Model types of tonalite-trondhjemite melts and their natural counterparts

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Several models have been proposed for the origin of tonalite-trondhjemite (TT). The most likely petrogenetic process is considered to be partial melting of mafic sources such as amphibolite, eclogite and garnet-bearing granulite that is proved by experiments on natural amphibolites. It is clear that trace element composition of TT mainly depends on residue mineral association, which in turn is closely related to $P-T$ conditions. Consequently the composition of natural TT can be used to evaluate the melting conditions.

Available experimental data (residue mineral content and degree of melting) (Beard and Lofgren, 1991; Sen and Dunn, 1994; Rapp and Watson, 1995; Winther, 1996) allow to calculate possible concentrations of some trace elements in model TT melts generated in wide range of P (3–22 kbar) and T (800–1040°C). To cover range of probable natural mafic rocks, trace element contents in model sources are assumed to be equal to that in tholeiites of the Archaean greenstone belts and MORB. Five types of model TT melts with different geochemical characteristics correspond to following distinct restites: gabbroid (Pg + Cpx ± Opx) (1), amphibolitic (Pg + Hb) (2), garnet-amphibolitic (Gar + Pg + Hb + Cpx) with low (<20%) and high (>20%) garnet content (3) and (4) and eclogitic (Gar+Cpx) (5). From first type to fifth the model TT melts are progressively depleted in *HREE*, Y and enriched *LREE* and Sr due to change of residue association.

Analysis of data set on the Precambrian and Phanerozoic TT suites shows that natural TT are comparable to their model counterparts in *REE*, Y and Sr contents. Proposed Yb–Eu diagram (Fig. 1) allows to reconstruct the general petrogenetic history of the natural TT. Yb concentration indicates the type of residue association and conforming most likely $P-T$ region of melt generation. In addition the trends of simultaneous Eu and Yb depletion allow to evaluate degree of fractional crystallization of parental melt since crystallization of main phases (hornblende and plagioclase) from TT melt decreases these element concentrations.

Excepting TT formed in low P (types 1 and 2) in according to Yb and Y content the most of the Archaean TT (not less than 70%) could originate in equilibrium with eclogitic and garnet-enriched amphibolitic restites. Proportion of TT extremely depleted in *HREE* decreases among the Proterozoic granitoids. Among the Proterozoic plagiogranitoids 4 and 5 types of TT are equally representative. The Phanerozoic TT and adakites have still higher typical Yb concentration (>0.65–0.7 ppm) that make impossible their origin in equilibrium with eclogitic and garnet-enriched amphibolitic restite. Thus variations in Yb show tendency of change of dominant residue associations and consequently prevailing P-T conditions of melting from the Archaean to Cenozoic. Probably adakites can not represent

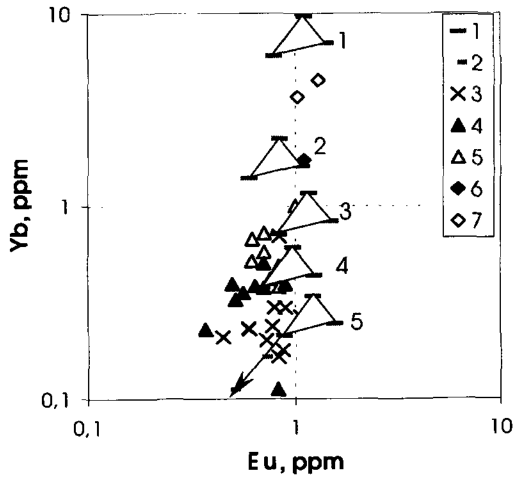

FIG. 1. Diagram Yb–Eu for the Archaean TT. 1–2: trace element concentrations in the model TT melts and melt undergoing by fractional crystallization; 3–7: trace element concentrations of five different geochemical types of the Archaean TT. Triangles with numbers show fields of probable compositions of five types of model melts formed from the Archaean tholeiites and MORB. Arrow shows the trend of fractional crystallization.

complete analogies of the most typical Archaean TT but are comparable to those TT which are formed in equilibrium with garnet-bearing amphibolites.

In addition to Yb variations the Proterozoic and the Phanerozoic TT and adakites progressively enriched in Sr (Fig. 2). It is mainly the feature of granitoids with higher Yb (> 0.6 ppm). Increased Sr content in natural TT in relation to model melts may be due to melting of mafic sources with initial high Sr concentration or enriched in Sr by postmagmatic processes. Nevertheless it does not explain extremely high Sr content in some adakites (up to 1800 ppm) and the Proterozoic TT (800–1400 ppm) from south-western margin of the Siberian platform. The possible model of such high-Sr TT origin may include melting of mafic source enriched in Sr with removal of eclogitic restite followed by mixing of initial melt with residue minerals and their dissolution during melt ascent. Resulted melt essentially preserves high Sr concentration but is distinctly enriched in Yb.

Reconstructed $P-T$ parameters indicate only relative depths and thermal conditions of melt origin. According to geochemical data four tectonic settings may be revealed. Extension regime in conjunction with isotherm rise which are characteristic of spreading zones corresponds to the first type TT. Second type TT can be formed in low depth and at relative low temperature conditions conforming to thin crust regions such as immature ocean arcs. High pressures and temperatures necessary to fifth type TT occur in the basement of the thick crust or in the mantle depth that could corresponds to the melting of the underplating or tectonically removed basalts or the melting of descending slab in active or palaeosubduction zones. The third and fourth types TT are formed at intermediate pressure mainly typical to low crust conditions.

It is possible that change of prevailing P-T conditions and geodynamic setting of TT generation from the Archaean to the Phanerozoic is due to evolution of the Earth's thermal regime and plate-tectonic processes. For early Precambrian the most common process could be slab melting in high temperature but less deep subduction zones whereas the low crustal melting of basalts related with extension regime and heat influx was dominant in the Phanerozoic. Exceptions are the high-Sr adakites and TT whose formation could be immediately related with subduction processes. The Proterozoic period was the time of the diverse geochemical types of TT and corresponding tectonic setting of their formations.

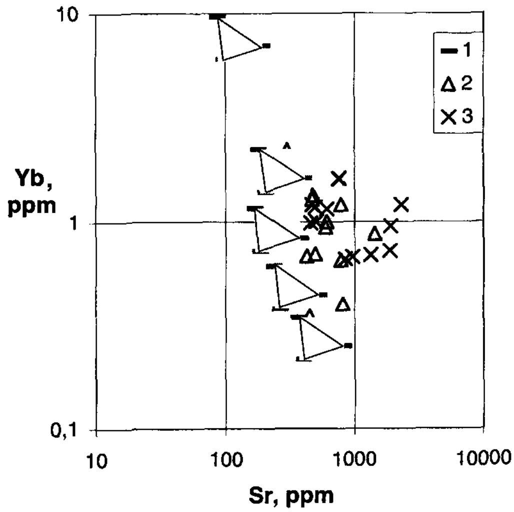

FIG. 2. Diagram Yb–Sr for the Phanerozoic TT and adakites. 1: trace element concentrations in the model TT melts; 2–3: trace element concentrations in the Phanerozoic TT and adakites. Triangles with numbers show fields of probable compositions of five types of model melts formed from the Archaean tholeiites and MORB.

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