MINERALOGICAL AND MICROSTRUCTURAL EVIDENCE FOR WATER-ROCK INTERACTION DURING THE VILARIÇA STRIKE-SLIP FAULT NUCLEATION AND PROPAGATION EVENTS (NE PORTUGAL).

A. Mateus and F.J.A.S. Barriga
Dep. Geol. Fac. Ciências Univ. Lisboa, Bloco C2-Piso 5, Campo Grande, 1700 Lisboa, Portugal

Abstract: Comprehensive and multidisciplinary characterisation of five segments of the Vilariça strike-slip fault show that the deformation cycles responsible for the fault zone nucleation/propagation in hercynian times (late D_3 to late D_4 regional phases of deformation) comprise periods of intense fluid circulation. The hydrothermal activity lead to strong and polyphasic alteration of the host rocks and to the development of siliceous fault precipitates that are locally enriched in sulphides + carbonates ± electrum and/or golden silver. Fluid bulk composition evaluation (inferred from fluid inclusion data and from the stability conditions of the successive hydrothermal mineral parageneses) suggests that the origin of the early •quo-carbonic solutions pumped to the fault zone is mainly metamorphic. The last stages of the fault zone evolving path involve, on the contrary, the circulation of aqueous, highly modified, meteoric fluids.

Resumo: A caracterização multidisciplinar detalhada de cinco segmentos do desligamento de Vilariça revela que os ciclos de deformação responsáveis pela nucleação/propagação da zona de falha em tempos hercínicos (fases de deformação regional tardi D_3 a tardi D_4) compreende periodos de intensa circulação de fluidos. A actividade hidrotermal, conduzindo à alteração polifásica e pronunciada dos domínios rochosos adjacentes à zona de falha, permite ainda o desenvolvimento de precipitados siliciosos localmente enriquecidos em sulfuretos + carbonatos ± electrum e/ou prata dourada. A avaliação da composição global dos fluidos intervenientes nos vários patamares evolutivos (com base nos dados de inclusões fluidas e nas condições de estabilidade das sucessivas paragéneses minerais de alteração hidrotermal) permite atribuir uma origem metamórfica às soluções aquo-carbónicas bombeadas para a zona de falha no decurso dos eventos de deformação mais precoces. Os últimos estádios evolutivos da zona de falha envolvem, pelo contrário, a circulação de soluções aquosas meteóricas bastante modificadas.

Key words: late-hercynian strike-slip faults; P-T-t evolving path; hydrothermal fluid chemistry.
Palavras chave: desligamentos tardi-hercínicos; percurso P-T-t; quimismo dos fluidos hidrotermais.

The Vilariça Fault Zone (**VFZ**) is one of the major left-lateral NNE-SSW elements of the profuse strike-slip fault network in the NW Iberian Peninsula that was generated in late-hercynian times (D_4 and late-D_4 regional phases of deformation) - *e.g.* Ribeiro (1974). The geometry of the **VFZ** northern segment (in Trás-os-Montes region) shows more or less pronounced inflections in strike and branch development at different scales that are ascribable to the coalescence of en echelon strike-slip fault segments, and/or to the influence of pre-existing structural anisotropies, such as semi-ductile shear zones of Westphallian or earlier age. Comprehensive and multidisciplinary characterisation of five northern fault key-segments revealed that polyphasic siliceous precipitates of hydrothermal nature seal either the main fault zone or subsidiary structures (fig.1). Relics of granitic and quartz-phyllitic protomylonites, as well as ultracataclasites of volcanic nature, can be found within the quartz fault fillings, reflecting the typical deformation regime related to the early tectonic increments along the fault, probably induced by the late-D_3 regional stress field. Quartz-cataclasites and siliceous breccias (sometimes enriched in Fe and/or Mn oxides and hydroxides) are, therefore, the most common fault rocks, and constitute the privileged record of the active deformation mechanisms in brittle regime. Nevertheless, according to the available microstructural data, it is possible to distinguish the main quartz generations that are correlative of the fluid pulses associated to deformation cycles which took place in semi-ductile /semi-brittle transition, semi-brittle and brittle regimes, respectively (Mateus & Ribeiro, 1991; Mateus *et al.*, 1991; Mateus, 1995).

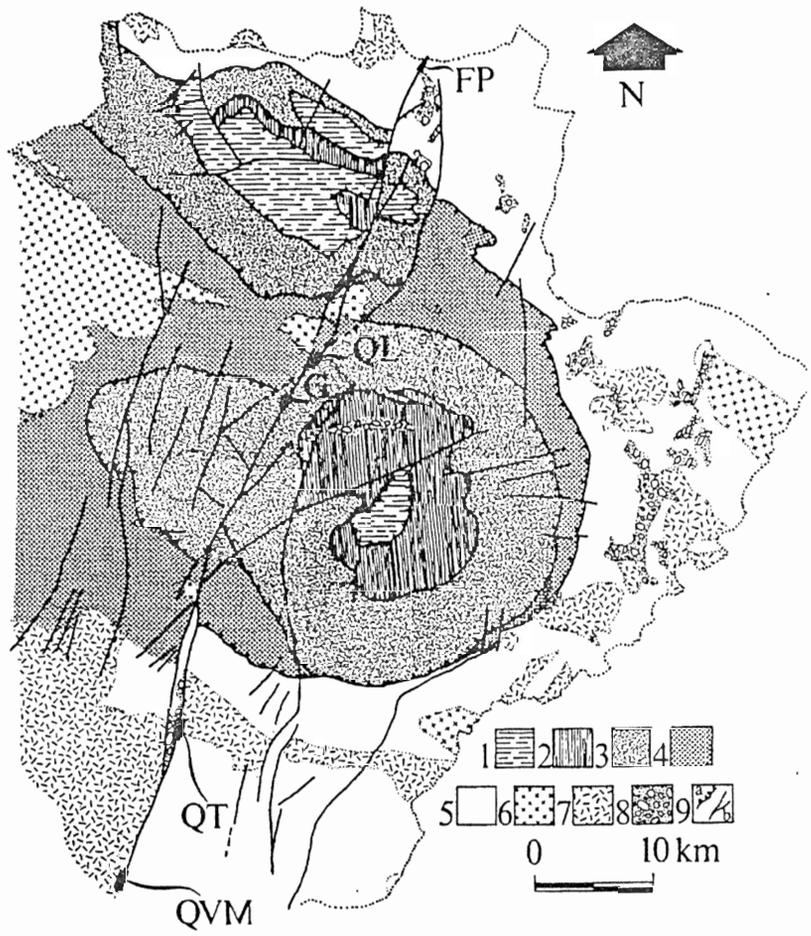

Fig.1 - Synthetic geological setting of the **VFZ** northern segment (symplified after Ribeiro, 1974) and localisation of the studied fault segments: Quinta Vale do Meão (**QVM**), Quinta da Terrincha (**QT**), Grijó (**G**), Quintela de Lampaças (**QL**), and França-Portelo (**F-P**). **1** - Upper Allochthonous Unit; **2** - Ophiolite Complex; **3** - Lower Allocthonous Unit; **4** - Para-autochthon; **5** - Autochthonous Domain; **6** - Late-hercynian granites; **7** - Hercynian granites; **8** - Cenozoic cover deposits; **9** - **a)** Major thrust plane; **b)** Main fault trace.

The polyphasic fluid pumping to the fault zone is also responsible for the development of metasomatic processes in fault host lithologies, leading usually to strong silicification and sericitisation complemented by minor chloritisation and dissemination of sulphide (pyrite ± arsenopyrite + sparse amounts of sphalerite, galena and chalcopirite) and carbonate (mostly siderite ± Mg-siderite ± dolomite) when in presence of siliceous fault precipitates enriched in those minerals and/or their oxidised equivalents. It is worth to note that the sulphide-carbonate paragenesis within quartz veins may comprise electrum and/or golden silver as accessory phases. Strongly altered, clay enriched, bands underline the reactivated faults. In a general perspective, the polyphasic hydrothermal alteration led to gains of variable amplitude in Zn, Pb, Cu, Mn, Sb, As, S, Bi, Ga and U, besides the obvious silica increase. Significant gains in W(±Sn) are also characteristic of highly deformed granitic domains, particularly those that were object of syn-D_3 semi-ductile deformation, subsequently retaken by **VFZ**. Alkali and earth-alkali (as well as Fe and Mg) contents are highly dependent on the amount and the nature of primary and secondary phyllosilicates (K-micas, chlorites and clays). For all the studied cases, there are, however, significant variations on the hydrothermal alteration intensity and typology which denote: (i) the influence of primary parageneses; (ii) variable fracture density; (iii) distinct fluid/rock interactions; and/or (iv) different fluid compositions, as put in evidence by fluid inclusion studies. Mass balance calculations suggest that the bulk alteration in fault host lithologies led to volume increases in the range 14 - 18% (Mateus, 1995; fig.2).

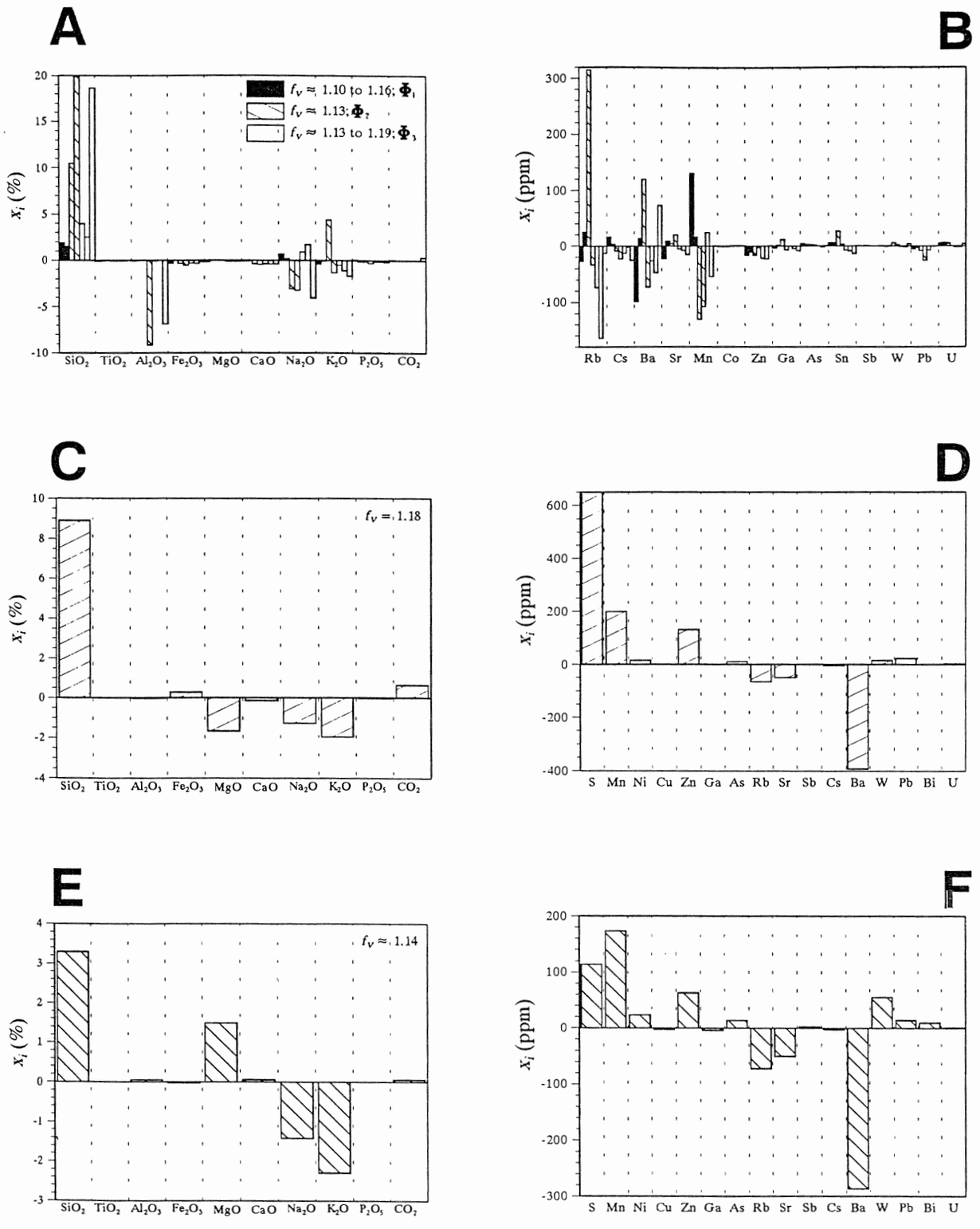

Fig.2 - Gains and losses of major element oxides and selected trace elements in hydrothermally altered granite facies Φ_1, Φ_2 and Φ_3 (**A**; **QVM** and **QT** fault segments) and metasediments (**B** and **C**; **QVM** and **F-P** fault segments, respectively), expressed as wt% or ppm per 100 g of rock, for the most probable volume factor (f_v). Mass balance calculations were performed according to the methodology proposed by Gresens (1967). Adapted from Mateus (1995).

The general evaluation of fluid inclusion data and of stability conditions for the successive hydrothermal mineral parageneses (based on experimental results, theoretical thermodynamic analyses and on the available mineral chemistry data) suggests that (fig. 3; Mateus, 1995):

(i) the hydrothermal fluids associated to deformation cycles in semi-ductile and semi-ductile/semi-brittle transition regimes are aquo-carbonic, reduced and acidic. With few exceptions, their salinity ranges typically from low to moderate values (< 15 eq wt% NaCl). High $a(K^+)/a(H^+)$ and $a(Ca^{2+})/a^2(H^+)$ fluid ratios can also be inferred for a decreasing temperature gradient between 350°C and 250°C, under global pressures within the highly probable range 1.5 - 3 kbar;

(ii) the fluid pulses correlative of the deformation cycles in semi-brittle regime (200-250°C, 1-2 kbar) include mainly aqueous, acidic and reduced solutions with a low density CO_2 phase and low salinity (usually ≤ 5 eq wt% NaCl). From the correlative metasomatic processes it is also possible to point out relative enrichments in Na^+ and Mg^{2+} ($\pm Fe^{2+}$), as well as a gradual temperature decrease covariant with the $a(K^+)/a(H^+)$ and $a(Ca^{2+})/a^2(H^+)$ fluid ratios;

(iii) the deformation cycles in brittle regime trigger off the circulation of aqueous, oxidising and relatively acidic fluids with variable salinities (< 6.5 eq wt%NaCl) under temperatures below 200°C and global pressures not above 1 kbar. Relative K^+ and Fe^{2+} ($\pm Mg^{2+}$) fluid enrichments can be also highlighted from the chemical signature presented by the late-secondary mineral assemblages.

According to the available data, the development of the gold-silver mineralisations in the França area (N of Bragança), as well as the deposition of sulphides and carbonates within the siliceous fault-zone filling in the Quintela de Lampaças sector (N of Macedo de Cavaleiros), are mainly due to the circulation of hydrothermal fluids during seismic events in a semi-brittle/brittle transition regime. In this context it should be emphasised that the period of gold-silver alloys formation post-dates the major events of sulphide/siderite deposition, being so ascribable to the low-temperature hydrothermal activity synchronous of the deformation cycles in brittle regime (Cathelineau *et al.*, 1993; Barriga *et al.*, 1995; Mateus, 1995).

Fluid bulk composition evaluation suggests that the origin of the early fluid pulses pumped to the fault zone is mainly metamorphic, although significant changes of the primary chemical signature may be attributed to system despressurization via seismic yielding. Mixtures of variable proportions between metamorphic and modified meteoric solutions are correlative of the deformation events that occurred in semi-brittle and semi-brittle/brittle transition regimes. The last stages of the **VFZ** evolving path embraces, probably, the circulation of highly modified meteoric fluids.

Acknowledgments: This study was financed through EEC Contract MA2M-CT90-0033 (Multiannual R&D Programme) and JNICT Contract PMCT/C/CEN/103/90. W.S. Fyfe, F. Longstaffe; M. Cathelineau and A. Ribeiro contributed with extensive and stimulating discussions. They are most gratefully acknowledged. A. Mateus acknowledge also an INIC PhD schollarship (1991/94).

References:

Barriga, F.J.A.S.; Ribeiro, A.; Fyfe, W.S.; Longstaffe, F.J.; Mateus, A.; Dias, R.; Cabral, J.M. (1995) - *Mineralizações auro-argentíferas associadas à Falha da Vilariça no sector de Quintela de Lampaças*. Projecto nº PMCT/C/CEN/103/90 do Programa Mobilizador em Ciência e Tecnologia, J.N.I.C.T. - Relatório Final: 110 pg..

Cathelineau, M.; Boiron, C.M.; Palomero, F.G.; Urbano, R.; Florido, P.; Pereira, E.; Noronha, F.; Barriga, F.J.A.S.; Mateus, A.; Yardley, B.; Banks, D. (1993) - *Multidisciplinary studies of Au-vein formation. Application to the Western part of the Hesperian Massif (Spain- Portugal)*. Project Nº MA2M-CT90-0033, Multiannual R & D Programme (1990-1992) on Primary raw - materials and recycling of non-ferrous metals, EEC - Final Report: 391 pg..

Mateus, A. (1995) - *Evolução tectono-térmica e potencial metalogenético do troço transmontano da Zona de Falha Manteigas-Vilariça-Bragança*. Dissertação de candidatura ao grau de Doutor, Fac. Ciências da Universidade de Lisboa: 195 pg. (TOMO I); 994 pg. (TOMO II).

Mateus A., Barriga, F.J.A.S., Ribeiro, A. (1991) - "Cyclic deformation and flow instabilities in the nucleation of the Vilariça strike-slip fault, NE Portugal". *Mechanical Instabilities in Rocks and Tectonic*, Terra Abstracts Supplement 5 to Terra Nova Volume 3: pg. 25.

Mateus A., Ribeiro, A. (1991) - "Scaling analysis of fracture patterns adjoining the Vilariça strike-slip fault zone, NE Portugal: a Geometric approach to fault nucleation and growth modelling". *Toronto 1991 - G.A.C./M.A.C./S.E.G. Meeting*, insert to the *Canadian Mineralogist*, vol. **29**, part **1**: pg. A81.

Ribeiro, A. (1974) - *Contribuition à l'étude tectonique de Trás-os-Montes Oriental*. **Mem 24** (n.s.) *Serv. Geol. Portugal*: 168 pp.

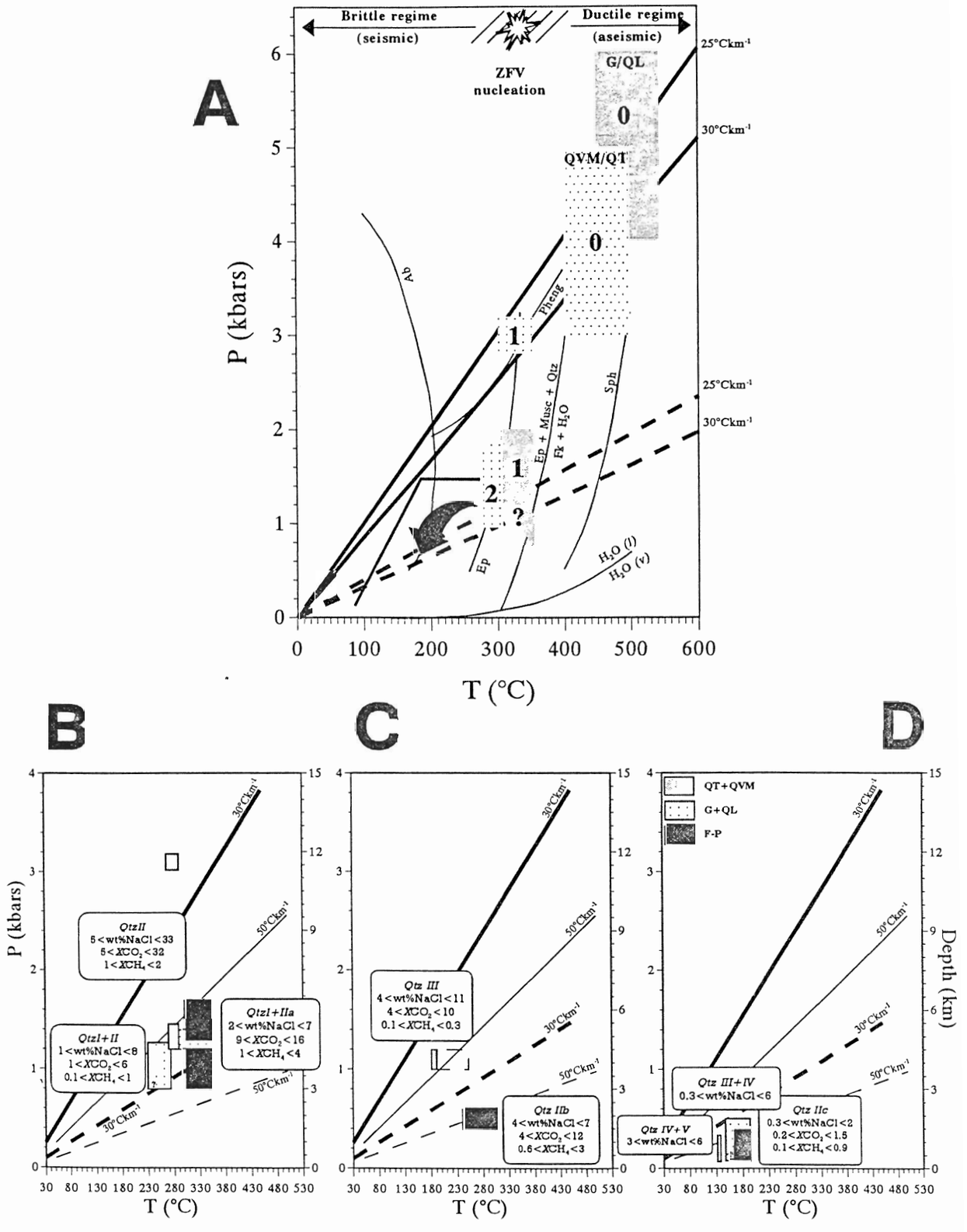

Fig.3 - Schematic representation of the P-T-t evolving path for the Variça strike-slip fault according to the available fluid inclusion data and to the P-T stability domains of the hidrothermal mineral parageneses as well as the observed microstructures (**A**). Diagrams **B**, **C** and **D** contain the most pertinent chemical parameters obtained from microthermometry data of fluid inclusions in different quartz generations of the five studied fault segments whose deposition is correlative of the hydrothermal activity that took place in semi-ductile, semi-brittle/brittle transition and brittle regimes, respectively.