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Prognostication of primary diamond deposits

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Abstract

Prognostication of primary diamond deposits (kimberlites and lamproites), located within diamondiferous provinces on ancient cratons, is based on using geological, geophysical and morphostructural models for kimberlite/lamproite zones, fields and clusters. The zones that control kimberlite/lamproite emplacement are characterised by widespread development of intrusive and volcanic rocks and block structure. They are reflected in geophysical data by sharply contrasting, elongated magnetic and gravity anomalies. The zones are divided into transcurrent intracratonic, rift-related and zones of anomalous mantle. Within these broader zones kimberlite/lamproite fields are characterised by dome/block-shaped uplifts in geological structures; by sub-circular seismic, gravity and magnetic anomalies, and by concentric–radial morphological structures. They may be recognised by the integrated analysis of geological, geophysical and topographical maps, as well as aerial and satellite images. Several new kimberlite fields have been found using these techniques.

1. Introduction

The term ''exploration'' as used here includes all the operations leading to the discovery of diamondiferous kimberlite/lamproite deposits, and may be subdivided into at least two stages: area selection and prospecting. The process of area selection may be based on several considerations: economic, mineralogical, possibilities of obtaining exploration licenses, etc. The most effective approach to area selection, which avoids wasting time and money, is a preliminary geological–geophysical study of the territory, and determination on this basis of the most prospective areas for future prospecting work. This process we call ''prognostication'' since the aim is to predict the location of primary diamond deposits.

2. Principles of prognostication

The most important part of the work at the initial stage of prospecting for diamonds within unexplored territories is the compilation of prognostic maps. The main task of this process is the rejection of non-prospective territories and the selection of the areas with the highest priority for detailed prospecting. Prognostication of a territory at the initial stage may be carried out without conducting new field work, by using regional geological and geophysical maps, satellite images and air photographs; existing prospecting results (finds of diamonds and indicator minerals, occurrences of alkaline ultramafic rocks, etc.) are important supplementary data. The compilation of maps of prognosis is based on geological–geophysical models of known areas where kimberlite or lamproite volcanism occurs: these are divided into fields, clusters and individual pipes. We have generated such models in the course of our investigations of Yakutian and Arkhangelsk kimberlites. These models turned out to be applicable also to diamondiferous regions of Africa and Australia. The efficiency of the prognostication principles given below has been proven in practice:

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over the last five years four new kimberlite fields were forecasted and subsequently discovered in Northern Siberia, the Arkhangelsk region, the Ukraine and Belorussia.

Depending on the extent of previous studies, the following stages of prognostication can be defined, each corresponding to appropriate map scales.

1. General prognostication of continents and provinces on 1 : 5 mill.–1 : 2.5 mill. scale, with definition of potentially diamondiferous subprovinces and tectonic–magmatic zones.

2. Regional prognostication of provinces and subprovinces on 1 : 2.5 mill.–1 : 1 mill. scale, during which possible kimberlite/lamproite fields are localised; these could be clustered in regions.

3. Local prognostication on 1 : 250,000–1 : 100,000 scale, directed toward delineation of the most prospective areas within defined kimberlite/lamproite fields, and pipe clusters within known or recently discovered fields.

4. Detailed local prognostication on 1 : 50,000–1 : 5,000 scale, which is actually part of the prospecting for individual kimberlite/lamproite bodies and their preliminary evaluation.

For each stage of prognostication there a specific procedure — a set of methods which depends both on geological features of the territory and on feasibility (availability of maps and information, degree of previous prospecting, etc.).

Below is a summary of the main principles of general and regional (to some extent local as well) prognostication, that we have tested during more than two decades in Russia, Yakutia, Ukraine, Belorussia and some other regions of kimberlite/lamproite-type diamond deposits.

3. Diamondiferous territories

Diamondiferous territories of different size and economic value are distinguished within ancient cratons and can be referred to the following hierarchies: kimberlite/lamproite provinces, subprovinces, zones (belts), fields, and clusters, in order of decreasing size. The term "region" will be used here without specific connotation of size.

The term "*diamondiferous kimberlite/lamproite province*" implies both a geological and a geographic–

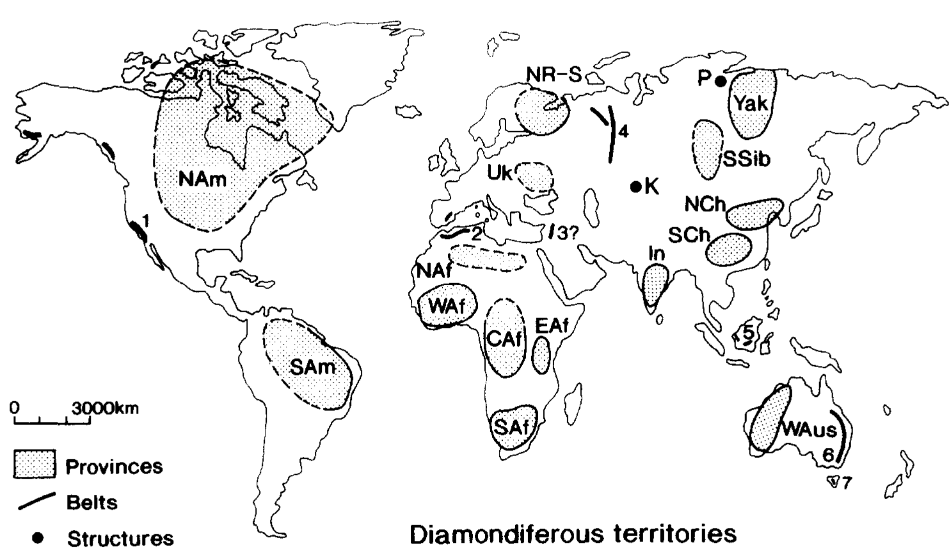

Fig. 1. Diamondiferous territories of the World. Provinces: NAm — North American, SAm — South American, NR–S — Northern Russian–Scandinavian, Uk — Ukrainian, Yak — Yakutian, SSib — Southern Siberian, NCh — Northern Chinese, SCh — Southern Chinese, In — Indian, NAf — Northern African, WAf — Western African, CAf — Central African, EAf — Eastern African, SAf — South African, WAus — West Australian. Belts: 1 — Western Pacific, 2 — Western Mediterranean, 3 — Eastern Mediterranean, 4 — Ural–Timan, 5 — Kalimantan, 6 — Eastern Australia, 7 — Tasmania. Structures: K — Kokchetav (metamorphic), P — Popigai (impact). After Janse (1994b) with some new data.

economic meaning. A province usually embraces the whole of an ancient craton or a considerable part of one, and may include several kimberlite/lamproite fields (regions) of various ages as well as diamond placers (Fig. 1). Primary diamond deposits are still unknown within some such provinces (e.g. Guyanian), but they are no doubt present there. Other diamondiferous territories occur outside of cratons and are not included in such provinces; these comprise fold belts and structures of different origin (Nixon, 1995), but will not be considered here.

There are some qualitative criteria for the prognostication of diamondiferous provinces. An example is the well-known Clifford's rule, which recognises the localisation of diamondiferous kimberlites within Early Archaean blocks in contrast to areas within Proterozoic basement, which are usually barren (Clifford, 1966). Although postulated more than two decades ago, this rule is (in general) supported by almost all new discoveries of diamondiferous kimberlites (Janse, 1994b; Janse and Sheahan, 1995). However, the potential for discovery of diamondiferous lamproites within areas with even Late Proterozoic basement must also be taken into consideration (Jaques et al., 1986; Janse and Sheahan, 1995).

Another criterion is the value of the Earth's heat flow, which is usually not high within territories of diamond deposits on cratons (usually less than 40 mW/cm^2). Both of these empirical criteria may be explained by mantle structure, thickness and composition, according to current views (Griffin and Ryan, 1995; Helmstaedt and Gurney, 1995; Morgan, 1995).

Certain other magmatic rocks distinct from kimberlites and lamproites are reported to carry trace quantities of diamonds; these include monchiquites, basanites, meimechites, picrites, subalkali basalts, ultramafics (Kaminsky, 1984; Janse, 1994a). However, at present there are no reliable criteria to distinguish them from non-diamondiferous rocks of the same composition. These occurrences will not be discussed further here as to date none of them have yielded diamond in economic quantities.

4. Kimberlite-controlling zones

Kimberlite/lamproite intrusions within cratons usually are localised in zones of high magmatic permeability, as defined by the repeated intrusion of various types of igneous rocks. This results in a linear distribution of kimberlite fields within individual provinces. For example, on the Siberian Craton there is a linear distribution of most known kimberlite fields, traced in a NE direction from the Upper Vilyui River to the Lower Lena River (Fig. 2). This zone includes kimberlites of different ages, from Lower Paleozoic to Cretaceous, and transects all the geological lineaments, including doleritic dyke swarms and aulacogenes, which are considered to be ancient rift systems (Fig. 2).

The kimberlite-bearing zone of high permeability is a system of contiguous long-lived deep-seated major faults, controlling the intrusion of mantle (mafic and ultramafic) magmatism in cratons. It has been formed under a regime of uplift and compression and is characterised by well-developed block structure. The main features of such mobile zones are the following.

1. Widespread development of intrusive and volcanic rocks. Basic, ultramafic and even granitic intrusions, as well as acid volcanic rocks, are observed here. If basic volcanics are known within the adjacent craton cover, one may see an increase in their thickness toward a mobile zone.

2. The zones are of distinctly differentiated horst–graben block structure, and basement blocks often outcrop. Alternation of uplifted and subsided blocks occurs both along and across the strike of the zone.

3. The internal structure of a zone is complicated by widespread shear-thrusting and the occurrence of linear folds within the cover.

4. The cover rocks are sometimes metamorphosed from greenshist— up to amphibolite facies within a zone.

5. The geophysical fields of the zones characteristically show sharply contrasting, elongated magnetic and gravity anomalies.

These mobile zones are divided into (a) transcurrent intracratonic and (b) rift-related ones, depending on their geological position.

The Halls Creek zone of Western Australia is one of the typical *intracratonic mobile zones* and is an example of the occurrence of lamproitic rocks (Fig. 3). It contains the Argyle kimberlite–lamproite field, which includes the largest lamproite diamond deposit in the world. The zone is 40–50 km wide and has a NNE strike: it is traced from the junction with the King Leo-

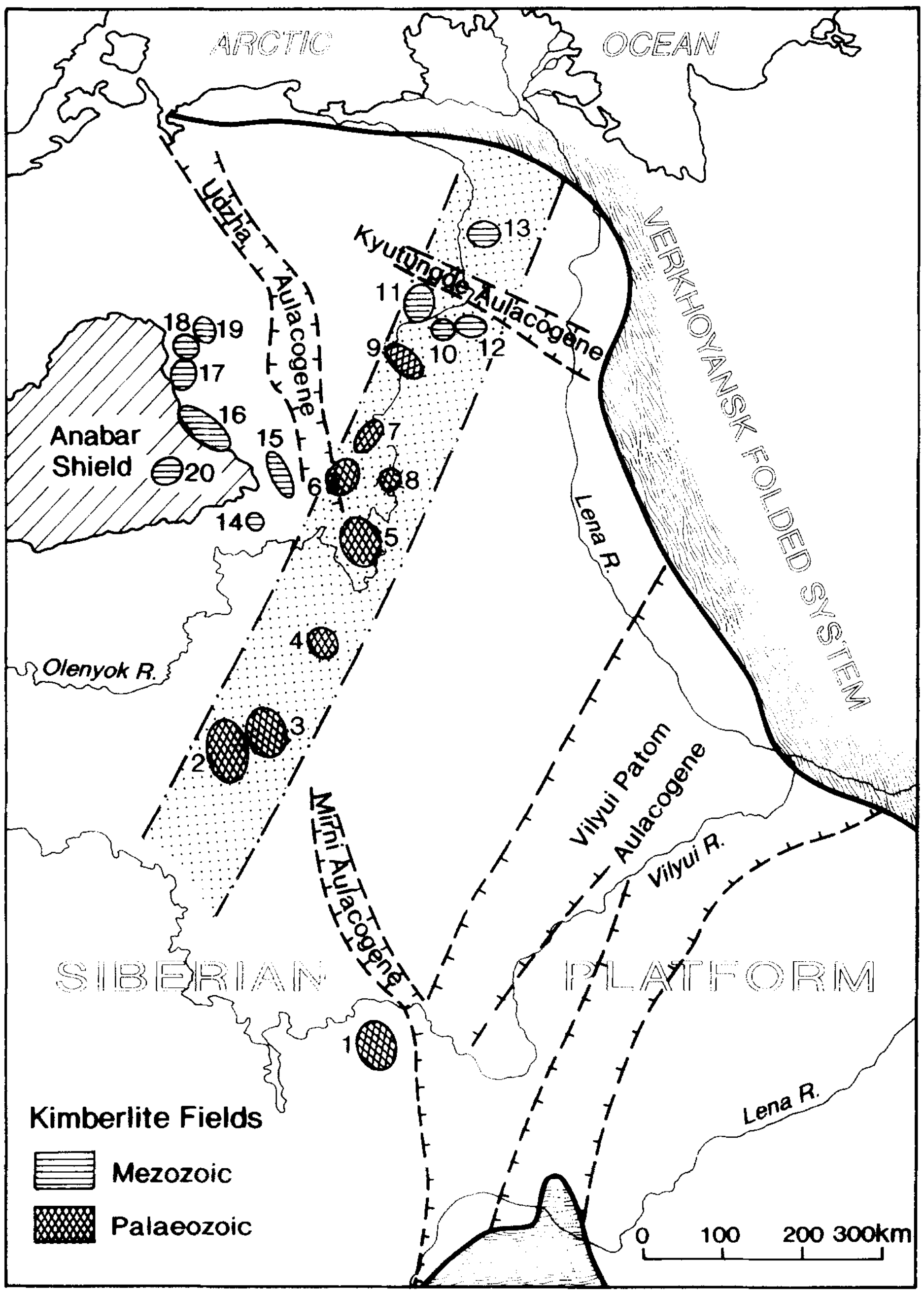

Fig. 2. Kimberlite fields on the Siberian Craton. Paleozoic fields: 1 — Little Botuobiya, 2 — Alakit, 3 — Daldyn, 4 — Upper Muna, 5 — Chomurdakh, 6 — West Ukukit, 7 — East Ukukit, 8 — Upper Motorchuna, 9 — Merchimden. Mezozoic fields: 10 — Upper Molodo, 11 — Kuoyka, 12 — Toluopka, 13 — Lower Lena, 14 — Kuranakh (Little Kuonamka), 15 — Luchakan, 16 — Djuken, 17 — Middle Kuonamka, 18 — Lower Kuonamka, 19 — Orto-Irigakh, 20 — Anabar. The linear NE zone including most of the Siberian kimberlite fields is shown by the stippled pattern.

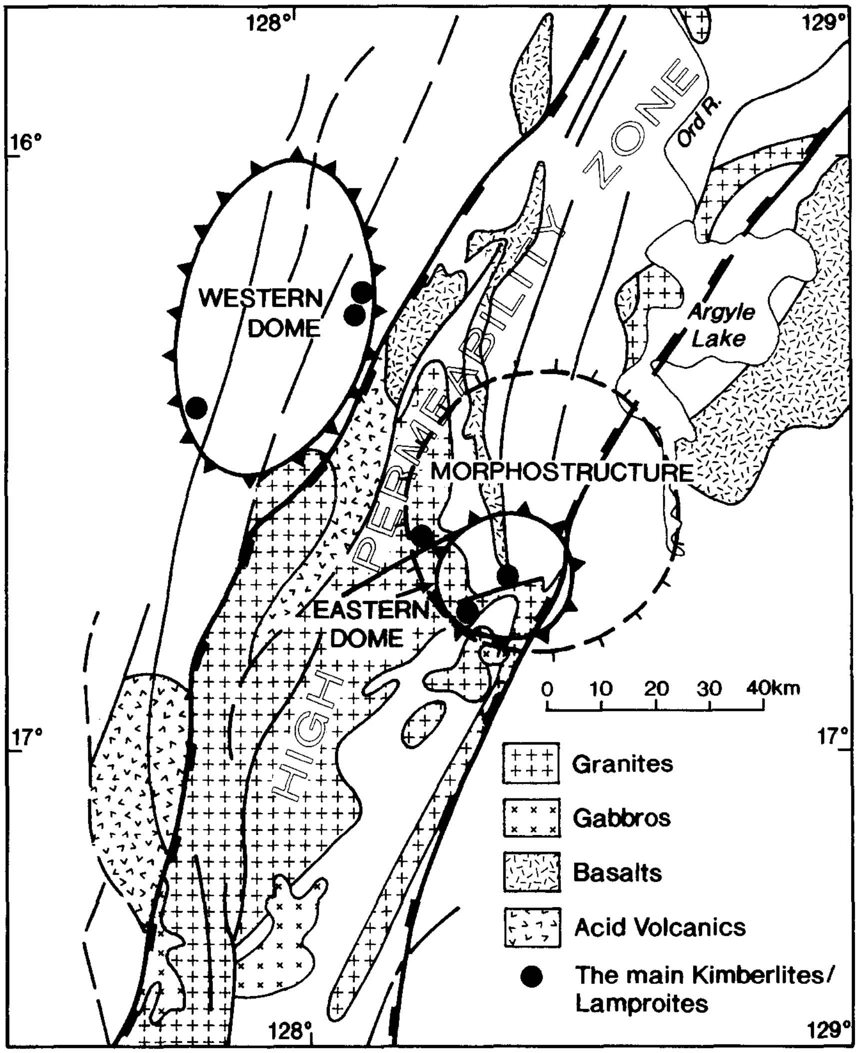

Fig. 3. Halls Creek Mobile Zone, West Australia. The zone of high permeability includes basic and acid intrusions and volcanics; kimberlite/ lamproite pipes are located within dome-shaped geological structures.

pold Mobile Zone and the Fitzroy Rift in the south to the Archaean Rum Jungle Complex in the north. It crosses the North Australian craton: the Kimberley Block, with a Lower Proterozoic cover up to 5 km thick, is located to the west, and the Sturt Block with Proterozoic–Phanerozoic cover 7 km thick to the east. Ultramafic, basic (gabbroids and diabases) and granitic intrusions, basic and acid volcanics, lamprophyres and kimberlites (within the "shoulder" part) are widespread within the zone. Two geological domes are distinguished within the zone: western and eastern. The first one coincides with the Eastern Kimberley field, the latter with the Argyle field.

The Albany–Fraser Mobile Zone of Western Australia, containing the Norseman ultramafic lamprophyre dykes within the "shoulder" part of the zone, is another example of an intracratonic mobile setting. Despite its relatively young age (which gives no possibilities for finds of economically valuable kimberlite pipes) it is characterised by all the geological and geophysical features typical for zones of high permeability and favorable for kimberlite/lamproite emplacement.

Another, *rift-related* type of mobile kimberlite-controlling zone usually is represented by the "shoulder" part of a rift zone, and is recognised as an area of differentiated block movements. It is characterised by

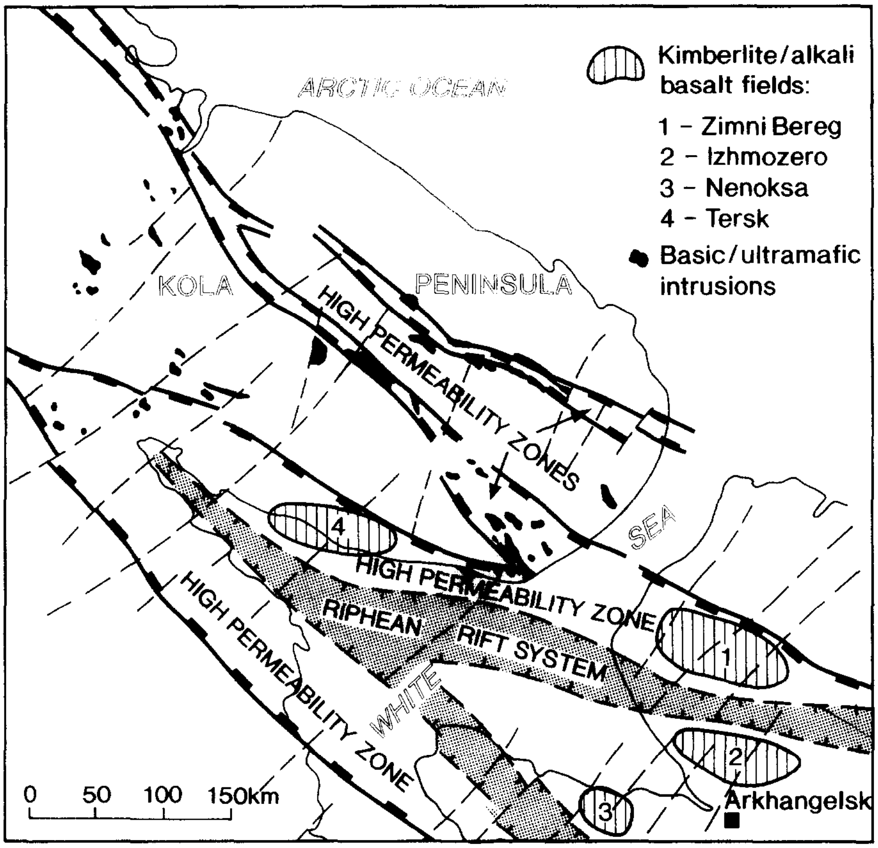

Fig. 4. Kimberlite-controlling zones in the northern part of the East European Craton (Northern Russia–Scandinavia Province), including the Arkhangelsk region and the Kola Peninsula. Zones of high permeability are extended to the NW in Scandinavia.

horst–graben structure along the strike of the rift with vertical faults showing throws of 1–2 km. A good example of such a structure is the Belomorian system of high permeability zones in the northern part of the Russian Craton (Fig. 4). It has a NW strike and includes, in the central part, the Onega–Keretsk Riphean rift system. The zones and orthogonal deep-seated faults are marked by mafic–ultramafic, alkaline and carbonatite intrusions, which are widespread on the Kola Peninsula. All known kimberlite and nephelinite–melilitite fields occur within the borders of the zone and are located on the "shoulders" the rift system. They usually coincide with the intersections of the zone by orthogonal faults. To the south, these faults define their own zone of high permeability, marked by geophysical anomalies.

The Belomorian system of zones includes the Zimni Bereg ("Winter Coast") kimberlite field with newly found pipes of economic significance, the barren Izhmozero kimberlite field, the weakly diamondiferous Nenoksa monchiquite field, and the Tersk kimberlite field on the Kola Peninsula. The Zimni Bereg Field lies at the intersection of the Belomorian zone of high permeability with the transverse Arkhangelsk Zone of tectonic–magmatic activity, which is represented by a set of NE-trending faults with step-like, small vertical displacements (about 100 m). The Arkhangelsk Zone also controls the Nenoksa monchiquite field on the Onega Peninsula. This zone, in contrast to rift systems, is weakly developed in the relief of the basement surface and is better expressed within the Vendian–Paleozoic cover.

The zones are characterised by "keyboard" structure along the strike of the rift, with vertical displacements up to 2 km. Kimberlite fields within such zones have the same specific "keyboard" structure, as in case of the Zimni Bereg field (Fig. 5). Four different blocks are distinguished within this field; they are distinctly

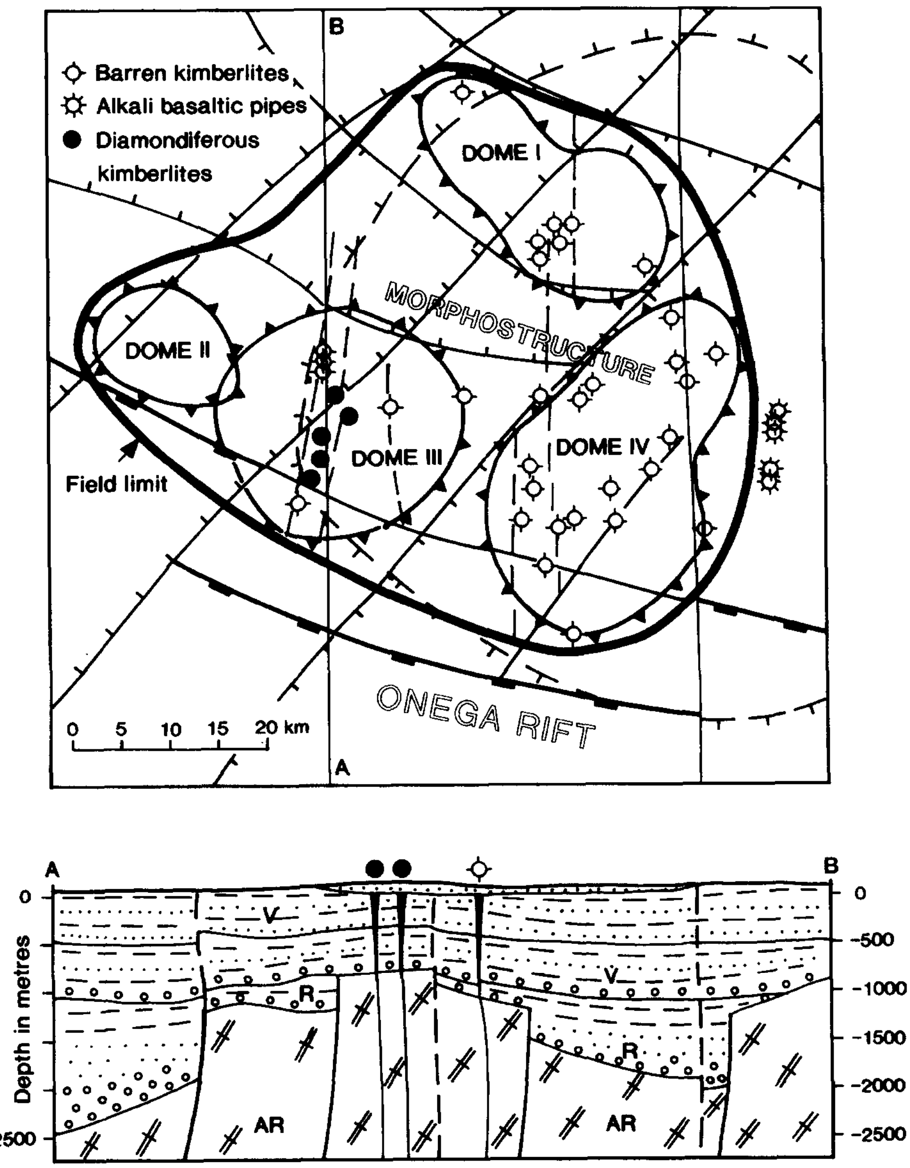

Fig. 5. Structure of the Zimni Bereg kimberlite field, Arkhangelsk region. I — map, II — cross-section. The field is located within the northern "shoulder" of the Onega Rift and consists of three groups of pipes, reflected in dome-shaped geological structures. No kimberlite pipes have been found yet within Dome II.

expressed in relief on basement surface and are confirmed by seismic surveys and deep drilling. They include the Zolotitsa Step, the Padun Graben, the Megorsk Step, and the Ruchyovsk Inlier. Graben-like depressions are filled by Riphean rocks (which are absent on basement inliers), and are weakly developed within the Vendian–Paleozoic sedimentary cover. All known diatremes of the Zimni Bereg Field are located within uplifted basement blocks, the Zolotitsa and Megorsk steps; the richest pipes of the Zolotitsa Cluster are located in the most uplifted transverse structure of the orthogonal Arkhangelsk tectonic zone.

The Zimni Bereg field forms a near-circular dome about 60–70 km in diameter in the sedimentary cover. In turn one may distinguish within its limits four smaller domes, 15–30 km in diameter. The height of

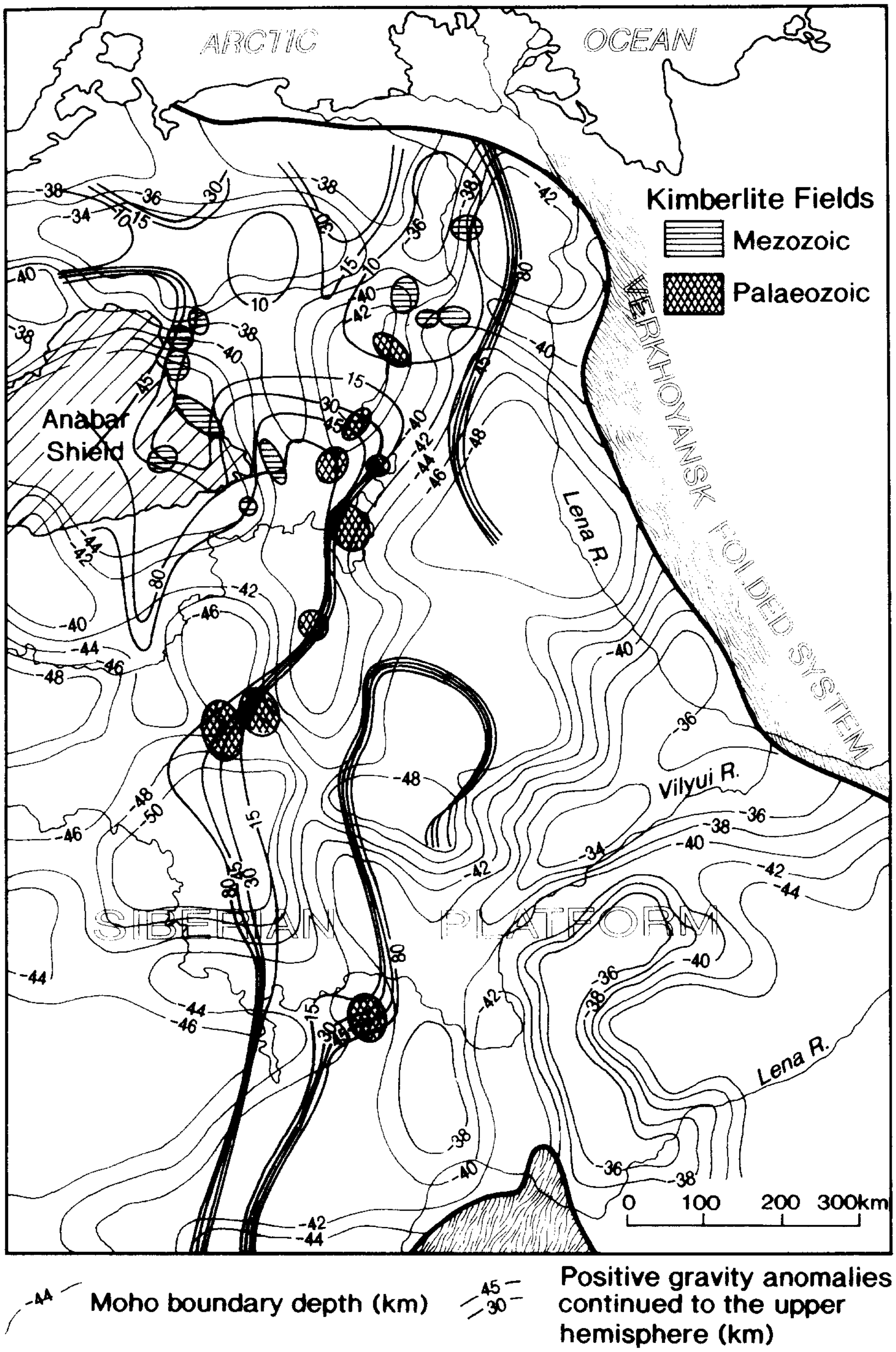

Fig. 6. Kimberlite-controlling zone of anomalous mantle in Siberia. There is no correlation between Moho depth and kimberlite position, and almost all the kimberlite fields occur within the contours of positive gravity anomalies continued upwards to 10, 15, 30, 45, 80 km altitude.

the domes located in Vendian rocks enclosing kimberlites is 50–70 m, and in Carboniferous deposits overlapping the diatremes, decreases to 20–30 m.

There is a very important regularity in the distribution of different diamond grades of the kimberlite/lamproite rocks related to rift structures. In the case of the Arkhangelsk Province, the economically important Zimni Bereg Field is located in the shoulder part of the rift. Going to the central axis we find the weakly diamondiferous Nenoksa monchiquite field situated at the NE closure of the Arkhangelsk horst within the Onega–Keretsk rift system. In Western Australia, the same position is occupied by the Wandagee field of weakly diamondiferous monchiquites, which are confined to the southern closure of the Yanrey horst within the Perth–Carnarvon Rift system. An analogous picture is seen within the Fitzroy Rift system. Here the less prospective leucitic lamproites of the Noonkanbah and Calwynyardah areas are located within the Fitzroy Rift, whereas the more diamondiferous (sometimes almost of economic grade) olivine lamproites of the Ellendale Field are located on one hand within the shoulder, the NE part of this Rift, and on the other hand in the transitional domain of the intracratonic King Leopold Mobile Zone. The Lennard Shelf, including the Ellendale field, is parallel to the Mobile Zone and to the Rift, is of 60–70 km width like the Belomorian zone, and also consists of parallel horst–grabens, complicated by a transverse uplifted block, which contains the Ellendale field. This construction is analogous to the model of White et al. (1995) for the crustal controls of kimberlite fields.

To summarise the metallogenic importance of rifts: one may expect economically exploitable kimberlite deposits of diamonds in the shoulder parts of rifts, representing the areas of differentiated block movements, whereas only weakly diamondiferous alkali-ultramafic rocks are known within rifts themselves.

There is a third type of kimberlite-controlling zone, which does not reflect well in geological structure but corresponds to geophysical lineaments, reflecting deep-seated features of the territories. We call them *zones of anomalous mantle*. Geologically they are expressed only weakly: sometimes they are located in anticlinal zones, and no marked displacements of the basement surface are observed.

A good example of an area of anomalous mantle is found in the Siberian Craton, within the Yakutian Kimberlite Province (Fig. 6). The distribution of kimberlite fields here extends NE from Central Yakutia to the Lower Lena River Basin in the north. In the regional pattern the zone is located at the submeridionally oriented intersection zone between two megablocks of the Siberian Craton, the Anabar and Tungus blocks. These megablocks differ in the structure and composition of their crystalline basement, and this is distinctly reflected in regional magnetic anomalies. The area of anomalous mantle, which corresponds to this lineament, was established by deep seismic data as a zone of high boundary velocities along the Moho. The area is recognised in the regional gravity field as a positive anomaly 100 km wide. This regional gravity maximum corresponds to a similar positive magnetic anomaly, in data upward-continued to 50 km. The zone of anomalous mantle also is accompanied in the geoelectric field by a quasi-linear conductivity anomaly (>50 Ohm at 100–300 Ohm background) at depths of 25–45 km. The reflection of the anomalous mantle in the geophysical fields could be explained by a sub-Moho accumulation of dense and highly magnetic magmatic rocks, which partly penetrated into the base of Earth's crust.

In general magma-active zones of high permeability, which may be considered as kimberlite-controlling zones, contain deep-seated basic–ultramafic rocks. It is because of these rocks that the zones are usually traceable in the gravity and magnetic fields as narrow, elongated high-frequency positive anomalies of three main types.

1. In the first case both fields show areal coincidence, indicating the presence of both dense and magnetic bodies.

2. In the second case narrower magnetic anomalies rim the gravity anomalies, thus emphasising the suture zones. The latter are expressed by basic-ultramafic bodies, bordering troughs and grabens.

3. In the third case several gravity and magnetic maxima are consistent laterally, which may be explained by the presence of highly-magnetic layered bodies in graben-like structures, filled with loose terrigenous sediment.

5. Models of kimberlite/lamproite fields

A kimberlite/lamproite field is an area containing kimberlite/lamproite bodies (pipes, dykes, veins, sometimes sills); the area is usually of subcircular or elongated shape and several tens of kilometres in diameter. It is exposed within a single geological structure, and usually the kimberlites are of one age group. About two hundred kimberlite/lamproite fields are now known on Earth, and each of them has its own individual features. Despite the diversity among the fields, a set of typical criteria is recognised in nearly every field, and in each geological situation. These include geophysical, geological, structural, tectonic and mineralogical features, which consequently may serve as predictive criteria and, taken together, produce a generalised forecasting–prospecting (prognostic) model.

Recognition of potential areas, compatible in the rank with diamondiferous fields, is regarded as a key element in the prognosis process, since these areas are intended for the prospecting work aimed at the direct discovery of diamondiferous bodies. The prospecting techniques will include airborne and terrestrial magnetic surveys, heavy mineral sampling, etc. (Macnae, 1995; Muggeridge, 1995).

5.1. Geophysical model of the field

The geophysical model reflects the deep-seated structure of the kimberlite field, and integrates the features of the vertical crust–mantle column (Fig. 7). The seismic parameters show the following features.

1. The crust/mantle boundary below a field usually is deformed and marked by an increase in the sub-Moho velocity from the common value of about 8 to 8.6 km/sec or more.

2. The lower crust is characterised by high velocities and an antiformal reflector above the Moho.

3. The middle crust is layered and increases in thickness up to 2–3 km to the area of seismic wave attenuation.

4. The upper crust has reflecting antiform surfaces and a lower seismic velocity than the middle crust; the boundary velocity increases toward the kimberlite field.

Gravity and magmetic fields typically show changes above the kimberlite/lamproite field, with varying degrees of contrast:

(a) In the middle-frequency spectrum level of the gravity field the anomalies become lower, and reversals of the magnetic field often occur; patterns of anomalies change from linear to circular and more complex configurations.

(b) In the high-frequency spectrum the predominant orientation of the linear anomalies persists, while anomalies of circular, sickle-like and other patterns

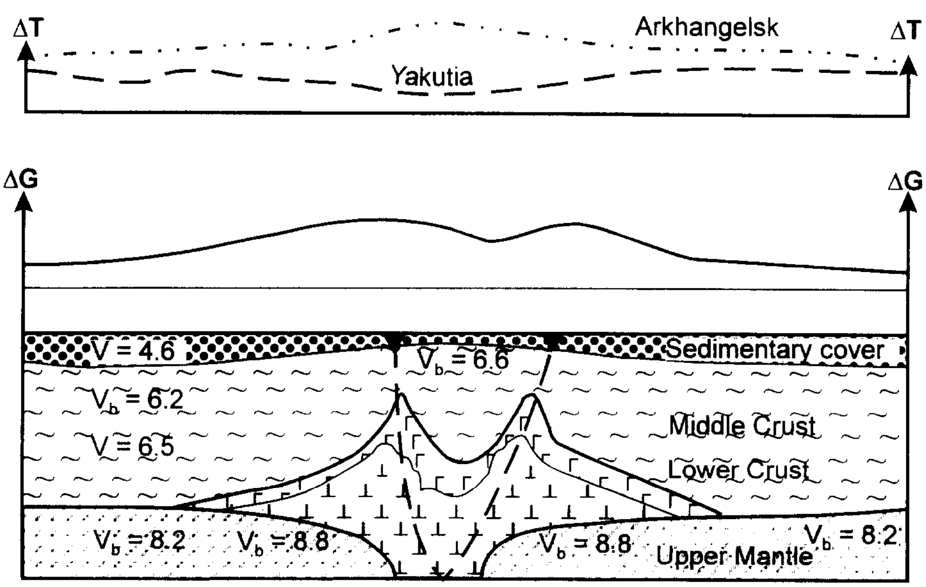

Fig. 7. Geophysical model of a kimberlite field. Both boundary (V_b) and average (V) velocities of seismic waves increase in the vicinity of the field. The regional gravity anomaly (ΔG) shows slow decrease on the background of a wider positive anomaly, reflecting a zone of high permeability. The regional anomaly of the total magnetic field (ΔT) may increase or decrease (depending on the type of kimberlite alteration), but a gradient generally is observed.

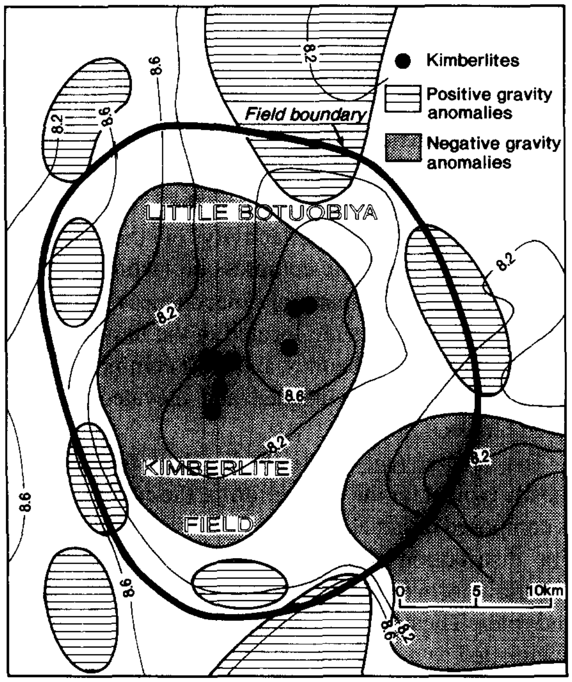

Fig. 8. Geophysical features of the Little Botuobiya kimberlite field, Yakutia. Isopleths of the seismic boundary velocity of the upper mantle are shown by dotted lines. Positive gravity anomalies are shaded; the field boundary lies within a negative gravity anomaly (stippled).

appear; gravity and magnetic field anomalies of the same sign commonly coincide.

An example of such features may be illustrated by the Little Botuobiya field in Yakutia, including well known the Mir, International and other pipes (Fig. 8). Kimberlite field contours include areas with high upper mantle boundary seismic velocity, up to 8.6 km/sec in contrast to common values of $V_b = 8.2$. In the regional gravity field, the kimberlite field coincides with a circular regional gravity minimum surrounded by positive anomalies.

5.2. Geological model

The geological model reflects the existence at depth of a crust–mantle irregularity, from 30 to 90 km in diameter. It includes the following elements.

1. An intersection of the zone of high permeability by transverse structures, which usually are deep-seated faults (see Fig. 4). Such faults are usually expressed on aerial photographs and satellite images, and are mapped by conventional geological techniques.

2. A dome- or block-shaped uplift 30–100 km in diameter (corresponding to the field dimension) with an elevation from a few tens to a hundred meters, and gradually dying out at depth. Dome-shaped uplifts are usually displayed in fairly plastic sedimentary cover rocks, while block-shaped uplifts are formed in more rigid cover rocks or within outcrops of basement (on cratons). The uplifts are characterised by complex structure and dense jointing of the slopes or a complex block-framework combined with domes, flexures, and narrow trench-like grabens. The sizes of these uplifts are revealed in the course of geological and structural mapping (where sedimentary cover is present the uplifts are recognised by changes in elevation of marker horizons) and interpretation of ring structures on aerial and satellite images.

3. Minor dome-shaped uplifts and blocks within the main dome, including intrusion-related domes and blocks, corresponding to pipes.

4. Fault systems, arranged in a roughly radial pattern of fractures with different orientation and centred near the apical part of the dome-like or block uplift.

5. Dispersion halos of diamond-indicator minerals may relate the above-mentioned structures to the kimberlite/lamproite field. Finds of diamonds within these dispersion halos indicate a diamond-bearing field.

6. The following could serve as the indirect criteria of a field: cluster distribution of local pipe-like magnetic anomalies within the above-mentioned structures, and geochemical halos of elements (Cr, Ni, Co, Ti, Nb, etc.) characteristic for alkali-ultramafic magmas.

Recognition of all the above criteria considerably increases the possibility of distinguishing and outlining proposed kimberlite/lamproite fields and, consequently, the effectiveness of the prognostication and subsequent prospecting.

A good example of such structure may be observed within the Little Botuobiya Field (Fig. 9). It lies within a circular negative gravity anomaly (Fig. 8) and is marked by an oval dome-shaped uplift about 30–35 m high and 10–13 km in diameter. Its structure is complicated by more small domes 1–7 km in diameter, located both on the borders and in the centre of the field. No kimberlites have been found within these small domes; pipe distribution within the field is controlled by faults. One of the most remarkable features is the existence of contiguous faults forming shadow graben-like structures up to 1 km wide. All the known

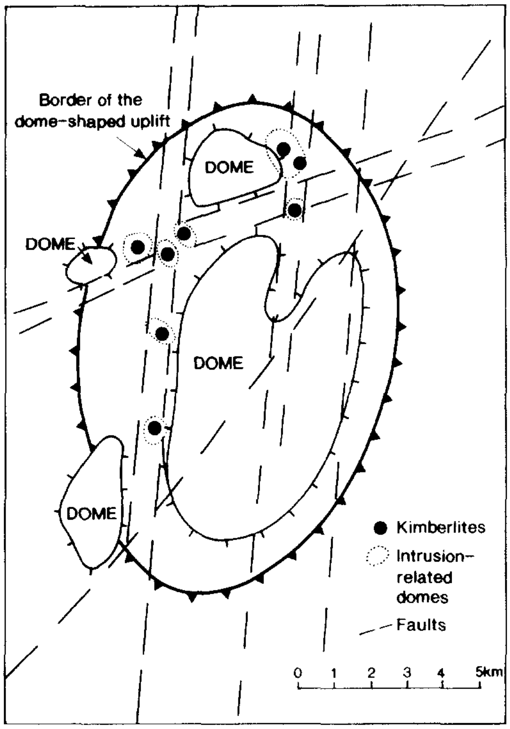

Fig. 9. Geological structure of the Little Botuobiya kimberlite field, Yakutia. Dome-shaped uplift includes all the known pipes, which are controlled by zones of contiguous faults.

kimberlite pipes are localised within such zones of contiguous faults, and are marked by small intrusion-related domes 1–2 km in diameter and by small kimberlite-bearing faults, causing elongation of the pipes and controlling the dyke orientation.

Two types of kimberlite/lamproite fields may be distinguished, based on their structure.

The *first type* is most typical of platforms composed of brittle rocks. Here the distribution of kimberlites and lamproites (and the shape of the fields) is controlled by structures such as faults. Kimberlite or lamproite bodies are disposed in such fields within contiguous fault zones and tend to concentrate in either elevated medium-size blocks or fault intersection nodes, which form the borders between elevated and subsided blocks. Dykes and the long axes of pipes are typically oriented parallel to kimberlite-enclosing fault systems (subzones). In the case of moderate erosion of the field, pipes dominate (as in Central Yakutia), whereas in areas of strong erosion dykes and veins are known to be dominant (e.g. the Liberian Shield in West Africa). In particular cases, when the zones of contiguous faults show evidence of having been healed by dykes of basic composition before the intrusion of kimberlites, pipes and veins of kimberlite are located within the subzones between the bodies of basic rocks or in fissures feathering off from the subzones (e.g. the Orapa pipe in Botswana). In cases when, during the period of intrusion of kimberlites, the activity of the subzones occurred under tectonic compression (which is rather typical for marginal parts of aulacogenes) kimberlite and lamproite bodies are located in the fissures feathering off from the subzones, and most commonly at the boundaries between subsided and elevated medium sized blocks.

The *second type* of kimberlite/lamproite field is mostly typical for the old platforms, the cover of which is composed of rather plastic (e.g. sedimentary) rocks. The distribution of kimberlites/lamproites (and the structural form of the field) is here controlled by faults and folds. The overall structure of the field is typically manifested as a dome-shaped uplift. Within this field kimberlite bodies concentrate (as they do in the first model) in subzones of contiguous faults within which the same relationships between them and bodies of basic rocks, and the same dependence of their location on tectonic stress conditions in the subzones, appear to hold. Among the kimberlite bodies subcircular-shaped pipes are dominant, and these pipes are located in the centre of medium-amplitude (15–30 m) domes rather than in the blocks. Such domes are most commonly disposed along the kimberlite-enclosing subzones or above the fissures formed by the feathering of these zones (e.g. Little Botuobiya Kimberlite Field in Yakutia, Fig. 10). The sizes of the domes enclosing the pipes are typically 3–5 times greater than the diameters of the pipes. In addition to the structures mentioned above, larger domes of 5–10 km in diameter are rather commonly met within such fields; however, this effect on the distribution of kimberlites remains to be explored. Possibly, these domes might determine the disposition of individual kimberlite clusters.

Each type of field contains 8–60 diatremes and minable ones make up 5–25%, rarely up to 50% of them. Diatremes often form chains of various length and groups. Kimberlites and lamproites occur at different intervals within the chains (from several dozen metres to 2–3 km) along kimberlite-enclosing faults. The latter are feather faults off the kimberlite/lamproite-controlling fault zones or components of them. The number

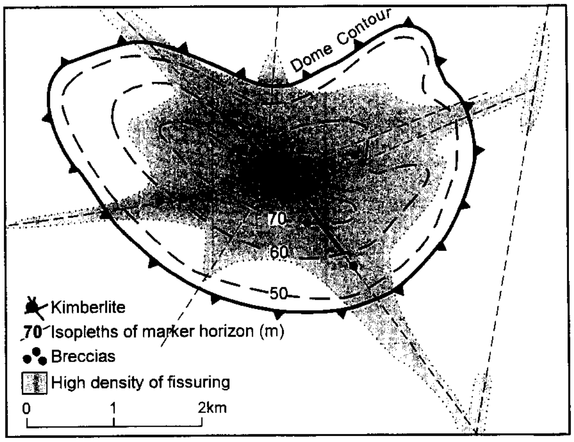

Fig. 10. Structural features of the area around the Mir Pipe. A subcircular dome surrounds the pipe, and is complicated by a radial fault system. Magmatic and tectonic breccias surround kimberlites and faults; a high density of fracturing, accompanied by secondary calcite development, emphasizes the structure.

of diatremes within the chains may vary from 2 to 10. When one body has been found within a field one might expect others nearby, and at some distance a new cluster of kimberlite–lamproite pipes.

5.3. Morphostructural model

Morphostructural studies are based on the reflection of deep-seated structures in the surface relief; they require detailed study of topographic maps, aerial photographs and satellite images. Kimberlite fields show large concentric–radial structures of 100 km and more in diameter (Figs. 11, 12). Sometimes they include smaller concentric structures, which may represent pipe clusters (Fig. 13). Comparison of the results of morphostructural analysis with data obtained on the basis of geophysical investigations has shown their coincidence: it has been established that both methods allow the recognition of deep-seated structures, which may be related to magmatic chambers.

The morphostructural expression of kimberlite fields includes local ring structures of radial–concentric pattern which are divided, depending on their morphology, into ring, dome, dome–ring, and flat ones; the latter are distinguished only by radial–concentric lineaments. The structures are up to 100 km in diameter, though usually not more than 40–60 km. They are generally localised within long-lived deep-seated faults, and especially at intersections of these with faults of other orientations. The structures under consideration are situated often in the central parts of large arch uplifts or arch–ring structures 200–300 km in diameter, complicated by systems of minor ring structures. According to our data, kimberlite bodies are concentrated at points of intersections between concentric and radial elements of ring structures and cross-cutting faults. The latter often lack geological expression and show only jointing.

A good example is found in the Daldyn–Alakit region in Yakutia (Fig. 11). The Alakit and Daldyn kimberlite fields are reflected in two domes 50–100 km in diameter, which in their turn are located within a large dome-shaped morphological uplift 350 km in diameter. There is one more dome to the east of the two

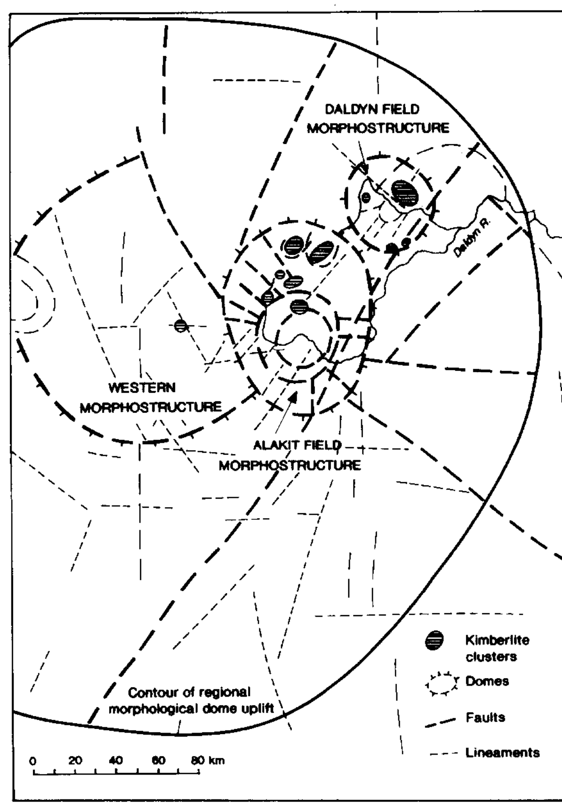

Fig. 11. Morphostructure of the Daldyn–Alakit kimberlite region, Yakutia. Alakit and Daldyn Fields are well distinguished in morphological structures, as well as prospective territory to the west. Morphological lineaments usually coincide with faults established by geological and geophysical data. They form a complicated structure of concentric–radial (thick lines), transitional (medium lines) and local (thin lines) lineaments. Kimberlite clusters are located within separate morphostructural blocks.

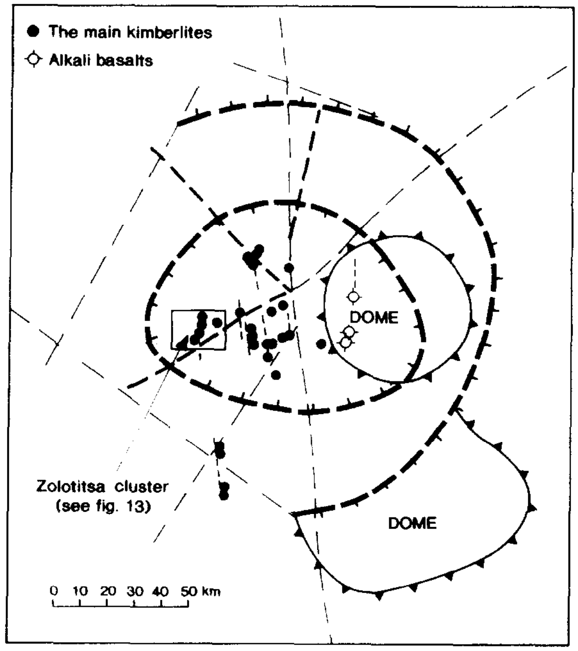

Fig. 12. Morphostructure of the Zimni Bereg Kimberlite Field, Arkhangelsk region. The field is located within a morphological depression, in the central part of a larger morphological dome structure. Radial patterns are well seen in radial (thick lines), regional (medium lines) and local (thin lines) lineaments. Kimberlites tend to occur near radial lineament zones and are controlled by submeridional local faults.

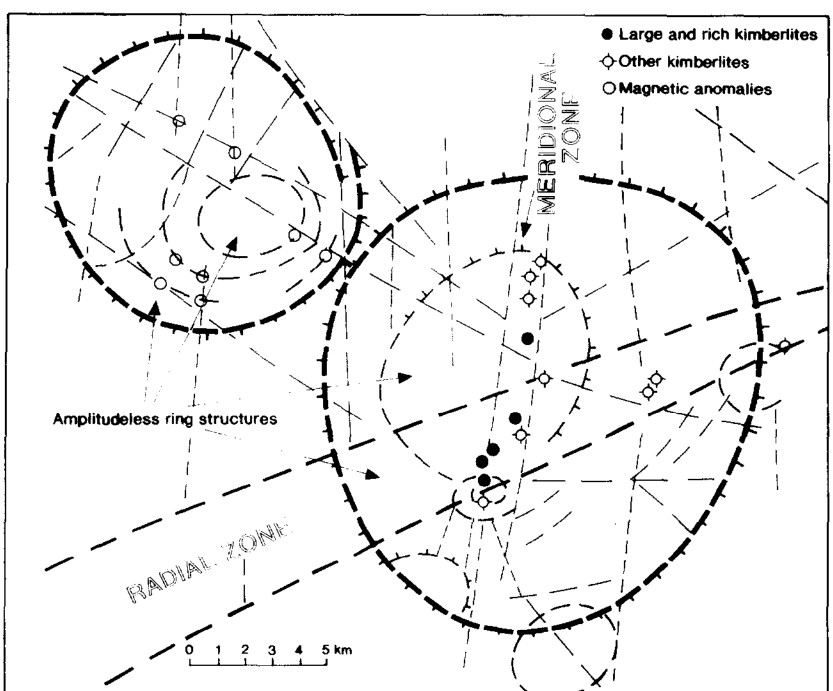

Fig. 13. Morphostructure of the Zolotitsa kimberlite cluster within the Zimni Bereg Field. Morphostructural data show the existence of one more prospective ring structure to the NW of the Zolotitsa cluster. No kimberlites have been found there yet, but some pipe-like aeromagnetic anomalies are present.

known fields, where just a single pipe has been discovered to date. The fields are located near zones of intersection between regional transcurrent faults, which are distinguished both by geological and morphostructural data. Each field-dome is constituted in its turn of radial–concentric forms, and rather regular emplacement of kimberlite pipes may be observed within them.

Another example of morphostructure is observed in the Arkhangelsk region (Fig. 12). A large dome 150 km in diameter forms the outer ring border of the Zimni Bereg kimberlite field, and on this background a depression ring exists, which includes about 85% of all known pipes. In contrast to the geological structure of the field (see Fig. 5) a well developed radial structure is observed, and kimberlite clusters are found within the main radial lineaments; but individual pipes generally are localised according to submeridional deep-seated faults, which are usually distinguished by geophysical and geological data.

The Zolotitsa kimberlite cluster with its five kimberlite pipes of economic importance is located within one of the most impressive radial lineaments (Fig. 13). They are exposed at the intersection of this radial lineament with a submeridional fault zone, which forms — as in the case of the Little Botuobiya field (see Fig. 9) — a system of two submeridional contiguous faults, with a narrow graben-like structure between them. The same twinned character is displayed by a radial lineament, and the largest and most diamond-rich pipes occur at the intersection of the radial and submeridional fault zones.

The morphostructural method of prognosis is not the main one, since sometimes the same features could be seen in association with other deep-seated structures, related not to diamonds but to gold and other metals. However, when used in conjunction with the geological and geophysical models it may be rather useful.

6. Synthesis

The data presented above describe empirical regularities in the geological, geophysical and morphostructural structures of diamondiferous territories on ancient cratons. They may be explained by deep-seated magmatic and tectonic processes, and they do not contradict modern concepts in petrology and tectonics. At the same time, as with all geological regularities, these are not developed in the same way in every case: each newly found kimberlite province and field shows its own features, reflecting the real geological situation.

These regularities may be considered as a basis for prognostication of new kimberlite / lamproite areas during the initial stages of study of any territory. Based on the geological, geophysical and morphostructural models described here, one can compile maps of prognosis for diamonds in a new territory. This work does not need, in its initial stages, a special field study of the territory; it may be carried out simply by analysing topographical, geological and geophysical maps, as well as aerial and satellite images at different scales. The most effective procedure is to compile the different prognostic maps (geological, geophysical, morphostructural, and image-interpretation) independently, and then to synthesise them to select the best areas for prospecting work. Usually after getting results of reconnaissance prospecting, new regularities in the distribution of kimberlite / lamproite bodies appear, and in such a case the prognostic maps must be renewed, reflecting new data.

After this stage the detailed prospecting may be started, with a higher probability of success. In Russia, after detailed studies of all the kimberlite regions, we used these techniques with good results, and four new kimberlite / lamproite fields were found over the last years in different provinces. We have later found evidence for agreement between these models and real situations within kimberlite / lamproite provinces on the African and Australian continents.

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