# RELATIONS BETWEEN VERTICAL MOVEMENTS AND RECORDED ISOTOPIC AGES IN AN OROGEN. THE VERTISCOS GROUP AS AN EXAMPLE

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## A B S T R A C T

Isotopic age determinations of metamorphic minerals usually yield the ages at which the final cooling of the rock in which they participate brought them bellow the "closure temperature" corresponding to each combination of isotopic system and mineral used. By using different isotopic systems on the same metamorphic minerals a fragmentary but, nevertheless, useful time-temperature relation can be established. If the temperature-depth relation (the geotherm) for the period indicated by the isotopic datings can be constrained, then temperature-depth and time-depth relations can also be determined. The average uplift and cooling rates of an orogen for a certain period of time in the past can thus be calculated.

Application of the above to the Late Jurassic "Vertiscos orogen" yields an average uplift rate of 0.3 to 0.4 km/M.a. and an average cooling rate of 4 to 6.5°C/M.a. for the Early Cretaceous Epoch.

# ΣΧΕΣΕΙΣ ΜΕΤΑΞΥ ΚΑΤΑΚΟΡΥΦΩΝ ΜΕΤΑΚΙΝΗΣΕΩΝ ΚΑΙ ΑΠΟΤΥΠΩΜΕΝΩΝ ΙΣΟΤΟΠΙΚΩΝ ΧΡΟΝΟΛΟΓΙΩΝ ΣΕ ΕΝΑ ΟΡΟΓΕΝΕΣ. Η ΟΜΑΔΑ ΒΕΡΤΙΣΚΟΥ ΩΣ ΠΑΡΑΔΕΙΓΜΑ

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## Π Ε Ρ Ι Λ Η Ψ Η

Οι ισοτοπικοί προσδιορισμοί ηλικιών μεταμορφικών ορυκτών κατά κανόνα αποδίδουν τις ηλικίες στις οποίες η τελική ψύξη του πετρώματος κατέβασε τη θερμοκρασία τους κάτω από τη "θερμοκρασία αποκλεισμού" που αντιστοιχεί σε κάθε συνδυασμό ισοτοπικού συστήματος που χρησιμοποιείται στη γεωχρονολόγηση αφενός, και ορυκτού στο οποίο εφαρμόζεται αυτή αφετέρου. Η χρησιμοποίηση διαφόρων ισοτοπικών συστημάτων στα ίδια κατά προτίμηση ορυκτά ενός μεταμορφικού σχηματισμού μπορεί να μας αποδώσει αποσπασματικές μεν, αλλά χρήσιμες σχέσεις χρόνου-θερμοκρασίας. Εαν η σχέση θερμοκρασίας-βάθους (η γεώθερμη) που επικρατούσε κατά τη χρονική περίοδο που αποδίδουν οι γεωχρονολογήσεις μπορεί με κάποιο τρόπο (από τα πετρολογικά δεδομένα π.χ.) να προσδιοριστεί, τότε μπορούν παράλληλα να προσδιοριστούν σχέσεις θερμοκρασίας-βάθους και χρόνου-βάθους. Οι σχέσεις χρόνου-βάθους μας δίνουν τη μέση ταχύτητα ανύψωσης του εσωτερικού ενός ορογενούς για τη χρονική περίοδο που εξετάζεται. Η ανύψωση αυτή είναι αποτέλεσμα

των επιφανειακών ή ενδογενών μηχανισμών εξουδετέρωσης του θετικού αναγλύφου, με τη συνδρομή και της τάσης διατήρησης της ισοστατικής ισορροπίας.

Εφαρμογή των παραπάνω σε ισοτοπικά δεδομένα των πετρωμάτων της ομάδας Βερτίσκου επιτρέπει να εκτιμηθούν ο μέσος ρυθμός ψύξης (4 έως 6.5°C/M.a.) και ο μέσος ρυθμός ανύψωσης (0.3 έως 0.4 km/M.a.) του εσωτερικού του "ορογενούς του Βερτίσκου" κατά τη διάρκεια του Πρώιμου Κρητιδικού, αμέσως μετά τη συγκρότηση του ορογενούς αυτού κατά το Υστερο-Ιουρασικό.

## INTRODUCTION

The internal Hellenides are characterized by their involvment in Early Alpine (Late Jurassic to? Early Cretaceous) orogenic events. The Vertiscos group is an integral part of the internal Hellenides. Late Jurassic folding (Kourou 1991; Sidiropoulos 1991) and the emplacement of the Arnea type leucogranites in this group (Zervas 1984, De Wet 1989) are manifestations of its involvment in the Early Alpine events.

It has been suggested (Kourou 1991; Sidiropoulos 1991) that the Arnea type granitoids are products of crustal anatexis and are related to continental collision. Bebien et al 1986; De Wet 1989; and Dimitriadis and Asvesta (in press) argue for a Middle-Late Jurassic transtentional-transpressional regime near the western margin of the Vertiscos group, above an eastward subduction. A Late Jurassic thickening of at least parts of the Vertiscos continental crust is therefore rather certain. Actually, the presence of magmatic looking kyanite in some of the sattelite pegmatites shouting off the Arnea granitoids testify their generation at elevated pressures, i.e. at depths corresponding to the lower parts of a thickened continental crust. The existence of a mountain range (called here provisionally "the Vertiscos orogen") which was assembled by Late Jurassic as a result of either a frontal collision or of a series of thrusts in a transpressional regime, seems thus very likely. The Vertiscos, Kroussia and Kerkini mountains should be considered as remnants of this Late Jurassic orogen.

No sediments other than Plio-Pleistocene intramontane fillings have ever covered the metamorphic basement exposed in these mountains, therefore the "Vertiscos orogen" was never leveled down since its formation. However, Tertiary tectonism must have also contribute to some extent for the present high relief in these mountains.

Immediately after its formation and continuously since then, the "Vertiscos orogen" should had been exposed to destructive processes (erosion and tectonic denudation) and as a result its deeper parts, responding isostatically, should had been uplifted and progressively cooled.

If erosion was the sole destructive process and if it was acting at a moderate stable rate of 0.3 mm $yr^{-1}$, a thickness of 45 km of crustal material should had been removed from the surface and an equal amount of uplift should had hapened in the deeply buried parts of the " Vertiscos orogen " from Late Jurassic to present. The rate of erosion is declining with time (or with decreasing relief), but the additional action of the tectonic denudation probably compensates for it. It is therefore likely that the rocks exposed today on the surface in the Kerkini, Kroussia and Vertiscos mountains are actually the uplifted to the surface deeper parts of the Late Jurassic "Vertiscos orogen". As such, they should had experienced a post-Late Jurassic cooling due to their gradual uplift. An interesting question is whether this uplift-cooling path has been anyhow recorded in the rocks now at the surface. It is argued here that traces of such a path have indeed been recorded, allowing estimations of the post-Late Jurassic average uplift and cooling rates of the deeper parts of the "Vertiscos orogen". The methodology used to make these estimations is presented next.

## ESTIMATING AVERAGE UPLIFT AND COOLING RATES FROM ISOTOPIC AGE DETERMINATIONS

Average cooling rates of the metamorphic rock components of an orogen for particular periods of time in the past can be estimated, if isotopic age determinations by different methods on their minerals are available (fig.1).

Any isotopic dating method involves the analysis of daughter products which may diffuse through solids. Diffusion is a highly temperature depended process. For each combination of a given isotopic system and a given mineral on which this system works, there is a certain temperature , called "closure temperature", bellow which diffusion of the daughter products outside the mineral becomes insignificant and the isotopic clock starts counting the time (Dodson, 1973,1976). The age obtained from a certain mineral of a metamorphic rock by using a certain isotopic system as a rule signifies the time when the temperature of the rock fell for the last time bellow the closure temperature corresponding to the isotopic system and the mineral used in dating. Different combinations of isotopic systems and minerals can thus provide usefull, although fragmentary, temperature-time relations. These can be converted to temperature-depth relations, if the crustal geotherm at the period of interest can be reasonably constrained. The time-depth relations are further readily converted to average uplift rates for the period considered. The validity of the resulted temperature-depth relation and of the constrained geotherm can be checked against idependently obtained by geothermobarometry temperature-pressure relations.

## ESTIMATING THE POST-LATE JURASSIC UPLIFT AND COOLING RATES OF THE VERTISCOS GROUP METAMORPHICS

The only existing isotopic data suitable for the application of the above method in the Vertiscos group metamorphics are the results of datings performed on mineral separates of two Vertiscos samples (Papadopoulos and Kilias, 1985). My interpretation of these datings is at variance with the interpretation given by Papadopoulos and Kilias, who considered the ages obtained as mineral growth ages. These same ages are here considered as cooling ages.

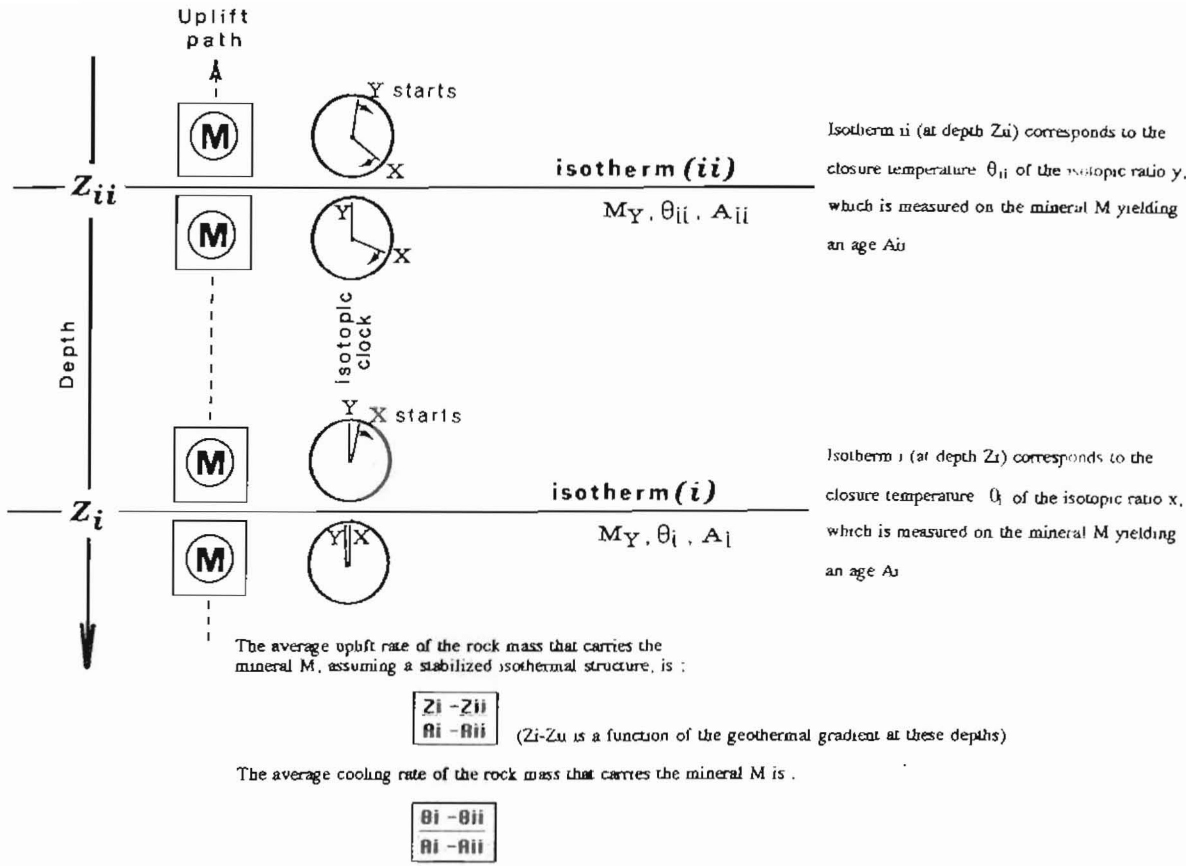


**Fig.1.** Calculating average uplift and cooling rates from isotopic age data.

The combinations (mineral and dating method) selected are the ones for which the closure temperatures are supposed to be well known, while at the same time these temperatures are not low enough to be influenced by factors other than the uplift controlled cooling. The fact that the samples used are only two, certainly means that the finally reaching results, must be considered as only approximates. However, the usefulness of the method is fully demonstrated.

The minerals and the methods used and the result of the dating of the Vertiscos samples are given bellow, allong with the closure temperatures corresponding to each mineral and dating method used.

Sample RA4

| | |
|---|---|
| Rb-Sr on white mica separate.<br>Closure temperature: 500°C<br>Age: 131 ± 10 M.a. | K-Ar on white mica separate.<br>Closure temperature: 350°C<br>Age: 108 ± 4 M.a. |

Sample RA10

| | |
|---|---|
| Rb-Sr on white mica separate.<br>Closure temperature: 500°C<br>Age: 146 ± 15 M.a. | K-Ar on white mica separate.<br>Closure temperature: 350°C<br>Age: 110 ± 4.6 M.a. |

The two samples (RA4 and RA10) record a cooling of 150°C (from 500 to 350°C), attained in 23 and 36 M.a. respectively during Early Cretaceous. The difference in the recorded time lapse in the two samples probably signifies differences in the uplift rate from place to place in the orogen, but as a first approximation we can accept that the recorded durations of cooling from 500 to 350°C are representatives for the whole orogen.

An average cooling rate of about 4 to 6.5°C/M.a. is thus calculated for the "Vertiscos orogen" during the Early Cretaceous. To calculate the average uplift rate however, the geothermal gradient of the orogen during the same period must be somehow constrained. This can be done using petrological data.

The Late Jurassic thickening event had been preceded by a rather long lasted extensional phase, during which the Vertiscos crust had been thinned and was intruded by mantle derived basic melts ( the Jurassic "ophiolites" of the Vardar-Axios zone, and possibly also the basic Volvi complex). The thinned Vertiscos crust was heated by the basic intrusions and partially melted, producing aplitic melts in which the common presence of cordierite megacrysts (later replaced by kyanite+garnet) testify the low pressure conditions prevailed during the extensional phase, (Dimitriadis et al in prep.).

The above tectono-metamorphic evolution constrains the geotherm just after the Late Jurassic thickening event. Since before it the geotherm was very shallow, with the lower crust having attained temperatures of at least 700°C, the thickening couldn't produce the initially steep transient geotherm predicted in the model of England and Thompson (1984), but rather one much closer to the average continental -and therefore rather stable-geotherm (about 15°C/km), with the reasonable provision that the thickening terminated the basic intrusions and the extra heating of the crust. The important consequence of this is that the decompression path followed during the uplift of the deeply buried rock masses in the "Vertiscos orogen" was possibly very close to the quickly established normal geotherm, without the post-thickening extra heating deviation, also predicted in the model of England and Thompson (1984).

Adopting a 15°C/km geothermal gradient dyring the Early Cretaceous for the "Vertiscos orogen", the calculated for the two samples average uplift rates are 0.3 and 0.4 km/M.a.

This Early Cretaceous uplift was the isostatic rebound caused by the unloading of the orogen from its surface material. This unloading had to be of the same rate (0.3 to 0.4 km crustal thickness removed/M.a.). This is actually a fairly reasonable rate of decreasing relief in young orogens.

## CONCLUSIONS

By interpreting the ages yielded by different methods of isotopic datings on mica separates of two Vertiscos samples as cooling ages, and by adopting a 15°C/km geothermal gradient for the "Vertiscos orogen" during the Early Cretaceous (shortly after its assembly in Late Jurassic), an average uplift rate of 0.3 to 0.4 km/M.a. and an average cooling rate of 4 to 6.5°C/M.a. were calculated for the deeper parts of this orogen during the Early Cretaceous.

## REFERENCES


Bebien,J., Dubois,R. and Gauthier,A., (1986). An example of ensialic ophiolites emplaced in a wrench zone: the Innermost Hellenic Ophiolites Belt. Geology. 14, 1016-1019.

De Wet,A.P., (1989). Geology of part of the Chalkidiki peninsula, Northen Greece. PhD Thesis, Wolfson College, Cambridge, 177 p.

Dimitriadis,S. and Asvesta,A., (in press). Sedimentation and magmatism related to the Triassic rifting and later events in the Vardar-Axios zone. Bull. Geol. Soc. Greece, XXVI.

Dodson,M.H., (1973). Closure temperature in cooling geochronological and petrological systems. Contrib. Mineral. Petrol. 40, 259- 247.

Dodson,M.H., (1976). Kinetic processes and themal history of slowly cooling solids. Nature, 259, 551-553.

England,P.C. and Thompson,A.B., (1984). Pressure-temperature-time paths of regional metamorphism, Part I: Heat transfer during the evolution of regions of thickened continental crust. J. Petrol. 25, 894-928.

Kourou,A., (1991). Lithology, Tectonics, Geochemistry and Metamorphism of a part of the western Vertiscos group. The area NE from lake Koroneia. PhD Thesis, Univ. of Thessaloniki 461 p.

Papadopoulos,C. and Kilias,A., (1985). Alterbeziehugen zwischen

Metamorphose und Deformation im zentralen Teil des serbomazedonischen Massivs (Vertiscos Gebrige, Nord-Griechenland) Geol. Runds. 74, 77-85.
Sidiropoulos,N., (1991). Lithology, Geochemistry Tectonics and Metamorphism of the northwestern part of the Vertiscos group. The area of Kroussia mountain north from Kilkis. Phd Thesis, Univ. of Thessaloniki, 592 p.
Zervas,S., (1984). The $^{87}Rb$-$^{87}Sr$ isotopes as tracers of geological and petrological phenomena. Application in the Serbo-Macedonian massif (Greece). Habil. Thesis, Univ. of Athens, 181 p.