Rapid diapir growth, a triggering agent of a 6 1/2 magnitude earthquake on October 29, 1966, in Acarnania (Greece)

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Summary. — There exists good evidence that diapir growing occurs at a rate similar to the rate of sedimentation. Taking this into account, it is reasonable to assume that differential, rapid loading, during the filling of the Kremasta reservoir, combined with a deeper penetration of fluids, may have affected the large-scale deformation of the Triassic strata of gypsum in Acarnania and probably increased diapir growth at a catastrophic rate; consequently long-term stability of the diapiric formations of gypsum disturbed by excessive deformation may have resulted in a premature release of the regional strains in the form of a very shallow earthquake on October 29, 1966.

Riassunto. — Esistono buone testimonianze che l'accrescimento del diapiro avvenga con una velocità pari a quella di sedimentazione. Partendo da questa premessa, è ragionevole presumere che l'improvviso carico, a seguito del riempimento del bacino di Kremasta, sommato ad una più profonda penetrazione di liquidi, possono aver contribuito alla deformazione di grandi proporzioni subita dagli strati Triassici del gesso in Acarnania e probabilmente aver aumentato in modo catastrofico la velocità di accrescimento del diapiro; di conseguenza la lunga stabilità delle formazioni diapiriche di gesso disturbate da ecessiva deformazione, possono aver provocato una prematura liberazione delle tensioni regionali sfociata quest'ultima, il 29 Ottobre 1966, sotto forma di un terremoto molto superficiale.

It is rather well established and generally accepted that many triggering forces of relatively small magnitude, in comparison with the main deep-seated strain producing forces, may change under certain favourable conditions the rate of strain release in a stressed region being close to breaking strength [3].

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After a long lack or complete absence of destructive shocks in the western part of central Greece an unusual earthquake activity started in the Kremasta dam area about three months after impounding of the artificial lake (1965, July 21) in the area of the Gavrovo zone. The activity culminated in three 6 1/4 to 6 1/2 magnitude shocks on February 5, 1966, October 29, 1966 and May 1, 1967.

The Gavrovo massif forms a faulted anticline with NNW-SSE running axis belonging to the Gavrovo – Tripolis zone; it consists of Upper Cretaceous reef limestones and Tertiary limestones surrounded by flysch deposits. On evidence of the "Institut Français du Petrole" (I.F.P., 1966), quoted by Richter and Mariolakos [5], the ca. 1000 m thick Upper Cretaceous limestones overlie ca. 1500m Early Cretaceous and Jurassic limestones and a Triassic formation of a salt cushion (gypsum, anhydrite and dolomite) of unknown thickness (s. Fig. 1).

At the beginning of the flysch deposition in the Ionian and Gavrovo zone at the Upper Eocene this area represented an uplift that was covered with the flysch not before the Oligocene. According to D. Rich-

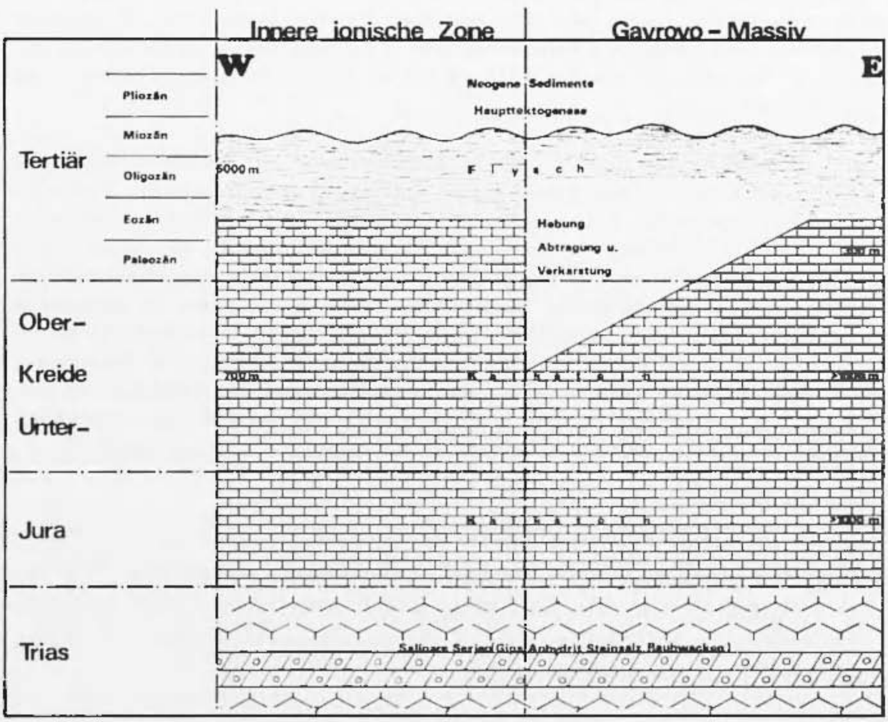

Fig. 1 – Stratigraphy of Gavrovo zone and inner Ionian zone after Dieter Richter and Ilias Mariolakos [5].

ter and I. Mariolakos (⁵) the uplift movement was caused by halokinesis (s. Fig. 2), producing numerous faults that strike nearly parallel to the direction of the Gavrovo anticline. The same tectonic evolution was put forward by A.G. Yagüe (⁸) for the Camarillas gorge in Spain.

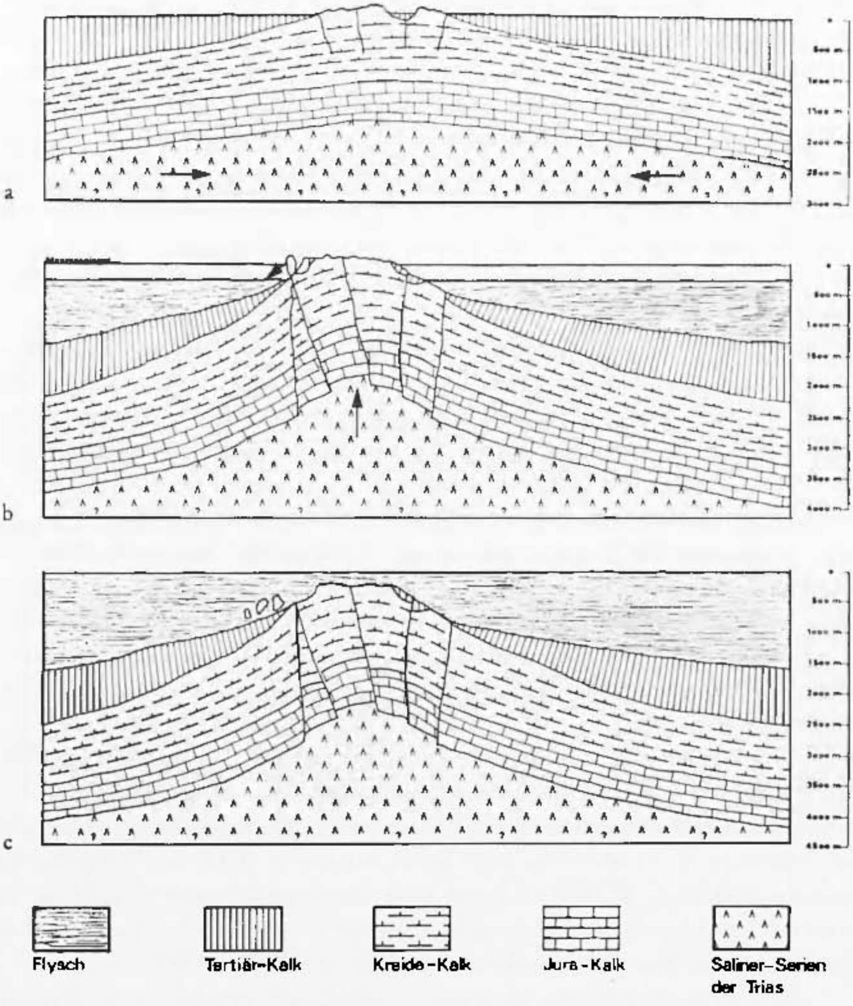

Fig. 2 – Schematic diagram showing the uplift process of Gavrovo Massif after Dieter Richter and Ilias Mariolakos (⁵):

a) Marginal movement of salt towards the Gavrovo area during the higher Upper Cretaceous, Palaeocene and Eocene;
b) Formation of a salt cushion in the Gavrovo area and accelerated uplift at the beginning of flysch deposition, breaking off of huge fragments;
c) Diminution of uplift and equalization of the relief in the Oligocene.

There exists good evidence that diapir growing occurs at a rate similar to the rate of sedimentation ([4]). Taking this into account, it is reasonable to assume that differential, rapid loading, during the filling of the Kremasta reservoir, combined with a deeper penetration of fluids, may have affected the large-scale deformation of the Triassic strata of gypsum in Acarnania and probably increased diapir growth at a catastrophic rate; consequently long-term stability of the diapiric formations of gypsum disturbed by excessive deformation may have resulted in a premature release of the regional strains in the form of a very shallow earthquake on October 29, 1966 (38.9°N, 21.1°E; $h = 1 \pm 5.5$ km, $M_s = 6\ 1/2$). The restriction of the highest intensity (VIII) to just one locality (Katouna) speaks well for the shallowness of the focus.

A similar case, well documented, was observed at the dam site in the Camarillas gorge, Spain, December 8, 1961, and presumably at the dam sites of Canelles-Santa Anna, Spain, June 9, 1962 ([9]) and also at the dam site of Oued Fodda, in Algeria, from January to May 1933 ([6]). There is evidence in spectacular fashion that movement of the salt is even now affecting the uppermost sediment layers at the sea floor of western Mediterranean ([7]).

Earthquakes triggered by water loading and/or lubrication are in general associated with normal faulting; this was the case of the Kremasta earthquake on February 5, 1966 (39.1°N, 21.7°E; $h = 16 \pm 4.7$ km, $M_s = 6\ 1/4$). The Katouna earthquake of October 29, 1966, was associated with thrust faulting (s. Fig. 3); this is in accordance with that one should expect if rapid diapir growth has acted as triggering mechanism (s. Fig. 4).

The epicenter of the second late aftershock of May 1, 1967 (39.6°N, 21.3°E, $h = 34 \pm 3.2$ km, $M_s = 6\ 1/2$) and that of October 29, 1966, are almost equidistant from the epicenter of the Kremasta earthquake of February 5, 1966. The fault mechanisms of both late aftershocks were similar, i.e. of reverse type; it is then possible the evaporites to extend northwards and the same triggering agent to have also acted in the case of the Drosopeghe earthquake of May 1, 1967.

The rate of diapiric processes is relatively greater when diapirs are approaching or reaching the surface (s. Fig. 4); thus the rate of movement of evaporites at far greater depth should be markedly less than the rate of growth of a well-developed diapir approaching the surface. This might explain, at least to some extent, why the progressive, jerky relief of the regional stress field was manifested disastrously

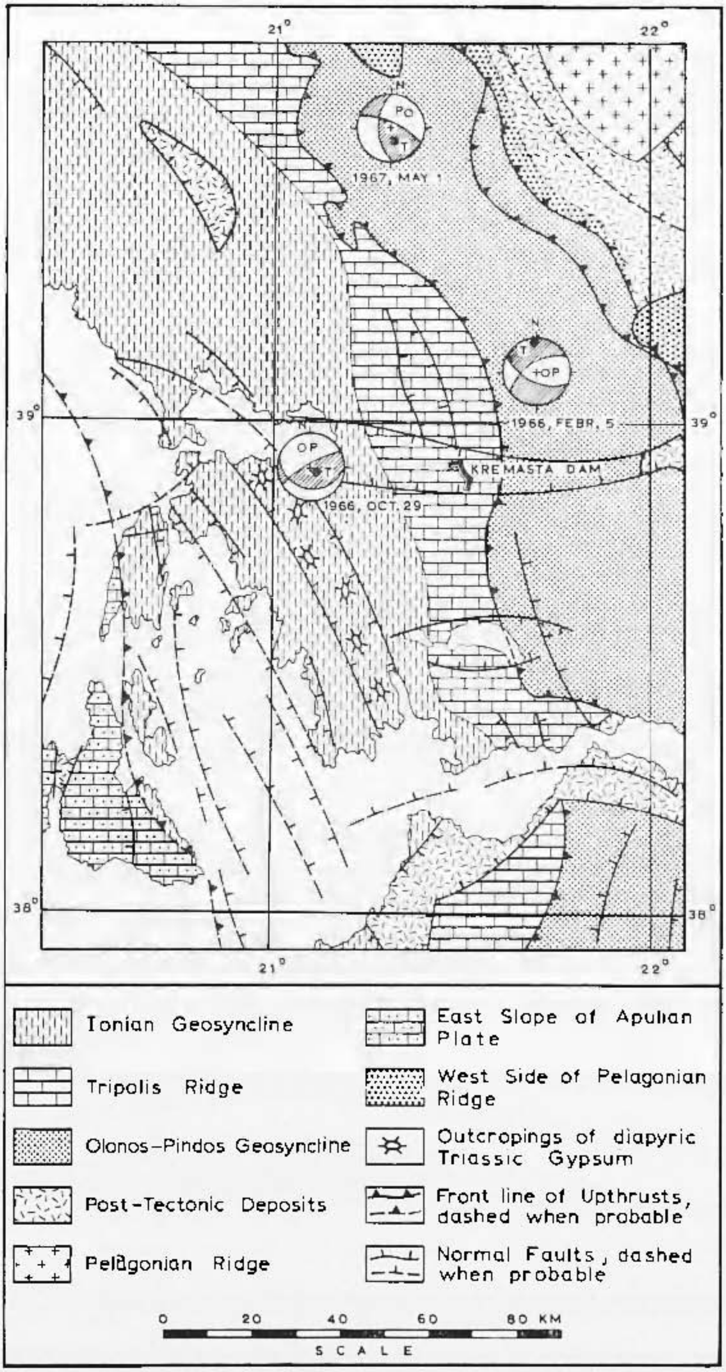

Fig. 3 – Structural lineaments (1) and fault - plane solutions for the main earthquake of 1966, Febr. 5, and the two late aftershocks of 1966 Oct. 29 and 1967, May 1 (2). The focal mechanisms are shown as equal-area projections of the lower focal hemisphere. The open circles are the axes of compression, *P*, and the closed circles are the axes of tension, *T*.

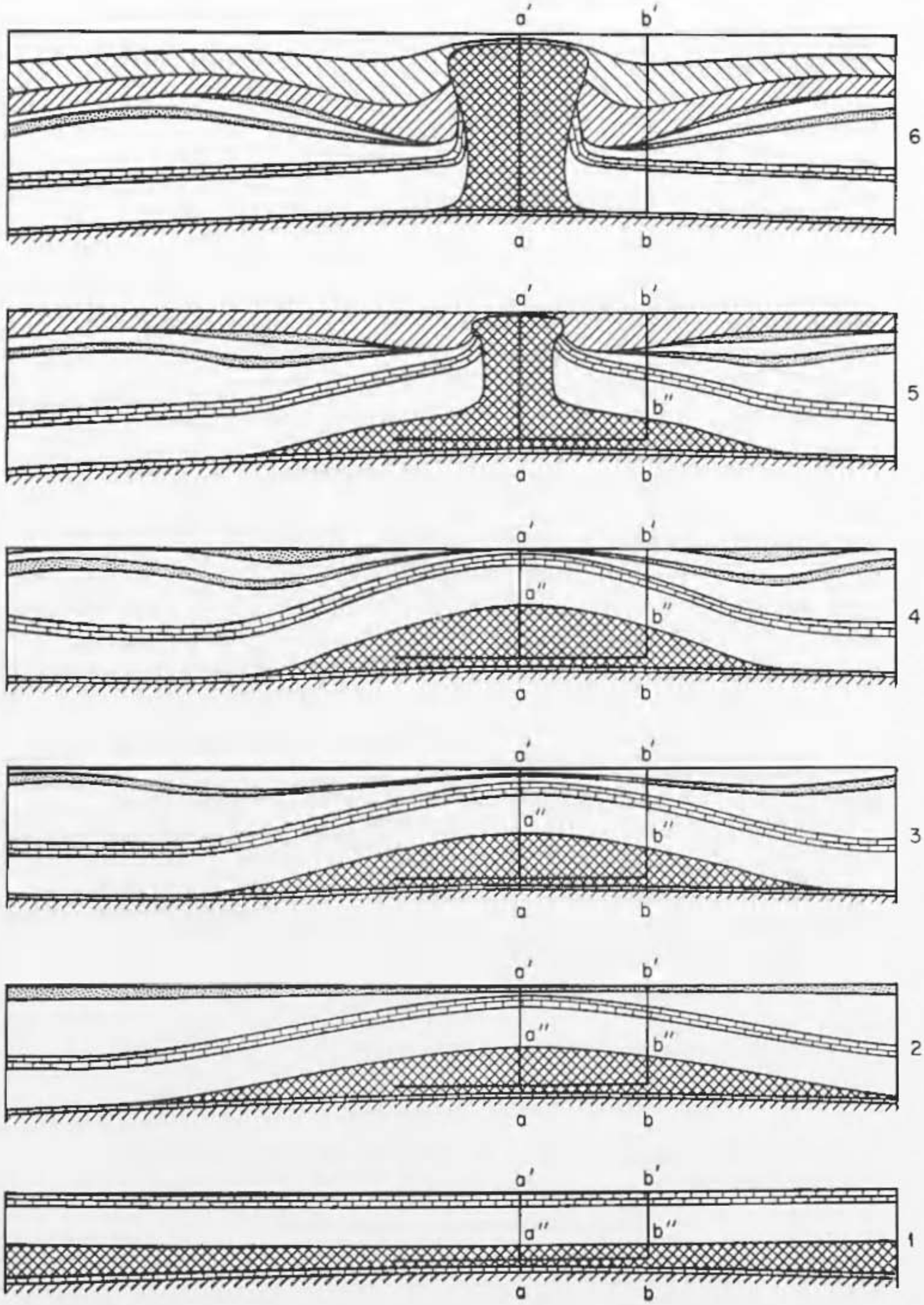

Fig. 4 - Diagrammatic development of a salt structure after FERRUCCIO GERA (4).

at Katouna, in the north end of the belt of the outcropings of diapiric Triassic gypsum (s. Fig. 3), ca. 7 months earlier than at Drosopeghe.

The stratigraphy of Gavrovo zone and inner Ionian zone and the uplift process of Gavrovo massif (5), make the suggestion of a rapid diapir growth being responsible for the relief of the regional stress field more certain. The idea is corroborated by the presence of many warm sulphureous springs in the area considered; the existence of

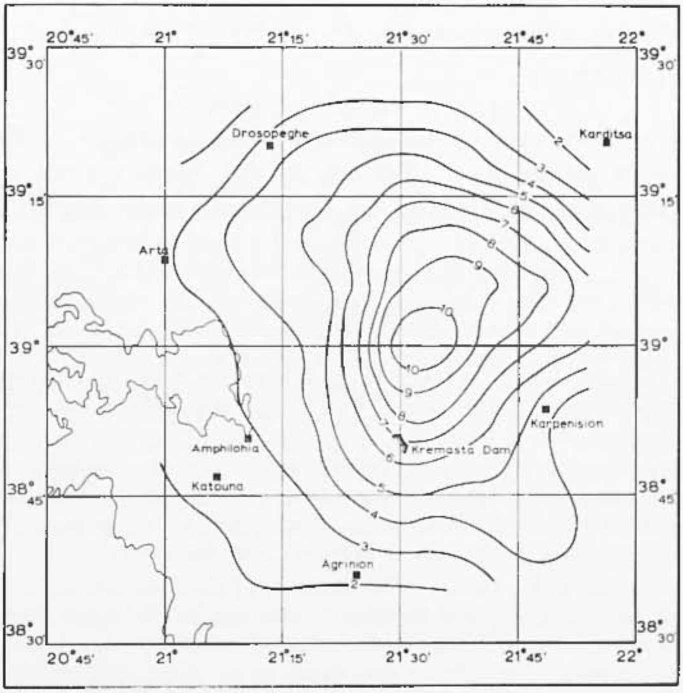

Fig. 5. – Map showing earthquake density over a 7-year period, 1964-1970, after two iterations. Density is measured as the number of events per 0.1° latitude-longitude rectangle.

sulphureous springs indicates that inflow of surface waters extends as deep as the Triassic gypsum layer at least. It should be added that sulphureous springs have been closed during the construction of the Kremasta dam. This also must have contributed to the change of the stress distribution pattern in the region considered.

The 6 1/2 magnitude earthquakes on October 29, 1966, and on May 1, 1967, having occurred in the aftershock period started by the

Kremasta earthquake on February 5, 1966, on the outskirts of the 1964-1970 earthquake density zone (s. Fig. 5), reveal their interplay and close connection; thus the label "late aftershocks" we have put on them is well justified.

The center of the earthquake density pattern over the 7-year period, 1964-1970, is close to the instrumental epicenter of the Kremasta earthquake, i.e. about 18 km to the North of the Kremasta dam. Locations and focal depths for all earthquakes are those given by I.S.C.

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