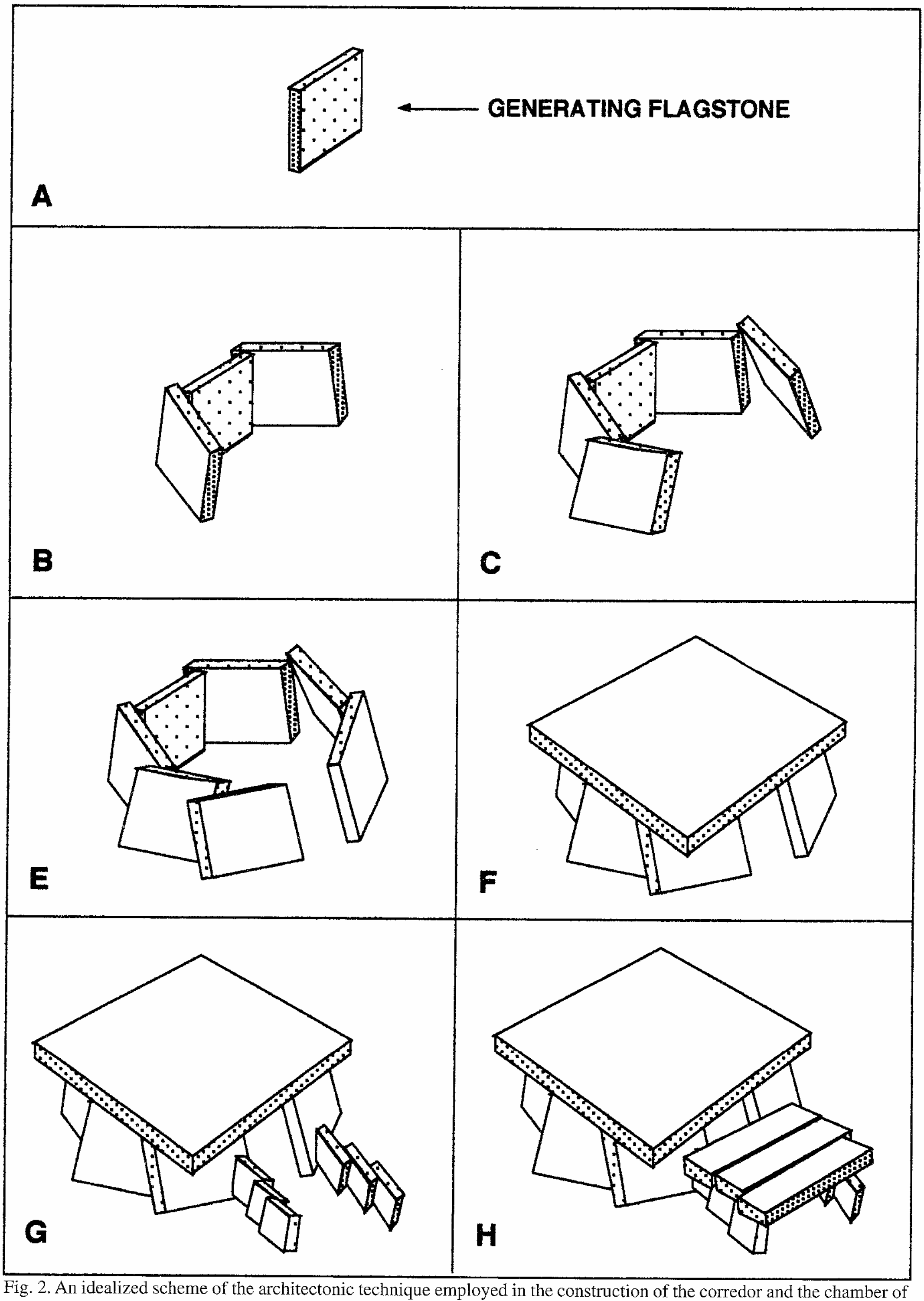

Fig. 2. An idealized scheme of the architectonic technique employed in the construction of the corredor and the chamber of dolmens in the Rioja Alavesa showing the generating stone and the imbrication of the succesive stone.

stones, the following system of forces has been outlined (Fig. 3):

P = the weight of the stone.

T1 and T2 = the weight of the covering stone.

(R1, R2), Ry and Rz = ground reactions.

A1 and A2 = actions (pushes) between the stones.

Other forces such as the wind, active or passive additions to the monument, foundation instability, have not been taken into account because we consider that their importance is so slight as to be negligable.

T1 and T2 refer to the points where the covering stone (Fig. 2) is supported, which might be at only one point, and in some cases none at all. Any horizontal force associated with these forces would be diminished or neglible because of friction in the points of contact between the stones.

R1 and R2 represent a set of horizontal forces spread along the emplacement section which varies with the tangent of the angle of the stone against the earth. Thier importance depends largely on the deformability of what the stone rests on. As is shown in Figure 3, R1 and R2 are compensatory forces. Ry (also shown in the diagram) is a very small force which only compensates the lack of parallelism between A1 and A2.

A1 and A2 are almost horizontal, having an angle similar to that formed between the stones. This angle is very important in the explanation of the system of forces. Thus in the case of the generating stone A2 = 0 and R2 has the same sign as A1, which means that the stones have a clear tendency to fall inwards.

The relation between the set of forces can be explained by the transmission from one stone slab to another of the resulting vector force. For example, the T1 and T2 of the stone nearest the corredor (Fig. 2) and its own weight (P) give rise to the following reactions: R1, R2, Rz and A2; of which A2 is transmitted to the neighbouring stone as A1. This A1 vector (with T1, T2 and P of the neighbouring stone), gives rise, in the same way to the vectors R1, R2, Rz and A2 in the second leaning stone, together with a small Ry, now that A1 and A2 are not parallel. These forces are transmitted successively to tha generating stone which recieves two A1 vectors, one on each side.

The magnitudes of A1 and A2 are related by the cosine of the angle formed by the two neighbouring stones, this being A2 = 0 where the stones are ortogonal (Fig. 4). Thus, the magnitudes of the A vectors steadily increase, as they have to compensate for the momentum which is introduced by P and T, the stone not being upright. Nevertheless, these vector magnitudes decrease where the sideways angle between the stones is more pronounced. In an extreme example, with all the stones nearly parallel, the generating stone would have to compensate for little short of the weight of them all. This makes it extremely important to take into consideration the very high stresses at the contact points between the stones, which act on small surfaces in relation to their weight.

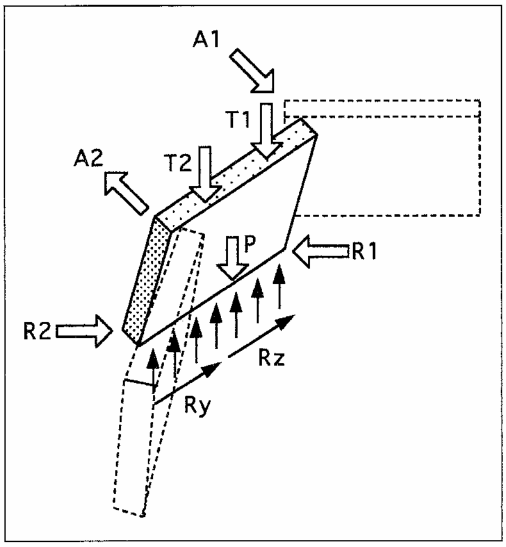

Fig. 3. Decomposition of the force field between two adjacent stones.

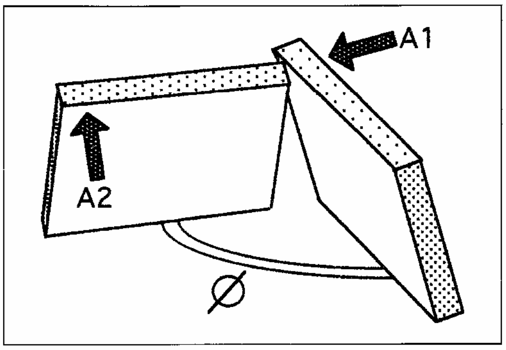

Fig. 4. The A1 and A2 forces related to the cosine of the angle formed by the stones. A2 = 0 when Ø = 90°.

THE CAUSE OF THE FALLS

In all the dolmens studied there are some fallen stones. A total collapse might well be caused by the fall of the generating stone, whereas the fall of an intermediate stone would not have such a drastic effect. In the latter case, when A1 is not compensated for by the fallen stone, all those resting against each other should fall succesively towards the corredor (Fig. 5).

In order to upset the stability of the dolmen since its construction and cause the fall of stones, the following possibilities have been taken into account:

1) stone weathering: this would alter the points of contact, and the geometrical pattern would be changed with the appearance of hollows, and consequent stone movement would occur.

2) foundation changes: for the loss of balance caused by swivelling, the existence of Rz is fundamental, which increase as the angle between the stones increases. A change in Rz support could well lead to such loss of balance and the risk of a fall.

3) human interference: demolition would mean the uncovering of the tumulus and consequent removal of the stones. In none of the monuments studied is there evidence of demolition or vandalism on such scale. Only the recent reconstruction of the Layaza dolmen shows direct evidence of human interference.

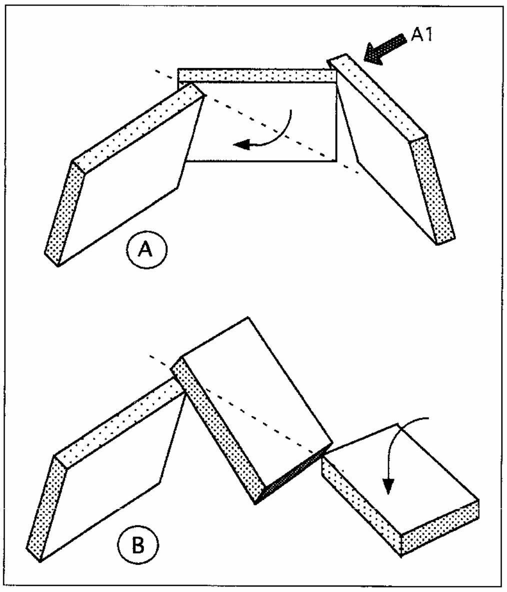

Fig. 5. When the force A1 is not compensated, the stone swirells and when this happens, all those stones fall which have successively transmitted thier forces towards the stone in question, i.e., those nearest the corredor.

4) earthquake: a seism acts as a set of inertia acceleration forces, with variable magnitudes and directions, during a specific time period. On reaching the threshold limit the fall of a stone could occur.

The two first possibilities, weathering and foundation movement, can be taken as randum and difficult to ascertain. There is no external evidence of point contact hollowing or abrasion. As has pointed out, human interference seems to be unlikely, especially as there are no signs of deliberate demolition. So the idea of a seism as a cause of the partial collapses seems to be the most probable, particularly as the fallen stones lie in the same direction: a fact which suggests that an earthquake was the cause of their fall.

We have said that prior to an earthquake the constructional deficiencies in all the monuments are similar, while the positioning of the stones is also similar: which would lead us to expect almost equal results in almost equal monuments from the same shock. Nevertheless, the stability threshold differs from stone to stone as does the acceleration direction of the earthquake, thus a perfect symmetry is not to be expected, only a generally similar pattern (Fig. 1).

The vertical seismic accelerations can be considered as an increase in the weight of the stone. The horizontal accelerations are those which directly increase the A1 forces, which, as has been shown, are fundamental to the monument's equilibrium. Clearly, stones perpendicular to the seism acceleration are more likely to be affected by this acceleration, and more likely to fall. Thus the fallen stones must be perpendicular to the source of the seism. In other words, each fallen stone defines an isoseismic line.

In order to determine the intensity of the seism, the stability threshold of the A1 force must be known; and thus, the contact section of the stone with its neighbour. With the data available such determination is not possible.

THE SAN MARTÍN DOLMEN

On the excavating the San Martin dolmen (Barandiarán et al., 1964) one of the central chamber stones was found fallen (Fig. 1). Above and below this fallen stone arqueological remains were found, which means that the dolmen was used both before and after the fall of the stone. The remains below the stone date from between 3,400-3,200 B.C. and those above from 2,200 B.C. onwards. So the stone must have fallen (taking into account purely archeological evidence, Vegas-Aramburu, pers. comm.) around 2,700 B.C..

Following the logic of what has been said above, the seism which produced the fall of the stone in the central chamber of the San Martin dolmen can be orientated as E-W, which is to say, perpendicular to the N-S position of the fallen stone. The Catalogue of Isoseismical Lines of the Iberian Peninsula (Mezcua, 1982) shows that seism with N-S isoseismic line come from the Pyrenean Zone. More specifically, from regional investigation (Mezcua et al., 1983; Martínez-Torres et al., 1988) the emission centre of this earthquake is in the Pamplona Fault.

So, around the year 2,700 B.C. an earthquake of unknown intensity occurred; perpendicular to the fallen stone in the San Martin dolmen, which may have had its origin in the Pamplona Fault.

CONCLUSIONS

Dolmens are widely found in Western Europe. The process of their construction observed in the Rioja Alavesa in the North of Spain suggests that they have the singular additional property of being historical recording seismographs. From an analysis of the system of forces which keep the monument stable, it can be deduced that the orientation of the fallen stones is perpendicular to the source direction of seismic waves. For this reason the position of the fallen stones reveals an isoseismic line.

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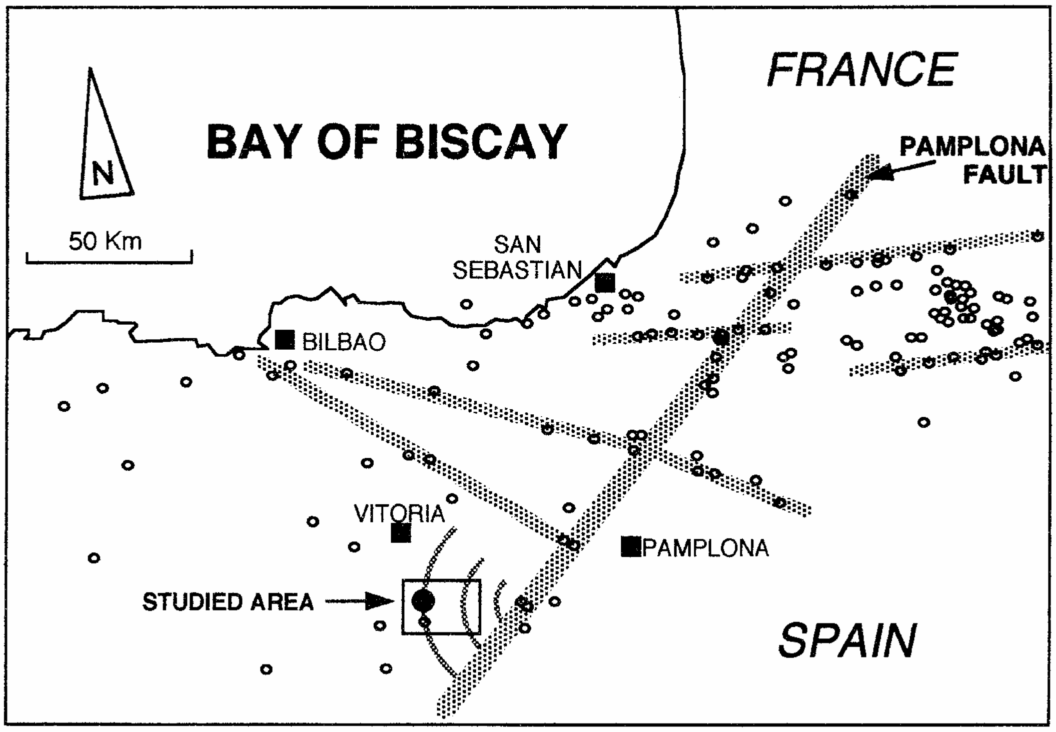

Fig. 6. Epicentric distribution in the Western Pyrenees (Mezcua et al., 1983) and the principal aligning of the seisms (Martínez-Torres et al., 1988). The black dot represents the San Martin dolmen and the semicircular lines the direction of the seism deduced from the orientation of the fallen stone.

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