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GEOLOGY

# Tectonic Fragmentation of Basaltic Melt

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Morphologically unusual small (10 × 5 cm) basic segregations have been found in Lower Carboniferous metamorphosed sandy–schistose rocks in the Late Hercynian Tastau volcanoplutonic structure (hereafter, pluton) in eastern Kazakhstan. They apparently resemble nodules, boudins, or pebbles in conglomerate. The mode of occurrence of these segregations suggests that they have intrusive contacts with sedimentary host rocks and that their formation is related to the fragmentation of basic melt during its synkinematic injection into a rapid shear strain zone. Tectonic processes probably comparable with present-day upper crustal earthquakes decreased the viscosity of the metasedimentary matrix, provoked surface tension at the melt/matrix interface, and separated some portions of the melt as oval and other rootless bodies. These conditions are discussed in the present communication.

The Tastau volcanoplutonic structure is situated in the central Zaisan Fold System within the Chara Shear Zone. The present-day structure of the Zaisan Fold System is regarded [1] as an accretionary wedge characterized by a tectonic juxtaposition of blocks, sheets, and slices of various (in composition and age) rocks and a predominance of inliers of oceanic crust. The Late Hercynian shear zone formed in consequence of the collision of the Kazakhstan and Altai–Mongolian continents. This collision led to the disintegration of continental margins, and to squeezing and extrusion of sediments of marine basins together with the underlying oceanic crust, folding, and faulting [2]. In the Chara Zone subjected to high pressures, the formation of serpentinite melange protrusions and duplexes [3] was accompanied by rotation of rigid blocks.

The formation of the Late Carboniferous–Early Permian Tastau and other Late Paleozoic volcanoplutonic complexes (Fig. 1) is related to the postcollisional extension in the Zaisan Fold System [4, 5]. In plan view, the studied structure is an elliptical body (13 × 18 km) consisting of two ring intrusions (Fig. 2). The country rocks host arcuate belts of diabase, syenite, granosyenite, and granite dikes that are conformable to the general trend of this structure. Granitic stock and a radial system of felsitic dikes occur in the center. The country sedimentary rocks consist of Lower Carboniferous polymictic sandstones and carbonaceous–clayey and clayey siltstones that are metamorphosed under conditions of greenschist facies and deformed into large linear folds. Metasedimentary rocks of the ring-shaped structure host dikes, veins, and linear NW-trending zones with numerous small (10 × 5 cm) basic segregations that correspond in composition to contaminated tholeiitic basalt. The basic segregations are located in linear zones that intersect the Tastau volcanoplutonic structure center (Fig. 2). The number of basic bodies increases toward the structure center, where the dikes are crosscut by granosyenites and granites of the central stock. The country rocks are transformed into hornfels both around this stock and within linear zones. Near the central stock, the country rocks underwent brecciation and cataclasis. The breccia consists of angular, oriented and varisized siltstone fragments incorporated into sandstone. The reverse strike-slip faulting in metasedimentary rocks is marked by C/C' and C/S extensional tectonites and sheath folds, which indicate the volumetric shear flow of rocks [6].

By morphology and character of contacts, the basic bodies may be classified into four types (Fig. 3). The first type includes *dikes* more than 10 cm thick. The second type comprises crosscutting *systems of veins* that are fragmented and deformed into sheath folds. The third and fourth types are *spheroidal and irregular bodies,* respectively.

The *spheroidal bodies* are most abundant. They occur as globules (hollow and sacculate structures) 2–10 cm in size. Their cross sections exhibit distinct contact zones. The hollow and sacculate segregations are a variety of globules with internal zone filled with metasedimentary rocks. The chilled margins at contacts with host rocks are observed both on the outer and inner walls of hollow bodies (Fig. 3).

The *irregular bodies* are the most diverse in morphology (amoeboid, oblong drop-shaped, fluidal, and

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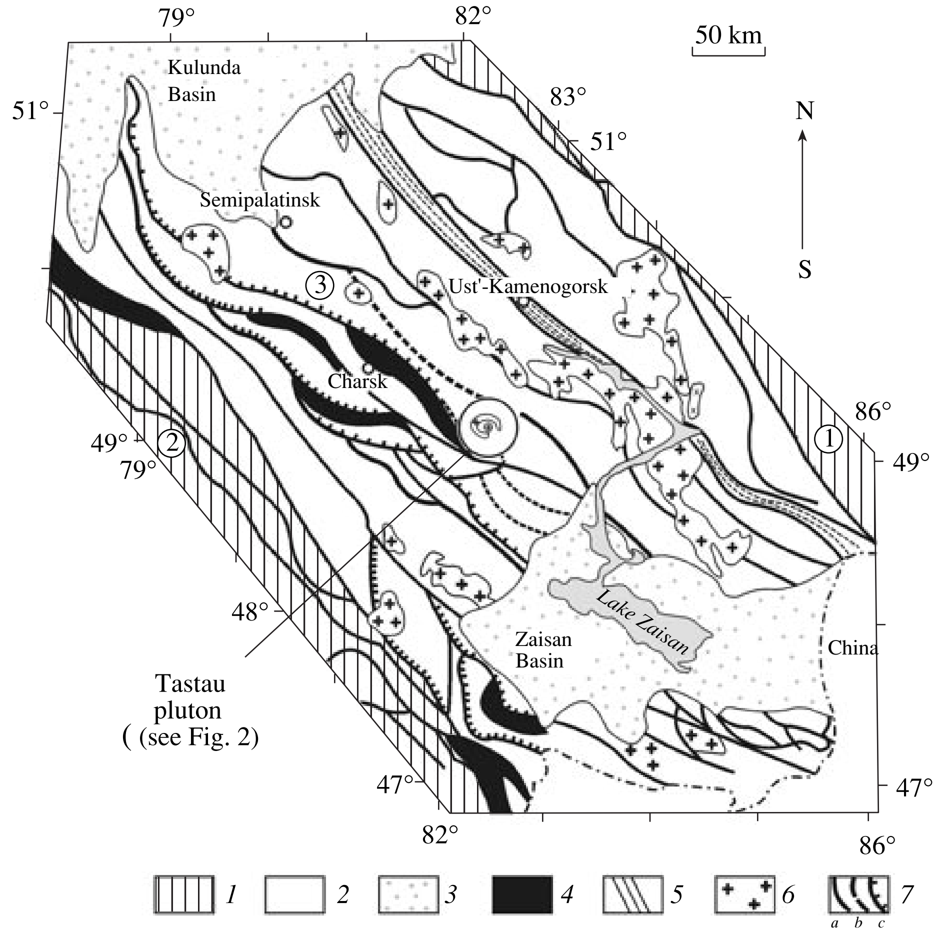


**Fig. 1.** Tectonic scheme of the Zaisan Fold System, eastern Kazakhstan (supplemented with data from [1, 4]). (*1*) Precambrian and Lower Paleozoic; (*2*) Middle–Upper Paleozoic and Mesozoic; (*3*) Cenozoic; (*4*) undivided complexes of the oceanic crust: serpentinite melange, ophiolites, and blocks of high-pressure metamorphic rocks; (*5*) undivided complexes of the Irtysh Shear Zone; (*6*) undivided (Middle–Late Paleozoic and Early Triassic) collision and postcollision granites; (*7*) faults: (*a*) proved, (*b*) inferred, (*c*) thrust faults. Lithostructural zones: (1) Gornyi Altai, (2) Chingiz, (3) Chara Shear Zone of the Zaisan Fold System.

lobed). They often group in chains conformable to the parental veins and dikes. Such bodies often have scalloped and other types of contact with host rocks.

The basic rocks have a rather uniform composition—massive clinopyroxene–plagioclase diabase and porphyritic diabase mainly composed of doleritic groundmass and phenocrysts of calcic plagioclase (An 94) and clinopyroxene (salite). Ore minerals and xenomorphic quartz make up the anhedral dissemination. Diabase is subjected to strong epigenetic alteration and replaced by epidote and calcite. Near the contact, the size of phenocrysts diminishes and clots of plagioclase phenocrysts cemented by devitrified glass appear. Pyroxenes are replaced by amphiboles. Calculations of *PT* parameters based on the Al content in amphiboles according to the method described in [7] yielded 700°C and 1 kbar [7].

The formation of such small rootless intrusive bodies is unusual, because the melt was injected into lithified rigid rocks. Dikes with parallel walls are usually formed during the injection of melt into relatively rigid rocks under hypabyssal conditions. Deformation of consolidated dikes promotes the formation of brittle extensional cracks and boudins. If the deformation continues, the boudins may rotate, undergo mechanical treatment, and transform into rounded bodies. However, in our case, all diabase bodies have undeformed inner and outer contacts. Thus, they are intrusive bodies (rather than boudins) with chilled margins. Hence, the scenario of boudinage is unacceptable.

The undeformed outer chilled zones of dikes, spheroidal, and other bodies indicate that the melt had been fragmented before its consolidation. This conclusion is also supported by the presence of ductile deformation of irregular bodies with scalloped and flamelike contacts typical of mechanical mixing of low-viscous environments [8].

The small size of basic bodies (10 ± 5 cm) indicates that the fragmentation was a very intense and short-term process [9], since such fragments are solidified very quickly. Granitoids, meladiorite, and diabase in

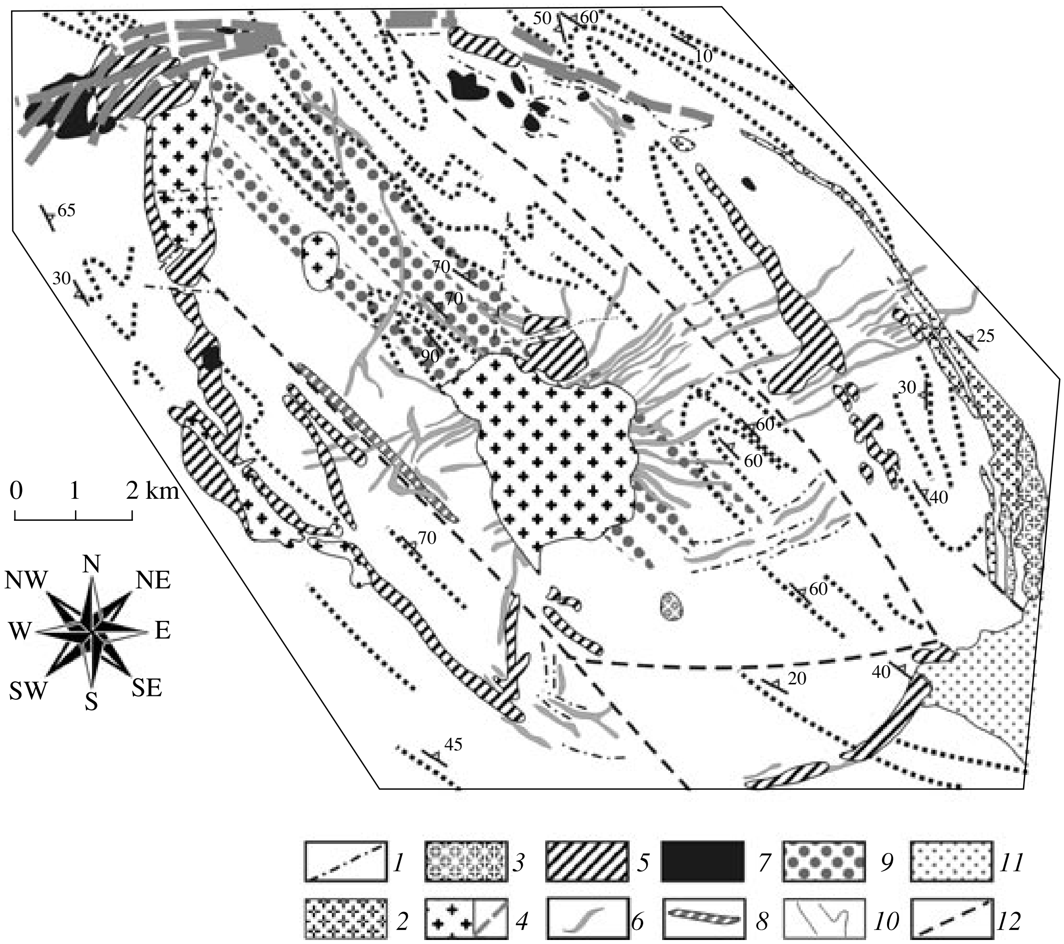


**Fig. 2**. Geological scheme of the Late Paleozoic Tastau volcanoplutonic structure (after [5]). (*1*) Postgranitic diabase, granosyenite and syenite porphyry dikes; (*2*) leucogranite; (*3*) quartz syenite; (*4*) granite and granosyenite; (*5*) melanocratic granosyenite; (*6*) subvolcanic felsite and granite porphyry dikes; (*7*) olivine gabbro and gabbronorite; (*8*) plagioporphyry rocks; (*9*) linear zones enriched in dolerites; (*10*) Lower Carboniferous sandy–shaly rocks; (*11*) loose sediments; (*12*) faults.

the framing of the ring-shaped pluton display structures testifying to magma mingling. This emphasizes the short-term character of tectonomagmatic events and indicates that the injection of basaltic melt occurred simultaneously with the emplacement of intrusive complexes of the Tastau association.

The melt was fragmented when the viscosity of the metasedimentary matrix decreased to a level comparable with the viscosity of basic melt. It is only in this case that separate portions of basic melt may acquire a spheroidal shape due to the surface tension and retain such morphology after solidification [10].

The short-term decrease in viscosity of the metasedimentary matrix is also indicated by the retained angular fragments and lack of sorting in small siltstone fragments in cataclasites.

The orientation of linear zones enriched in basic inclusions coincides with trends of the major shear faults in the Tastau volcanoplutonic structure and in the Chara strike-slip zone as a whole. Folds and extensional tectonites typical of shear strains are observed in the metasedimentary rocks [6]. One can observe within a single outcrop basic dikes and veins confined to the brittle extensional cracks that, together with country rocks, are involved in ductile deformation and transformed into sheath folds. These structures served as sources for irregular and spheroidal bodies (Fig. 3). The deformed dikes, veins, spheroidal, and irregular bodies are crosscut by systems of X-shaped thin (<2 cm) veins of the same composition. Hence, the melt injections bear spatial and genetic relation to the zones of volumetric shear flow. The morphology of basic bodies and their mode of occurrence indicate the sequence of injections and deformation from brittle failure to viscoelastic flow and then again to brittle fracturing.

The basic melt was injected virtually instantaneously at the moment of shear fracturing. The process was accompanied by scattering of the melt from dikes and veins to the irregular and spheroidal bodies. Depending on the vein orientation, the melt scattered either along the dike strike (with the development of pseudobudinage), at an acute angle (with the formation

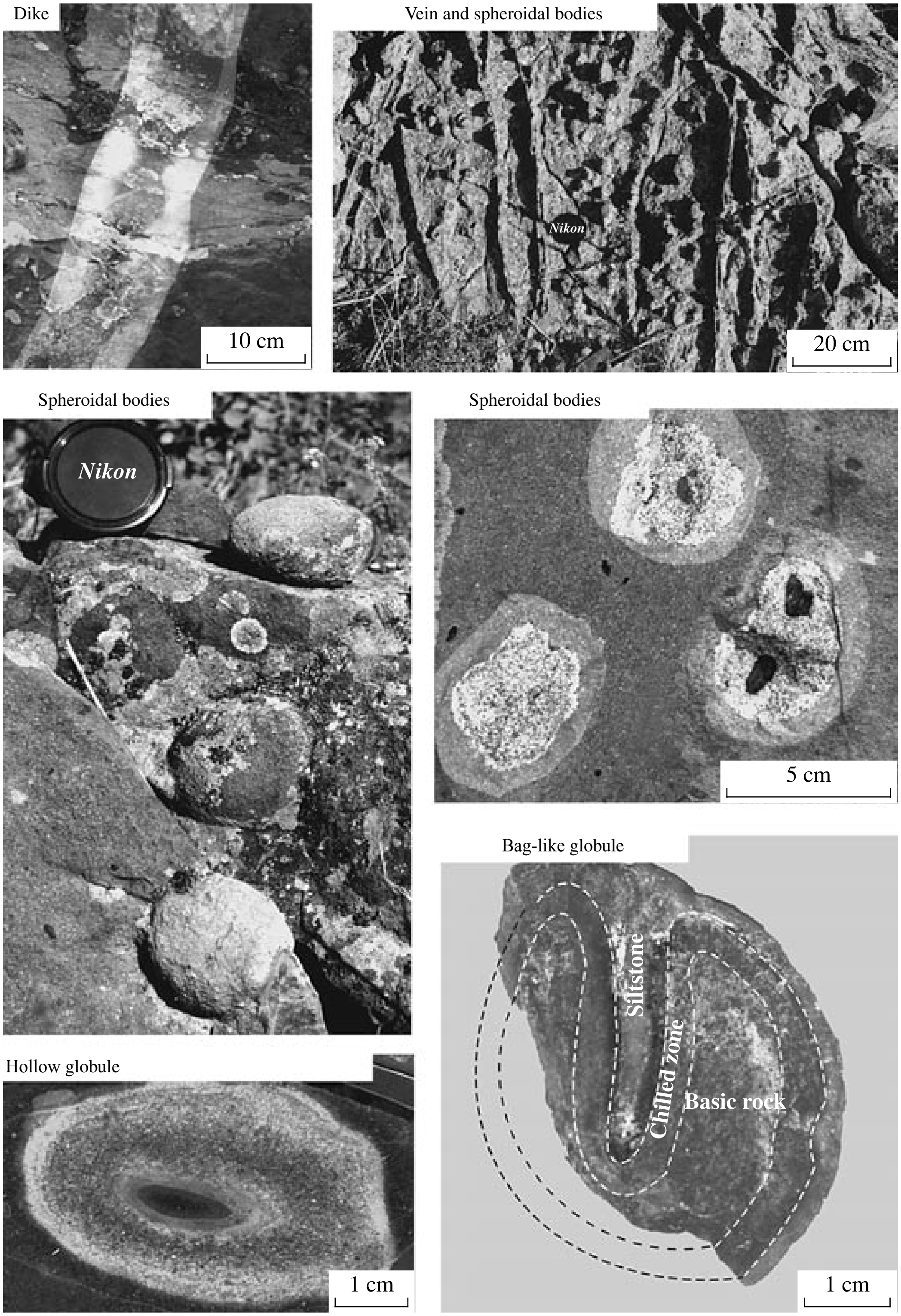


**Fig. 3.** Main types of diabase bodies in the Tastau volcanoplutonic structure.

of sheath flow folds), or along the flow scattering (Fig. 4). After the short-term decrease in the viscosity of the metasedimentary matrix, brittle fracturing again became predominant. This short-term and vigorous tectonic event provoked the melt fragmentation, on the one hand, and provided for the preservation of the already consolidated melt as hollow and sacculate globules with undeformed and chilled outer zone, on the other hand.

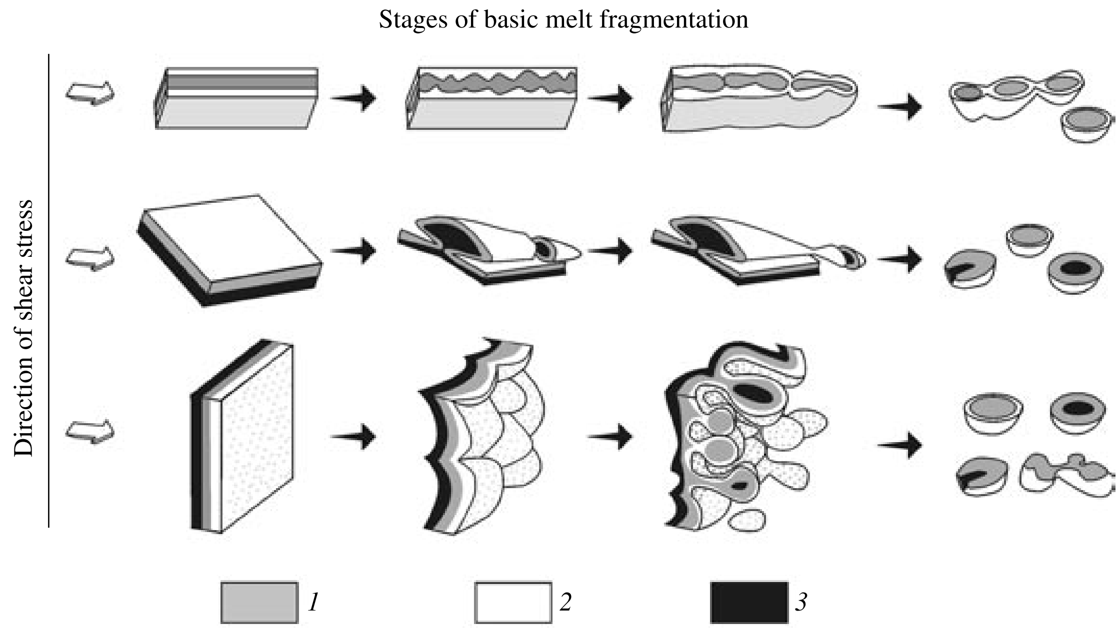


**Fig. 4.** Model of fragmentation of basic melt during the shear flow of metasedimentary matrix. (*1*) Basaltic melt; (*2*) sandstone; (*3*) siltstone.

Generation of basaltic melt commonly requires a high rate of lithosphere extension, which is necessary for the development of decompression melting in the mantle [11] and the magma ascent toward the upper crust. Fragmentation and scattering of melt took place during the short-term flow of the crustal material and was rapidly followed by fracturing typical of shallow-seated environments. Hence, the basic segregations described above may indicate an abrupt change of tectonic regime during the extension of collisional orogen.

The structures related to fragmentation and scattering of basic melt in the Tastau volcanoplutonic structure may be regarded as indicators of short-term (in terms of geological scale) processes in a medium with low viscosity that is comparable to the viscosity of melt.

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## REFERENCES

1. N. A. Berzin, R. G. Coleman, N. L. Dobretsov, *et al.*, Geol. Geofiz. **35** (7/8), 8 (1994).
2. N. V. Polyanskii, Geol. Kazakhstana, No. 4, 12 (1999).
3. S. Yu. Belyaev, *Tectonics of the Chara Zone, Eastern Kazakhstan* (UIGGM, Novosibirsk, 1985) [in Russian].
4. V. S. Kuzebnyi, P. V. Ermolov, and V. D. Tyan, *Problems of Igneous Geology in Siberia* (Nauka, Novosibirsk, 1978), pp. 3–21 [in Russian].
5. P. V. Ermolov, A. G. Vladimirov, A. E. Izokh, *et al.*, *Orogenic Magmatism of Ophiolitic Belts* (Nauka, Novosibirsk, 1983) [in Russian].
6. C. W. Passchier and R. A. J. Trouw, *Microtectonics* (Springer-Verlag, Berlin, 1996).
7. J. L. Anderson and D. R. Smith, Am. Mineral. **80**, 549 (1995).
8. T. Furman and F. J. Spera, J. Volcanol. Geotherm. Res. **24**, 151 (1985).
9. B. Zimanowski and R. Buttner, J. Volcanol. Geotherm. Res. **114**, 37 (2002).
10. D. Snyder, C. Crambes, St. Tait, and R. A. Wiebe, J. Geol. **105**, 75 (1997).
11. J. A. Pearce and I. J. Parkinson, Geol. Soc. London Spec. Publ. **76**, 373 (1993).