TECTONICS AND GEODYINAMICS

Nikolay Matushkin

Candidate of Geological and Mineralogical Sciences, Senior Researcher, Laboratory of Geodynamics and Paleomagnetism, Trofimuk Institute of Petroleum Geology and Geophysics, Senior Researcher, Laboratory of Geodynamics and Paleomagnetism of the Central and Eastern Arctic, Department of Geology and Geophysics, Novosibirsk State University, Associate Professor, Department of Geology and Geophysics, Novosibirsk State University. Research interests include: the structure and stages of development of the Siberian paleocontinent and the Arctic region folded belt; structural mapping, the identification of fold-thrust belts stages of formation, intrusive massifs, tectonic lenses and terranes; structural control in paleomagnetic studies; substantiation of tectonic units boundaries.

Course Goal

The main goal of this course is to form a detailed system of knowledge on the causes of deformations and motions in the lithosphere in the context of neomobilism (plate tectonics). The course helps to create a more complete geological viewpoint of the world, demonstrates the structure of the Earth as a complex natural system, and explains the relationships between tectonic, geodynamic, sedimentological, geophysical, and other processes, as well as the connections of magmatism and metamorphism with various geodynamic settings. The main statements of the Theory of Plate Tectonics are presented, along with their logical and scientific substantiation. The processes taking place in different tectonic and geodynamic settings are described in detail. Examples of regional and global structural and tectonic associations are given. The principles of tectonic zoning are presented along with solutions for visualizations of deformation and motions on tectonic maps. The course is also oriented towards the formation of skills in independent research, analysis, and generalization of data from various fields of geosciences.

The goal of the course is achieved by:

- presenting the modern state of Geotectonics as a scientific field on deformations and motions, giving an understanding on the nature of the tectonosphere;

- presenting a comprehensive understanding of plate tectonics;

- presenting detailed information on the types of tectonic and geodynamic settings, their geological and geophysical manifestations;

- deciphering the global periodicity of tectonic and geodynamic processes;

- developing skills in using maps and schemes of geological content.

Content

1. Geotectonics as a Scientific Discipline. Geotectonic Subjects, Their Divisions, Relations to Other Geosciences and Main Stages of Development

   Determination of geotectonics. The main subdivisions of geotectonics. Applications of geotectonics. Main stages of development of geotectonics as a modern scientific field: answering the question of the nature of mountain growth, volcanism, deformations and movement underground. 17th century, the first examples of systematization of geological information and models of a spherical Earth (Descartes, Steno, Leibnitz). 18-19th century, development of "plutonists" conceptions (Pallas, Hutton, von Buch, von Humboldt, Lomonosov). Uplift hypothesis, concept of 1-directional orogeny. 19th century, development of mapping and systematization of tectonic information, Kant-Laplace cosmogony and contractional orogeny hypothesis (De Saussure, Hall, De Beaumont). Concept of global folding ages, phases of folding (Bertrand). 19-20th century, concept of geosynclines (Hall, Dana, Stille), platforms school of thought (Haug, Karpinsky, Pavlov). Edward Suess, the first global generalization of the tectonic structure of Earth. Differences between Pacific and Atlantic oceanic margins. First half of the 20th century, crisis of the contraction hypothesis, alternative models, first arguments for continental drift. Hypotheses of subcrustal currents, pulsating Earth, expanding Earth, concept of convectional heat and matter transfer at depth. First ideas on the opening of the Atlantic (Bacon, Ortelius, Snider-Pellegrini). Study of Iceland by Osmond Fisher and conclusions on the opening and closing of oceans. The arguments of Alfred Wegener and rejection of his hypotheses. Second half of the 20th century. Discovery of the mid-oceanic ridges, of natural remanent magnetization, linear magnetic anomalies and magnetic inversions, and the asthenosphere. Plate tectonics as a change in the main paradigm from the viewpoint of natural philosophy.

2. Geotectonic Methods

   Structural methods. Structural analysis (micro-, petrographic, analysis of individual sites, regional, global). Lineament analysis. Historical methods. Paleotectonic analysis: facies and thicknesses analysis, analysis of stratigraphic breaks and unconformities, analysis of formations and geological complexes. Geological "formation". Geodynamic complex. Neotectonic analysis: geodesic and geomorphological methods of study of contemporary and newest motions. The laser reflector method. The Long Baseline Radio Interferometry method. GPS systems. Methods of comparative tectonics, physical (experiments) and mathematical modeling. Paleomagnetic methods. The main statements of paleomagnetism. The magnetic hydrodynamo. The spherical coordinates system. Magnetic declination and inclination. Ferromagnetic minerals. Acquired

magnetization in igneous and sedimentary rocks. Paleomagnetic poles. Apparent polar wander paths. Magnetotectonics. Magnetostratigraphy. Geomagnetic epochs, episodes and excursions. Linear magnetic anomalies of present-day oceans. The Actualism principle.

3. Principles of the Theory of Plate Tectonics, Their Substantiation and Stages of Formulation

The six principles of plate tectonics. The definition of the lithosphere and asthenosphere. Types of lithospheric plates. Evidence for the existence of boundaries between plates. Types of plate boundaries. Triple junction zones. Spherical geometry and Euler's theorem of 1770 in descriptions of plate drift. Three causes of plate drift. Mantle convection and its layering. Slab pull, ridge push. Modified plate tectonics, plume tectonics and its relation to plate tectonics. The example of Hawaii and other hot spots. Models of mantle convection. The transfer of heat and material.

4. The Tectonosphere and Types of Geodynamic Settings

The tectonosphere. Continental and oceanic crust. Suboceanic and subcontinental crust. The Mohorovicic discontinuity: the petrologic and seismic boundary on continents and in oceans. Interaction between the lithosphere and the asthenosphere. Isostasy. The models of Airy, Pratt and Dutton and their use in various conditions. The asthenosphere. The upper and lower mantle. The core and its relief. The relationship between the tectonosphere and other geospheres. Types of geodynamic settings and their combinations.

5. Continental Rifting

Past and present continental rifts. Definition of a rift. Morphology of a rift on the surface and at low depths. Passive and active continental rifting. Morphological models of rifting. Tectonic and geomorphological models of rift zones. The sedimentary infill of rift valleys. Symmetrical and asymmetrical rifting. Causes of magmatism, the bimodal complex. The "Afar" stage. The mantle diapir and decompression melting. The East African continental rift system. The Ethiopian and Kenyan rifts. The Somali plate. Carbonatite magmatism. Paleorifts – aulacogens. The examples on the East European platform. The Rhine graben. The Baikal rift zone. Rifts of Arctic Russia. The Rio Grande Rift. Geophysical characteristics.

6. Oceanic Rifting, Seafloor Structures

Rifting and the global system of oceanic rift zones. Rifts outside of the global system. Transition from continental to oceanic rifting. The Aden–Red Sea–Afar triple junction. Destruction of continental crust and seafloor spreading during rifting. Gakkel Ridge and the Mid-Atlantic Ridge. The Rio Grande continental rift and the East Pacific Rise. Distribution of heat flow and anomalies of seismic waves velocities. Deep roots of rifts from geophysical data. The model of seafloor spreading and tectonics in Iceland. Morphology of a mid-oceanic ridge in the ocean. Transform faults. Active and passive segments. Transformation points. Dependence of segmentation of spreading zones on the spreading rate. The formation of oceanic crust. The

magmatic chamber of a mid-oceanic ridge. Linear magnetic anomalies and determination of spreading rate. Comparison of slow and fast spreading zones. Spreading rate and the structure of ridges. Spreading rate and its effect on the composition of oceanic crust. Hydrothermal systems in mid-oceanic ridges and their causes and effects.

7. Areas of the Continent-Ocean Transition, Passive and Transform Margins

Microcontinents. Prolongation and jumping of spreading axes. The age and origin of present-day oceans. Transitional areas ocean-continent. Active and passive margins. The structure of a passive margin. The oceanographic profile, types of deposits. Clinoforms. Suboceanic crust and its subsidence. Volcanic and non-volcanic rifted passive margins. Models and examples. Seaward dipping reflectors (SDRs) and their types. Continental rupture and the limit of continental crust (LoCC). Litospheric rupture and the limit of oceanic crust (LoOC). Transform divergent and convergent margins. The western and southern African margin. The Californian margin. The Anatolian-Eurasian margin. The Australia-New Zealand margin.

8. Subduction Zones: Types, Structure, and Modes

Types of convergent interaction between lithospheric plates. Subduction as a setting of formation of continental crust. Origins of present-day subduction zones. Zoning of convergent margins. Frontal zone, axial zone, back arc zone. Active continental margins. Island arc types of margins. Ensimatic and ensialic arcs. The Mariana, Japan, Sunda and Andes subduction types. Comparison of the west Pacific and east Pacific subduction modes. Slab rollback, migration of the oceanic trench, effects on the continental margin. The state of tension of the lithosphere in a subduction zone. Morphology and depth of oceanic trenches. Sedimentation in the trench. The Mariana oceanic trench: asymmetry, lateral faults and banks, subduction of guyots. The accretionary wedge (prism), its composition and structure. The accretionary wedge of the Sunda continental margin. Differences in sedimentation in the Andes and island arc type subduction. Subduction erosion: basal, frontal. Jumping of the subduction zone. Accretion. Terranes and their types. Suture zones. Amalgamation. Superterranes. The Cordillera example.

Geophysical manifestations of subduction zones from seismic, gravimetric, magnetometric, magnetotelluric sounding, and geothermal data. Benioff-Vadati-Zavaritsky zones. Parameters determining the depth, angle and profile of Benioff zones. Depths of earthquakes – zoning, patterns and causes. Different morphology of seismic foci zones in the west Pacific and the east Pacific subduction modes. Magmatism in subduction zones. Model of magmatism in an island arc type subduction zone. Zoning of magmatism in island arcs. Volcanic front. Polarity of volcanism, volcanic series. Evolution of island arcs, development from ensimatic to ensialic arcs. Magmatism of active continental margins. Structure of the Andean margin and the volcanic-plutonic belt. Subduction of large aseismic ridges and its effects. Melting

of the slab, formation of ore deposits. Metamorphism in subduction zones. Paired metamorphic belts of Japan.

9. Collision, Obduction, Types of Fold Belts

Definition of collision. The Alpine-Himalayan fold belt. The India-Eurasia collision example: stages and kinematics, present-day state. Collisional and post collisional magmatism. Obduction: models and mechanisms. Obduction in the Gulf of Oman. Fold belts as a result of oceans closing. Types of fold belts: island arc type (west Pacific / accretional), Andean type (East Pacific), Cordilleran type, Alpine type (Himalayan). The early orogenic and postorogenic state of fold belts. Molasses and the foreland. Zonation of fold belts. Foreland basins. The outer and inner zones of fold belts. The Scandinavian and Scotland kinematic types of fold belt. Transitions from subduction to collisional belts. Terrane analysis used in zoning of fold belts.

10. Patterns in the Age of the Continental Crust, Cratons, Ancient and Young Platforms

Location of the oldest rocks on Earth. Precambrian blocks. Cratons, varying definitions. Ancient platforms. Definition of the folded framing of a platform. The northern and southern sets of platforms. Inner structure of the basement of an ancient platform. Granulite-gneiss regions and granite-greenstone belts. The difference between a craton margin, a platform margin, and a paleocontinent margin. Shields of ancient platforms. Platform (plate) cover. Aulacogens, syneclises, anteclises. Examples. Cratonization stage. Aulacogen stage. Plate stage. Sedimentary formations of the plate cover. Young platforms, the structure of their basement and relationship to the folded frame.

11. Intraplate Tectonics, Hot Spots, Hot Fields, and Mantle Plumes

Types of intraplate motions. Vertical motions and their causes. Main types of intraplate dislocations. Deformation of the India-Australian plate. The Palmirides of the Arabian plate. Ring structures. Controversy over the planetary fracture system. Lineaments and Deep faults, the modern interpretation of the term. Intraplate seismicity. Intraplate magmatism. Hot spots, their location and origins. The African and Pacific group of hot spots. Relationship of hot spots and the D layer. Types of mantle plumes. Structure and evolution of a mantle plume. Plume magmatism and its causes. Large igneous provinces: types, ages, and examples, geological manifestations. Correlation of mantle plumes, mass extinctions, and geomagnetic epochs. Correlation of mantle plumes and supercontinent breakup. The Siberian traps example. Yellowstone and the debate on its origin.

12. Orogenic Epochs, the Wilson Cycle, Supercontinents

The ages of contemporary fold belts from the Paleoproterozoic to the Cenozoic and the patterns of their location. The oldest oceans and fold belts. Folding epochs and phases, phase of tectonic activity. Understanding these terms in the context of plate tectonics. The Karelian, Grenvillian, Baikalian, Caledonian, Hercynian, Cimmerian, and Alpine folding. Examples of fold belts, origins of the names. Overlapping

of folding and multiple transformations of the crust. Bertrand epochs. The 'cyclicity' of fold belts and oceans evolution, the Wilson cycle and fold belt stages: embryonic (rifting), juvenile, mature, declining, terminal, suturing (relict). The hypothetical supercontinental cycle and its geological, tectonic, and geochemical indicators. The Ur (Vaalbara), Kenorland, Protopangea, Columbia (Nuna), Rodinia, Pannotia, and Pangea supercontinents. Hypothetical types of supercontinents. Possible causes of supercontinent breakup. Geological and environmental effects of supercontinent assembly and breakup.

13. Main Stages and Patterns of Earth Crust Development

Correlation of the evolution of the crust with the thermal and geodynamic evolution of Earth. Present-day interaction of geospheres and geodynamic settings of crust formation. Age patterns in the Earth's crust. The actualism principle in the context of Precambrian tectonics. Komatiites and blue schists as geodynamic indicators. Formation of the Earth and the geospheres. Hadean-Eoarchean stage – the first crust and deformations. Formation models of the protocontinental crust (4-3.5 Ga). Paleo-Neoarchean stage. TTG crust. Models for Plume-lid tectonics and Archean plate tectonics. Formation of the continental crust and the first supercontinent Kenorland (3.5-2.5 Ga). The issue of the time of onset of present-day-like plate tectonics. Ophiolites older than 1 Ga. Paleoproterozoic stage. The breakup of Kenorland, further growth of continental crust (2.5-1.7 Ga). Changes in the mantle convection mode. Mesoproterozoic stage (1.7-1 Ga). Neoproterozoic – middle Paleozoic stage (1-0.32 Ga). Versions of paleotectonic reconstructions. Late Paleozoic – early Mesozoic stage. Wegener's Pangea (0.32-0.2 Ga). Late Mesozoic – Cenozoic stage. Breakup of Pangea and the formation of present-day oceans. Formation of the present-day structure and landscape of the Earth (0.2-0 Ga).

14. Tectonic and Geodynamic Maps

Types of maps by scale and content. History of tectonic mapping in the 19-20th centuries. Transition to mobilism. Principles of tectonic maps. Principles of geodynamic maps. Specialized maps. Using terrane analysis for mapping. Examples of maps.