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GEODYNAMIC SETTINGS OF GEM CORUNDUM DEPOSITS

Victor P. Nechaev, Alexander I. Khanchuk
Far East Geological Institute, Far Eastern Branch, Russian Academy of Sciences

F. Lin Sutherland
Geodiversity Research Centre, Australian Museum, Sydney

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Abstract: The present compilation of the data on global distribution, age and origin of major ruby and sapphire deposits shows that all the deposits are associated with collisional geodynamic settings. There, the extreme thermobaric regimes generate fluids pushed out from fields of the highest collisional stress through thrust-shear faults. The faults often merge geological formations of contrasting nature and composition providing desilicification, an important corundum-producing process. The fluids metasomatize the surrounding Earth's crust and mix with magmas of different nature and chemistry: granitic-syenitic in the close vicinity of collisional zones and syenitic-basaltic in the distant regions. In addition, some magmas merely capture the older metamorphic corundums of deep origin, rework and transport them into the area of erosion to finally form the placer deposits. The major gem-corundum producing epochs correspond to the global orogenies: Alpine, Pan-African, and, to a lesser degree, Caledonian-Hercynian.

1 INTRODUCTION

This study consists of a compilation of the data available on global distribution, age and origin of major ruby and sapphire (gem corundum) deposits in order to elucidate geodynamic aspects of their formation and, thus, make a basis for their large-regional prospecting.

2 ORIGIN

Numerous studies show that natural gem corundums are of either magmatic or metamorphic (including metasomatic) origins (Sutherland and Schwarz, 2001; Saminpanya et al. 2003; Sutherland et al. 2003; Garnier et al., 2004; and references therein). The magmatic and metamorphic suites are distinct. The former are typically blue, green to yellow and color-zoned sapphires characterized by lower Cr/Ga and Ti/Fe ratios, lower REE contents, and a specific suite of mineral inclusions and associated megacrysts (zircon, Al spinel, Fe-Ti oxides, etc.). They make economically significant concentrations (placers) only in Cenozoic sediments derived from volcanics (mainly volcaniclastics) of alkaline or subalkaline basaltic series. The problems with origin of these deposits are that: 1) the associated magmatism has no distinct geochemical and geodynamic signatures; 2) hosting volcanic rocks contain corundums and associated megacrysts as either resorbed xenocrysts included in the basaltic groundmass or crystals forming coarse syenitic or metamorphic xenoliths. In addition, "magmatic" corundums of basaltic provinces are often associated with "metamorphic" ones forming mixed deposits (Sutherland and Schwarz, 2001; and references therein).

The metamorphic gem corundums are represented by ruby and sapphire with various (often fancy) coloration, higher Cr/Ga and Ti/Fe ratios, higher REE contents, and a specific suite of mineral inclusions and associated minerals (sapphirine, rutile and other distinctly metamorphic minerals). They are most commonly hosted by less siliceous rocks such as syenitic pegmatite and granulite, skarn-bearing marble, mica-rich shist, metasomatized ultramafics, etc. They also form placers, sometimes together with magmatic corundums.

We can summarize from the various petrological and mineralogical studies that metamorphic and magmatic corundums formed in overlapping P/T conditions, in most cases corresponding to the mid crust-upper mantle environment (Sutherland et al. 2003 and references therein), and under significant influence of fluids, major components of which were water, CO_3 and F or Cl. The fluids likely served as an active agent and medium of chemical exchange between the contrasting geological substances like ultramafic or calcareous rocks and acidic or salt solutions, providing significant growth of corundum crystals. The corresponding processes may be manifested in the magmatic (syenite with normative corundum), metasomatic (skarn, greisen, etc.) or mixed (pegmatite) forms.

3 SPATIAL-AGE DISTRIBUTION

Most of the magmatic sapphire deposits are located on continental margins associated with the West Pacific marginal seas in the back-arc areas of subduction zones (Vysotskiy et al., 2003; Sutherland et al., this volume), but some deposits are spatially associated with the intracontinental igneous provinces and active continental margins (Fig. 1). These deposits are not controlled by the basement, which is either cratonic or orogenic of any age.

The metamorphic ruby and sapphire deposits are spatially and temporally associated with plate-collision zones of the Alpine-Himalayan and Pan-African (Fig. 1, 2 and 3) orogenic belts. The less significant (or less studied) ones are related to the Paleozoic (Caledonian-Hercynian) orogenies.

The most informative data set is distribution of the Meso-Cenozoic deposits on world maps of recent tectonic activity (Fig. 3) and crustal thickness (Fig. 4). In these maps, one can see that celebrated deposits with the best quality gemstones are related to the thrust-shear zones surrounding the area of thickest Earth's crust, where the Eurasian Plate collides with the Indian Plate. A similar situation is seen on Meert's reconstruction of East Gondwana during the Pan-African orogeny (Fig. 2).

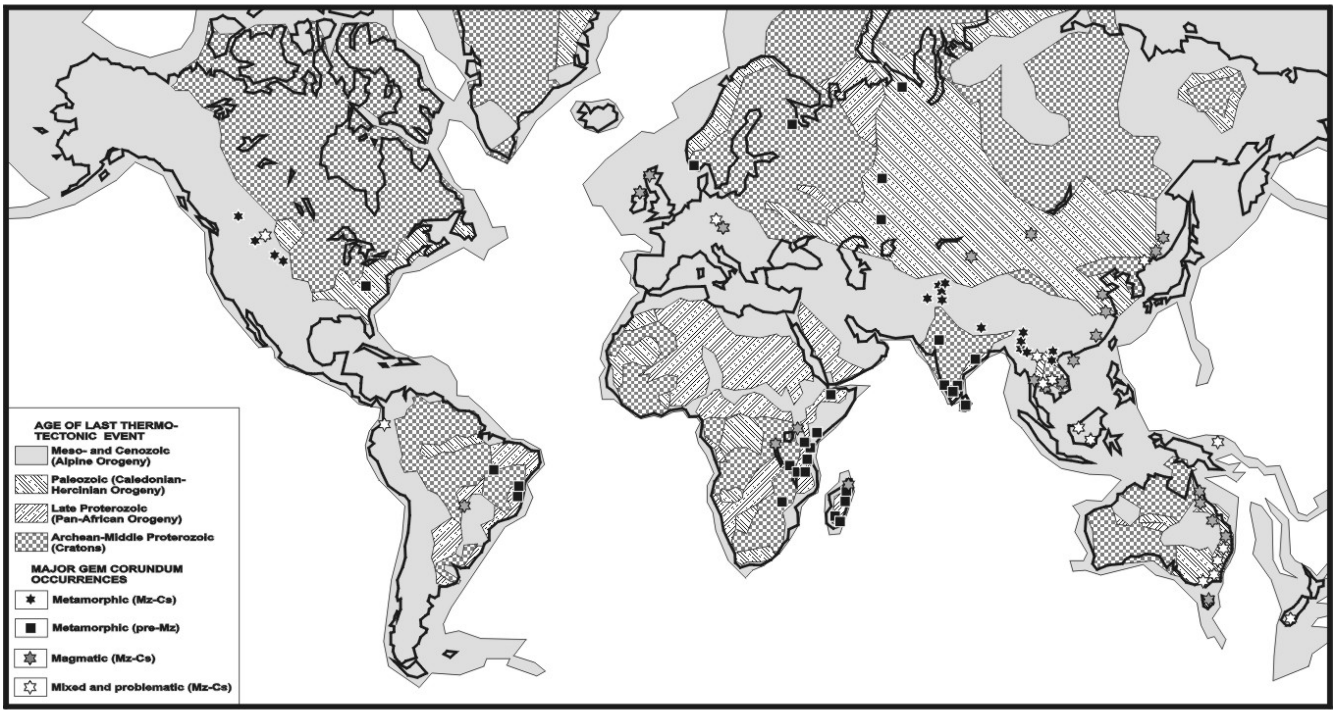

Fig. 1. Distribution of major gem corundum occurrences on the global map of age of last thermodynamic event (modified from the USGS on-line publication at http://quake.wr.usgs.gov/research/structure/CrustalStructure/index.html).

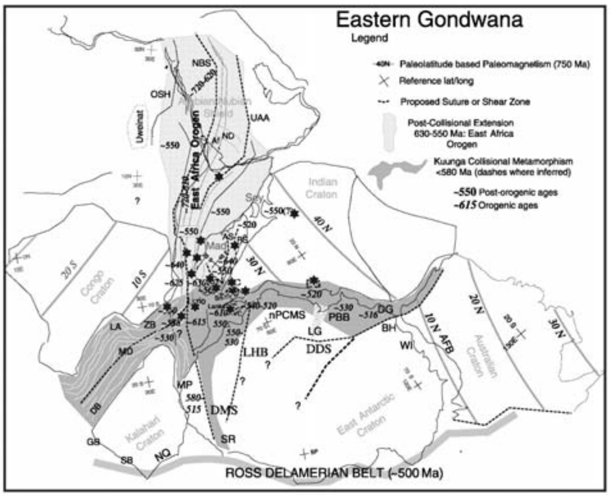

Fig. 2. Distribution of gem corundum deposits (black stars) on the Meert's reconstruction of Eastern Gondwana for the Pan-African time (Meert, 2002).

Other metamorphic and magmatic corundum deposits surround the less sharply manifested thickenings of the Earth's crust associated with active and passive continental margins or intracontinental basaltic provinces. It may also be suggested from the global view of Fig. 4 that the metamorphic corundum deposits closely follow the margins of the steepest crust thickenings, whereas the magmatic ones trace the distant margins of both steep and gentle crustal thickenings. Fig. 5 shows that the pre-Mesozoic metamorphic deposits of ruby and sapphire are also controlled by margins of the Earth's crust thickenings that are less strictly manifested. The latter may be easily explained by the fact that these thickenings indicate the older collisional situations as one can see in Fig. 2.

4 DISCUSSION AND PROSPECTING

From the observations above, we may conclude that gem corundum deposits of both magmatic and metamorphic origin are somehow related to the marginal areas of Earth's crust thickenings. The latter most likely result from a high P/T metamorphic-magmatic process creating-reworking the lithosphere where the plates collide. These natural thermobaric regimes generate fluids pushed out from fields of the highest collisional stress through thrust-shear faults (Wei et al., 2001). The faults often merge geological formations of contrasting nature (continental and oceanic origin) and composition (acidic and basic) providing desilicification, an important corundum-producing process.

The fluids metasomatize the surrounding Earth's crust and mix with magmas of different nature and chemistry: granitic-syenitic in the close vicinity of collisional zones and syenitic-basaltic in the distant regions. In addition, some magmas merely capture the older metamorphic corundums of deep origin, rework and transport them into the area of erosion to finally form the placer deposits.

Our model of gem corundum formation allows large-scale regional prospecting of new ruby and sapphire fields, a major instrument of which may be the crustal thickness map (see Fig. 4) in addition to other geological information. Especially important might be the terrane maps that can show us the areas of ancient plate collisions and associated faulting.

We also observe in Fig. 4 that the crustal thickening associated with the central Andean active continental margin resembles the Tibet Himalayan one. Therefore its surroundings to the north and south may be marked as distinct prospects for the metamorphic ruby-sapphire mineralization of Cenozoic age.

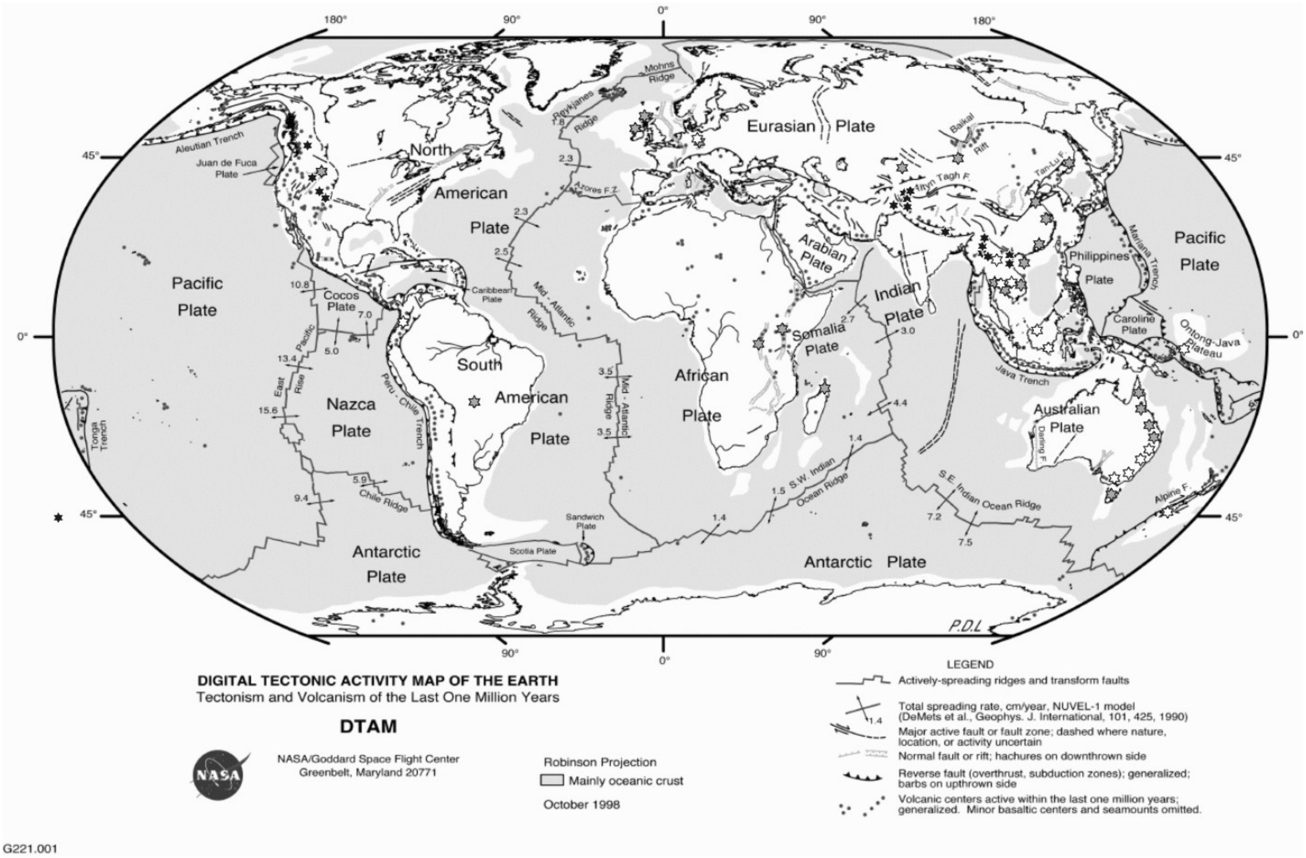

Fig. 3. Distribution of the Meso-Cenozoic gem corundum deposits on the NASA Digital Tectonic Activity Map of the Earth (available at http://denali.gsfc.nasa.gov/dtam/).

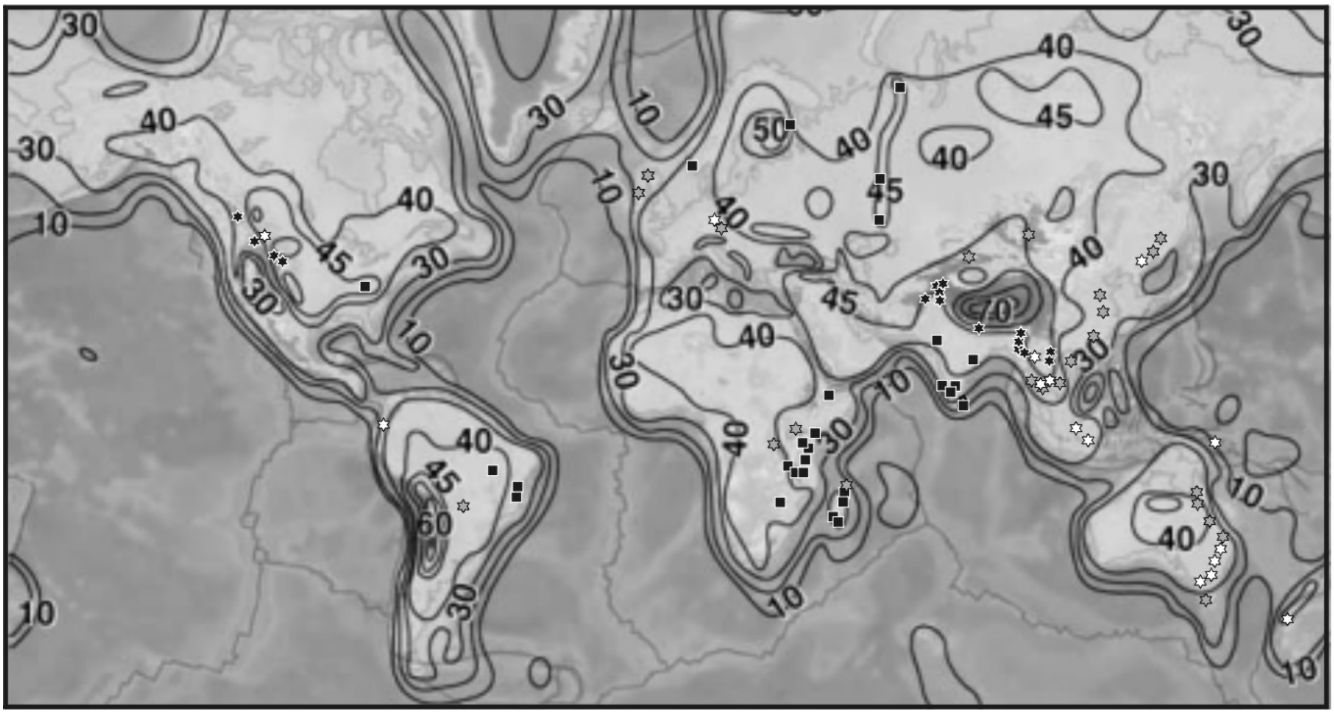

Fig. 4. Distribution of the Meso-Cenozoic gem corundum deposits on the USGS map of crustal thickness (from the USGS on-line publication at http://quake.wr.usgs.gov/research/structure/CrustalStructure/index.html).

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